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The dynamic interaction between memory and linguistic knowledge in children's language development: the role of sentence recall

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Abstract

The role of working memory in language acquisition has been widely reported in the developmental literature, but few studies have explored the role of sentence recall in the way working memory and related linguistic abilities evolve. This study seeks to explore the organization and development of the memory architecture underlying language using a longitudinal design. A total of 104 children were assessed on verbal working memory, phonological short-term memory, vocabulary and sentence recall skills at age 6 and one year later at age 7. Structural Equation Modelling analyses revealed a robust direct predictive effect of phonological short-term memory (pSTM) and vocabulary on sentence recall at Time 1 and of verbal working memory on sentence recall at Time 2, supporting Baddeley's working memory architecture (Baddeley, 2003). Additionally, pSTM and sentence recall abilities at age 6 predicted verbal working memory and vocabulary at 7 years, respectively, regardless of autoregressive effects. These results support the notion of the dynamic nature of the language system and suggest a key role of specific memory abilities underlying sentence recall in language development during childhood.

Keywords: language development, verbal working memory, vocabulary, sentence recall, storage, monitoring

Introduction

In recent years, much attention has been devoted to defining the specific mechanisms involved in the attainment of language skills, with the primary aim of identifying risk factors for language difficulties (Bishop, 2006; Ramus, Marshall, Rosen, & Van der Lely, 2013; Van der Lely, 2005). Measures of phonological short-term memory and verbal working memory have been widely accepted as primary markers of such difficulties in children with Specific Language Impairment (SLI), providing converging evidence about the key role of memory mechanisms in language development (Archibald & Gathercole, 2006; Bishop, North, & Donlan, 1996; Mainela-Arnold & Evans, 2005; Montgomery, 2000; Weismer, Tomblin, Zhang, Buckwalter, Chynoweth et al., 2000).

More recently, using the sentence recall task, memory for sentences has been found to be a powerful and sensitive marker of language difficulties (Archibald & Joanisse, 2009; Conti-Ramsden, Botting, & Faragher, 2001; Stokes, Wong, Fletcher, & Leonard, 2006). According to the recent literature, efficient performance on this task lies in the child's knowledge of words and how they are ordered in the language (Moll, Hulme, Nag, & Snowling, 2015; Polišenská, Chiat, & Roy, 2015). Thus, the ability to recall whole sentences has been taken as a reliable indicator of a child's general ability to retrieve lexical and syntactic information consolidated in long-term memory as a result of experience. This memory measure, therefore, may constitute a core component of the basic cognitive architecture underlying language attainment. However, most studies exploring sentence recall are limited to clinical samples (Mainela-Arnold, Misra, Miller, Poll, & Park, 2012; Riches, 2012; Ziethe, Eysholdt, & Doellinger, 2013), and questions regarding how specific memory processes underlying language are organized and evolve in typical samples remain open. This study seeks to explore this issue using a longitudinal design.

Memory processes and language acquisition: the role of phonological short-term memory, verbal working memory, and sentence recall

Cognitive accounts have traditionally paid specific attention to distinct basic memory mechanisms as the breeding ground for language attainment, based on the notion that such mechanisms have great potential to condition a child's developmental trajectory (Bishop, 1992; Joanisse & Seidenberg, 1998; Pennington, 2006; Pennington & Bishop, 2009). The strongest relationship attested by developmental studies is arguably the one between phonological short-term memory and language. Phonological short-term memory (pSTM) is usually measured with the nonword repetition task, which taps into the ability to store unfamiliar phonological forms in memory for a short time. Concurrent correlational studies have linked this ability to a greater productive and receptive vocabulary, as well as with longer speech utterances in children aged from 2 to 4 years (Adams & Gathercole, 1995; 2000; Bowey, 2001; Gathercole, Service, Hitch, Adams, & Martin, 1999; Palladino & Cornoldi, 2004). Further regression studies have narrowed the scope of phonological short-term storage abilities to the construction of the lexicon in mid-childhood, showing that children aged between 4 and 8 years who are good at retaining specific sound structures are also good at incorporating new words into long-term memory (Blake, Austin, Cannon, Lisus & Vaughan, 1994; Gathercole & Baddeley, 1989; Jarrold, Thorn, & Stephens, 2009). Studies with SLI children also report this association (Coady & Evans, 2008; Conti-Ramsden & Durkin, 2007; Gathercole & Baddeley, 1990; Gathercole, Frankish, Pickering, & Peaker, 1999, Montgomery & Windsor, 2007; Weismer et al., 2000), providing support for the key role of pSTM in lexical attainment and vocabulary growth.

Several studies, however, sustain the view that although pSTM is crucial for internalizing words, it needs to be supported by a top-down monitoring mechanism that ensures phonological information is being efficiently processed. Arguments have been made for verbal working memory, assessed by the N-back or the backward digit span task, as a proxy of this ability, due to the additional processing demand posed by these tasks compared to the nonword repetition task. This measure has also been linked to children's vocabulary level (Cowan, Elliot, Saults, Morey, Mattox et al., 2005), but particularly to grammatical development. Specifically, concurrent regression studies reveal that typically developing children who report higher verbal working memory (WM) scores show better performance in tasks that involve grammatical processing, such as grammaticality judgment (McDonald, 2008), sentence completion (Gray, Green, Alt, Hogan, Kuo et al., 2017) or grammar production (Verhagen & Leseman, 2016). Similar results have been reported in primary school children with SLI (Alloway & Archibald, 2008; Archibald & Gathercole 2006; Montgomery, 2000; Montgomery & Evans, 2009; Robertson & Joanisse, 2010), suggesting that the ability to process and deal with verbal information contributes to a child's progress in lexical and grammatical abilities over childhood.

Following this evidence, pSTM and WM constitute core cognitive resources that assist the progressive organization of the language system in early childhood by guaranteeing efficient storage and monitoring of verbal information in a bottom-up manner. Some studies, however, suggest that a child's language knowledge at a certain developmental point has an influence on the way memory processes are employed, modulating their developmental course (Gathercole, 2006; Marchman & Fernald, 2008). This assumption is partly a consequence of experimental studies showing that children's verbal recall is sensitive to lexical features such as lexicality – better performance when the stimulus is a word with respect to a nonword- or word frequency (Garlock, Walley, & Metsala, 2001; Thomson, Richardson, & Goswami, 2005; Turner, Henry, Smith, & Brown, 2004). In the same vein, children's sentence recall also seems to benefit from lexical knowledge. Indeed, a number of studies have shown that their ability to recall sentences reflects individual variation in lexical abilities (see Alloway & Gathercole, 2005; Riches, 2012; Marshall & Nation, 2003), suggesting that memory demands required to correctly repeat sentences are highly dependent on verbal representations already stored in long-term memory.

Additionally, a number of naturalistic studies indicate that children acquire information about how lexical items are ordered in specific sequences according to their experience by rote memory (Bannard & Mathews, 2008; Tomasello, 2000). If proficient recall of word sequences during childhood depends on how explicitly they have been stored in long-term memory, differences in sentence recall performance might reveal how words and word order are represented in a child's mind at a certain developmental point as well as their ability to maintain these representations in memory (Devescovi & Caselli, 2007; Marshall & Nation, 2003; Willis & Gathercole, 2001). The sentence recall task has proven to be a good measure of this ability. It has been suggested that while executing this task, the lexical knowledge internalized by the child is transferred from long-term memory, facilitating serial ordering and production planning processes, leading to individual differences in performance (Acheson & MacDonald, 2009).

For example, several studies with clinical samples have reported that verbal representations in long-term memory have an impact on how well the task is performed. These works suggest that children exhibit a larger span when words are ordered into grammatical sentences than when the same words are randomly presented (the sentence superiority effect), and that the sentence span is influenced by their lexical skills (Mainela-Arnold & Evans, 2005; Mainela-Arnold, Evans, & Coady, 2010). This facilitation effect implies that efficient sentence recall is necessarily associated with vocabulary level (lexicon stored in long-term memory), and with additional knowledge of how the lexicon is sequentially arranged. Interestingly, this effect has also been observed in typically developing children (Kidd, Brandt, Lieven, & Tomasello, 2007; Polišenská et al., 2015).

These studies support the idea of a key role of sentence recall in the organization of the language system and suggest a potential interaction between different memory processes across development. Measures of sentence recall performance might reflect memory abilities that go beyond those attributed to WM and pSTM, since the tasks utilized to tap into these mechanisms only require processing sub-lexical properties of single items. While WM and pSTM subserve the maintenance of phonological information in memory, sentence recall draws on serial ordering and production planning abilities across higher levels of representation –not just phonemes into words but also words into sentences. However, to date, no study has explored the dynamic relations of these key memory mechanisms over time, or their relative role in the developmental organization of the cognitive architecture underlying language.

Organization of the memory architecture for language acquisition: Baddeley's model

The delimitation of distinct memory functions involved in language attainment sets an account within Baddeley's working memory model (2000; 2003), which understands language as a result of the relatively independent influence of specific memory mechanisms integrated in a multi-component cognitive network. A central component in the model is the phonological loop, a short-term memory device involved in the storage of lexical knowledge, which holds verbal information temporarily either by registering or by refreshing speech memory traces via rehearsal. This component is supported in the model by the central executive, a component involved in controlling and monitoring verbal information while this information is being processed or while performing other tasks. As seen, these components are a reflection of the pSTM and verbal WM, respectively. Accordingly, the model predicts that pSTM is directly involved in the increase in lexical knowledge in long-term memory (vocabulary level) with the indirect influence of verbal WM, a constraint that has received empirical support from the developmental literature (Alloway, Gathercole, Willis & Adams, 2004; Alloway, Gathercole & Pickering, 2006). This language architecture, however, does not explain how syntax is built from word to sentence level. According to Baddeley (2003), although the mentioned memory resources are certainly enough to retain frequent phoneme combinations in long-term memory, the demands required to internalize knowledge about word combinations into sentence structures exceeds the capacity of these two mechanisms. This function is conceptualized in the model by the episodic buffer, a backup store that activates chunks of information from long-term memory during storage and monitoring activities (Baddeley, Hitch, & Allen, 2009). This mechanism is fed by information about the lexicon stored in long-term memory, and connects it with the input that needs to be stored in pSTM under the control of the central executive (Jefferies, Ralph, & Baddeley, 2004). Due to this integrative function, the episodic buffer may have a crucial role in the coordination of the components in the model and on the way the language network evolves. Interestingly, several studies suggest that the sentence recall task taps into the functions attributed to the episodic buffer. The main argument is that this task demands specific resources from long-term memory, since the items to be encoded resemble real word sequences in the language. According to Baddeley et al. (2009), sentence recall performance specifically draws on two sources that boost efficient production: the phonological loop and lexical knowledge. However, the ability to hold verbal representations before production also involves monitoring abilities. Therefore, efficient performance in this task might depend on, and also predict, other memory processes over time.

One source of evidence supporting this view can be found in studies exploring the structural architecture of the three memory mechanisms in typically developing children. Principal component analyses on data from children aged 4 to 6 years indicate that, despite the moderate correlation found between verbal WM, pSTM and sentence recall, the three memory measures load into separate factors (Alloway et al., 2004; see also Archibald & Joanisse, 2009 with SLI children). Such evidence suggests that these measures constitute independent components of the memory architecture sustaining language, although to date, the dynamic relations between these components over time has not been explored longitudinally.

The present study

All in all, the evidence suggests that the language system consists of distinct memory abilities that develop hand in hand to enhance language attainment. Within this multicomponent framework, recalling sentences involves specific demands on long-term memory, which are absent or minimal in WM and pSTM tasks (Alloway et al., 2004; McCauley & Christiansen, 2015). However, despite the literature exploring the role of PSTM, WM and sentence recall in language attainment of typically developing children (Alloway & Gahtercole, 2005; Jefferies et al., 2009; Riches, 2012), to the best of our knowledge little is known about the way the memory network involved in language acquisition is organized and evolves. To date, the issue of how performance in each specific memory task predicts other memory measures over time remains unexplored. The present paper aims to respond to this question by assessing a sample of children on four components of Baddeley's working memory model previously described (working memory, phonological short-term memory, sentence recall and vocabulary as measures associated with the central executive, phonological loop, episodic buffer and long term lexical knowledge, respectively) at two different time points. Based on Baddeley's memory framework, we tested a model that reflected a predictive cascading relation from WM to PSTM and vocabulary and from these to sentence recall. Additionally, the model tested the relative potential of each component to predict the memory abilities longitudinally.

Method

Participants

One hundred and twelve first graders recruited from six different schools located in the suburban areas of Bilbao (Basque Country, Spain) took part in the study. All children entering first grade in these schools were invited to participate. Informed consent from parents was received from 112 children. The sample was composed of a majority of Basque-Spanish bilinguals whose main language was Spanish (98%, the remaining 2% were balanced bilinguals, who reported a high exposure to both Spanish and Basque). The amount of Basque-Spanish exposure was measured with a parent questionnaire and this variable was controlled for in the study. Each parent had to report the language they used with their children, in which language the children read books, did everyday activities, and watched TV, and the extent to which the child was exposed to Basque with people or friends inside and outside school. All parents reported daily exposure to Basque of less than 25% (limited to their school setting), while exposure to Spanish was reported at higher than 75%.

The children met the following inclusionary criteria for typical development: a) were enrolled in first grade; b) had no history of neuropsychiatric disorders (ADHD, autism spectrum disorder); c) no history of special education services; d) no record of speech and language therapy; e) no signs or diagnosis of SLI. Based on these criteria, eight children showed signs of language impairments—2SD in two or more language measures—and were excluded from the analysis. The final sample comprised 104 children. SES was determined using a questionnaire completed by parents and was ranked in the middle range. This study reports data for two phases: Time 1 (first grade, M age=6.4 years, SD=0.36; N=104) and twelve months later at Time 2 (second grade, M age=7.5 years, SD=0.35; N=104). All children were subject to the same phonics and reading instruction policy.

Tasks and testing procedure

All the children completed a battery of cognitive and linguistic measures administered in two sessions at the beginning of the academic year (November-December). Each child did all the tasks individually, in a silent room and following the instructions of the experimenter. Tasks were administered in a fixed order to all children.

Non-verbal IQ. The Matrices subtest from the Kaufman Brief Intelligence Test (K-BIT, Kaufman & Kaufman, 1990) was used to control for the non-verbal reasoning score across participants. According to the test manual, internal consistency estimates for the subtest range from .74 to .93. The task requires the child to point to the missing figure from a logical sequence or set. Trials are grouped in eight sets of five items each. Testing is discontinued when the child responds incorrectly to all of the items in one set.

Verbal working memory. This ability was measured using the backward digit span task in the WISC-IV (Wechsler, 2003). Seven sets of two trials each were presented. Each set incorporated an additional digit, starting from a two-digit trial. Digits were presented verbally by the experimenter, whose voice was fixed to specific within- and between-trial timing; the time between items was set to one second and the time between trials was set to ten seconds. The child was asked to repeat each trial aloud. Children's verbal responses were recorded to facilitate further transcription and analysis. The highest number of well-recalled digits was taken as the digit span indicator.

Phonological short-term memory was measured using *the nonword repetition task*, based on the classic paradigm (Hulme & Tordoff, 1989), consisting of auditorily-presented sets of syllabic nonwords, which the child is asked to repeat in the same order. For this purpose, four sets of six nonwords each were constructed using the Syllabarium database (Duñabeitia, Cholin, Corral, Perea, & Carreiras, 2010). Nonwords and sets were paired in bigram frequency (mean bigram frequency per set = 1.8), syllable frequency (mean syllable frequency per set = 12.1) and syllable complexity, with half including simple CV syllables (dete, nebuga) and half complex CVC syllables (tradi, gralepa). The first set consisted of two syllable chains, and each set incorporated an additional syllable up to a total of five. The total span was obtained by summing the total number of correctly remembered items.

Receptive vocabulary. To assess lexical knowledge stored in long-term memory, we used a *receptive vocabulary* measure, tested using the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997). This contains 175 cards with four pictures on each, where the child must indicate which image best represents the meaning of the stimulus word given by the examiner. One point is given for each correct identification. Raw scores were employed for experimental purposes. The test ended when the child made eight mistakes in twelve consecutive items.

Sentence recall. The sentence recall task included in the CELF-4 (Semel, Wiig, Secord, & Langdon, 2006) was used to measure ability to use the lexical and syntactic knowledge stored in memory under increasing linguistic constraints (see Klem, Melby-Lervåg, Hagtvet, Lyster, Gustafsson, & Hulme, 2015). This subtest is composed of 32 items, which were administered consecutively until more than three mistakes were made on the repetition of the same item in six consecutive sentences (e.g., *¿No terminaron los niños la prueba?/* "Didn't the children finish the task?", *Esta nota fue enviada por mi maestro*/ "This note was sent by my teacher."). The following criteria were used for scoring: verbatim repetition was given three points; one mistake on sentence recall was scored with two points; two or three mistakes on recall were scored with one point; and more than three mistakes scored no points. Mistakes were considered when one (or more) word within the original sentence was omitted, repeated, added, transposed or substituted for another one.

Analytical approach

Before calculating the descriptive statistics, the children's scores were examined for outliers, normality and missing data. The data were screened for univariate outliers, which were defined as cases more than 2 SD above or below the mean. No child met this criterion, and thus the final dataset for subsequent analyses consisted of 104 children. Data analysis was based on raw scores of correct responses in each task. As a first step, we conducted a Pearson correlation analysis for each time point. All correlation coefficients were below .50. Additionally, all variance inflation factors in the conducted regressions were below 2. This suggests that multicollinearity was not overly problematic in this study (Tabachnick & Fidell, 1996).

As a second step, and based on the constraints of Baddeley's model, we tested a model using structural equation modelling (SEM, Satorra & Bentler, 2001). The SEM model explored the concurrent predictive role of verbal WM (central executive measure), pSTM (phonological loop measure) and vocabulary (lexical knowledge in long-term memory) in relation to sentence recall (episodic buffer measure). This design follows the approach used by Alloway et al. (2004) to test the validity of the model's structure, but instead of using latent variables, we took only one measure tapping into each specific component of the model (backward digit recall, nonword repetition, and sentence recall), adding vocabulary as a long-term knowledge measure, which was absent in that study. In parallel, we explored the potential predictive role of the model's components in Time 1 on the same components in Time 2. To this end, we fitted the longitudinal model to test the predictive role of each memory measure on all the other memory measures over time. Of particular interest was testing which memory measures in Time 1 predicted children's scores on memory measures in Time 2, after controlling for autoregressive effects, as well as which specific mediation patterns explained the organization of the memory network over time. The model fit was evaluated using various fit indices. As a rule of thumb, model fit is considered good if chi-square is non-significant, the Root Mean Square Error of Approximation (RMSEA) is below .08 and the Comparative Fit index (CFI) is above .90 (Kline, 2005).

Results

Descriptive statistics and correlational analyses

The descriptive statistics for all of the variables at each time point are shown in Table 1. Reliability was calculated by analysing split-half coefficients, based on mean reaction times or percentage of correct items in each task. In all cases, reliability was adequate, and moderate to high in value. Skewness and kurtosis values for all measures indicated normal distributions of scores, with one estimate exceeding 2 (this being the kurtosis value for verbal WM at Time 2). A series of repeated measures analyses of variance established that there was significant growth in every variable (p < .001) over time except vocabulary and IQ.

Table 1

Descriptive data of performance on experimental tasks at Times 1 and 2.

Type of task	Mean	*SD*	Range	Reliability	Skew	Kurtosis
<u>Time 1</u>						
Verbal working memory (WISC backward digit span)	2.5	1	1-4	0.59	-1.21	1.22
Phonological short-term memory (Nonword repetition % correct)	63.5	17	33-100	0.68	-.02	-.476
Receptive vocabulary (Peabody Picture Vocabulary Test score)	57.1	24.1	9-96	0.96	-.398	-.738
Sentence repetition (Clinical Evaluation of Language Fundamentals)	48.2	15.1	10-77	0.95	-.452	.202
K-BIT matrices percentile	62.2	23.1	13-98	0.76	-.150	-.928
<u>Time 2</u>						
Verbal working memory (WISC backward digit span)	3.2	0.8	2-5	0.69	-.334	2.03
Phonological short-term memory (nonword repetition % correct)	71.3	14.1	42-100	0.60	-.078	-.73
Receptive vocabulary (Peabody Picture Vocabulary Test score)	54.2	25.2	10-99	0.96	-.184	-.915
Sentence repetition (Clinical Evaluation of Language Fundamentals)	56.9	12.08	23-85	0.90	-.340	-.101
K-BIT matrices percentile	58.2	23.8	12-99	0.75	-1.21	-.733

Note. Sample *N*= 104.

The correlation coefficients between all the main measures at Times 1 and 2 are shown in Table 2. Pearson correlation coefficients with Bonferroni correction for multiple comparisons revealed that at Time 1, vocabulary was moderately associated with sentence recall, $r(102) = .48$, $p = .001$; and to pSTM, $r(102) = .317$, $p = .001$. Associations between pSTM and vocabulary, $r(102) = .240$, $p = .01$, and between pSTM and sentence recall $r(102) = .242$, $p = .008$, were found at Time 2. Furthermore a moderate relation was found between vocabulary and sentence recall, which was slightly weaker than at Time 1, $r(102) = .41$, $p = .001$.

Table 2

Correlation coefficients among all memory measures and IQ at Time 1and Time 2.

	1	2	3	4	5
1. Verbal working memory (WISC backward digit span)	-	.129	.072	**.290****	.159
2. Phonological short-term memory (Nonword repetition)	**.233***	-	**.240****	**.242****	.107
3. Receptive vocabulary (Peabody Picture Vocabulary Test score)	.018	.102	-	**.410****	**.314****
4. Sentence repetition (Clinical Evaluation of Language Fundamentals)	.141	**.317****	**.485****	-	**.231***
5. K-BIT matrices percentile	.151	.113	.012	.101	-

Note. Sample N= 104. Values in the lower triangle represent correlations at Time 1 and values in the upper triangle represent correlations at Time 2.

* $p \leq .05$; ** $p \leq .01$.

Longitudinal predictive relations among memory components involved in language acquisition

For the full sample of 104 children, we tested whether predictive relations among the measures fitted Baddeley's working memory model and, specifically, whether sentence recall could be represented as the episodic buffer component. This possibility was tested in the model including direct paths from verbal WM to pSTM and from this to vocabulary, as well as independent feeding paths from the three components to sentence recall at Time 1 and Time 2. To examine the predictive effect of these memory components on the same memory measures over time, the model included cross-lagged paths from each component in the network at Time 1 to all the components at Time 2. The specific prediction was that sentence recall at Time 1 would be a possible longitudinal predictor of the three other components at Time 2, since, according to Baddeley's model, the integrative function of the episodic buffer lies in the fact that it draws on, and also feeds, processing, storage and lexical resources. IQ and age were included in the model as control variables.

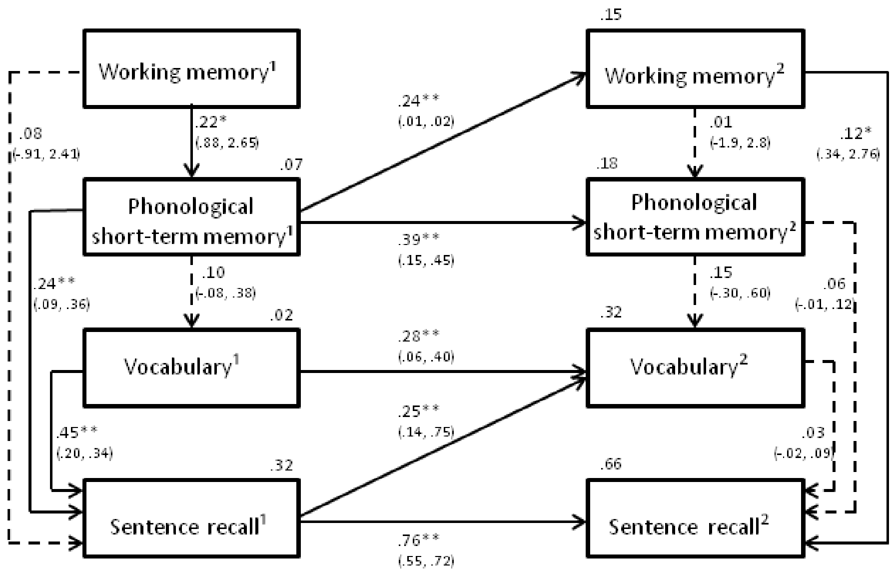

Figure 1. Path model with standardized estimates reflecting significant predictive relations between memory components at Time 1 and memory components at Time 2 including autoregressive effects and 95% confidence intervals for the full model (*N*=104). For the sake of simplicity, arrows reflecting non-significant longitudinal relations are not shown.

$* p \leq .05; ** p \leq .01.$

The model, depicted in Figure 1, provided an excellent fit to the data (χ^2 =1.13, df = 2, *p* = .567, CMIN = .567, CFI =.999, RMSEA = .001), and reflected that the components predicted by verbal WM differed from Time 1 to Time 2, and that sentence recall and pSTM were key significant longitudinal predictors of specific memory components at Time 2. Concurrently, the model reflected that when the children were 6 years old, their pSTM skills were predicted by verbal WM abilities, and that performance in sentence recall was predicted by pSTM skills and vocabulary, supporting the structure proposed by Baddeley (2003). However, at age 7, the children's performance in sentence recall was concurrently predicted only by verbal WM skills. Longitudinally, the model showed that sentence recall performance at Time 1 was a predictor of vocabulary at Time 2, explaining a moderate source of variance ($R^2 = .36$) even when autoregressive effects were taken into account. Additionally, pSTM skills at Time 1 predicted verbal WM at Time 2 directly ($R^2 = .60$), and sentence recall indirectly, through verbal WM, at that evaluation time. Not surprisingly, all autoregressive effects except that for verbal WM were relatively high, indicating that the evolution of the language memory system was modulated by each specific component over time. Nonetheless, with regard to the evolution of verbal WM, data reflected that this component was indirectly predicted by previous verbal WM and pSTM skills.

Taken together, these results support the theory of a language structure composed of specific processing and storage mechanisms that determine a child's potential to acquire language abilities. They demonstrate that verbal working memory and pSTM are key components involved in the functional organization of the language system, and that sentence recall, despite being a good proxy for lexical storage and processing abilities, has a relative potential to predict other memory components over time when verbal WM and pSTM are taken into account.

Discussion

Sentence recall performance has been widely used as a measure to evaluate language abilities over recent years. However, there are still many doubts about the cognitive mechanisms involved in this memory measure, and studies with non-clinical samples are surprisingly scarce.

The present work sets out to fill the existing gap in the literature by exploring its relative role in the developmental organization of the memory architecture underlying language in typically developing children. The contribution of our study within Baddeley's working memory framework (2000; 2003), is the longitudinal evaluation of sentence recall skills together with specific memory mechanisms (verbal WM, pSTM and vocabulary), using the same tasks and the same sample of children. Drawing on the framework's theoretical constraints, we tested a model reflecting a cascading predictive relation among the components with a twofold aim: to test the concurrent organization of memory measures at each evaluation time, and to explore whether this organization was mediated by specific longitudinal relations from Time 1 to Time 2. The results are remarkably clear cut, in line with our predictions, i) verbal WM skills were a key predictor of other memory components in the network concurrently; ii) sentence recall integrated the abilities involved in other components of Baddeley's memory network: pSTM and vocabulary were direct predictors of sentence recall at Time 1, with verbal WM being its only predictor at Time 2; iii) longitudinal predictive relations constrained the relative role of memory components in the network from Time 1 to Time 2, and explained the dynamic organization of the memory architecture over time. These data support the view of a highly interactive language system in childhood, and suggest a key role of different memory abilities in the evolution of this system over time. We describe our findings in more detail below.

The differential role of verbal WM and pSTM in the memory architecture underlying language

In view of suggestive evidence about sentence recall involving phonological, monitoring and lexical abilities (Alloway et al., 2004; Baddeley, Allen, & Hitch, 2010; Petruccelli, Bavin, & Bretherton, 2012), our first aim was to test whether, according to Baddeley's constraints, this memory component was directly predicted by verbal WM, pSTM and vocabulary level. A model reflecting a cascading relation from verbal WM to vocabulary through pSTM, and from these to sentence recall, provided excellent fit to the data. More importantly, different memory resources were involved in efficient sentence recall at each evaluation time. While at Time 1 verbal WM directly predicted pSTM, and sentence recall performance depended exclusively on pSTM and vocabulary skills, at Time 2 verbal WM was the only significant predictor of efficient sentence recall performance.

These data go beyond previous correlational studies (Adams & Gathercole, 2000; Alloway et al., 2006; Gray et al., 2017) and provide new insights into the degree of differentiation between pSTM and verbal WM and their specific involvement in language acquisition. First, they establish verbal WM as a key monitoring component influencing lexical and syntactic abilities in typically developing children (see de Abreu, Gathercole, & Martin, 2011; Chrysochoou, Bablekou, Masoura, & Tsigilis, 2013). Second, our data reveal that the specific role of each memory component in the ability to maintain and retrieve word sequences changes with time, suggesting a greater involvement of verbal WM in this ability as age increases. Although our data support the claim that sentence recall is modulated by the three memory components, they suggest a differential role of such components in the formation of exhaustive representations of how the lexicon is arranged in the language over time.

Indeed, the shift observed in our study from an indirect predictive relation of verbal WM to sentence recall through pSTM, at Time 1, to a direct relation at Time 2, suggests that monitoring processes might clearly be involved in children’s abilities to retain and repeat word sequences once their basic lexicon has been formed. This is in line with studies showing that while pSTM is crucial in the formation of the lexicon during childhood (Gathercole, 2006; Mainela-Arnold et al., 2010), verbal WM skills are related to syntactic processing (de Abreu et al., 2011; McDonald, 2008; Verhagen & Leseman, 2016). Accordingly, the involvement of verbal WM in sentence recall might be more evident with time as children have already reached a certain vocabulary level and when the information to be processed becomes more complex.

Several authors have suggested that the sentence recall task entails this complexity, because it requires recalling and monitoring both lexical and syntactic information. For this reason, it taps into abilities that go beyond lexical formation. This assertion is supported by two sources of evidence. On the one hand, performance on the sentence recall task shows stronger correlation values with children's sentence comprehension abilities than the nonword repetition task, which in turn correlates highly with vocabulary measures (Cain, Bryan, & Oakhill, 2004; Marshall & Nation, 2003; Seigneuric, Ehrlich, Oakhill & Yuill, 2000). On the other hand, several works have reported a relation between sentence recall and executive skills (Acheson & McDonald, 2009; Alloway et al., 2005; Cain, Oakhill, & Bryant, 2004; Verhagen et al, 2016). The strong predictive role of verbal WM in the sentence recall performance of our children at Time 2 sustains this view. This relation is assumed to indicate that provided the child is more able to deal with complex verbal information, the need to activate longer memory traces makes higher demands on the memory system (Mainela-Arnold et al., 2012; Poll, Miller, Mainela-Arnold, Adam, Misra, & Park, 2013). Thus, the functional overlap between the two measures might explain why sentence recall and backward digit tasks have sometimes been used indistinctly to test working memory in the developmental literature (Chrysochoou et al., 2013; Seigneuric & Ehrlich, 2005).

This pattern of results finds support from studies with clinical samples, which reveal that the percentage of SLI children with verbal WM impairments doubles that of children without (Archibald & Gathercole, 2006; Archibald & Joanisse, 2009). Interestingly, although pSTM deficits are typical in all clinical samples (Riches, 2012), children with additional verbal WM impairment show a worse developmental trajectory in syntactic development (Archibald et al., 2006; McDonald, 2008). The present data are consistent with this evidence, and suggest that monitoring and planning mechanisms become more necessary as the processing of both structural and semantic aspects of the input increase (Engel de Abreu et al., 2011; Lewis, Vasishth, & Van Dyke, 2006).

However, and without neglecting the importance of monitoring abilities in the functional organization of the language system, longitudinal predictive relations in the model revealed that pSTM skills are crucial in the development of the cognitive architecture underlying language. Note that pSTM directly predicted sentence recall performance at Time 1, and indirectly at Time 2 through sentence recall and verbal WM skills. In line with previous studies associating pSTM with greater vocabulary development (Alloway et al., 2004; Chrysochoou et al., 2013; Gathercole et al., 1994; Jarrold et al., 2009) and longer speech utterances early in childhood (Bowey, 2001; Palladino & Cornoldi, 2004), our data indicate that children's ability to maintain and retrieve complex representations in memory depend on their previous phonological storage abilities (see also Gathercole, Tiffany, Briscoe, Thorn, & ALSPAC team, 2005). One possibility is that pSTM skills provide the linguistic outset that supports the construction of verbal representations based on existing memory traces and the use of other memory resources. This measure might, therefore, constitute a reliable early indicator of a child's potential to develop further language abilities. These results are in line with the argument that phonological processing skills and lexical knowledge could lay the ground for the incorporation of new items or more complex structures into the system (Adams & Gathercole, 2000; Blake et al., 1994; Gathercole, 2006; Morra & Camba, 2009). Indeed, the specific demands to activate, transfer and produce increasingly larger chunks of verbal information which are inherent to the task may not only explain the predictive role of verbal WM in sentence recall in our study but also shed light on the reasons why this task is sensitive to general language abilities in both clinical (Archibald & Gathercole, 2006; Leclercq, Quémart, Magis, & Maillart, 2014; Riches, 2012; Stokes et al., 2006) and non-clinical samples (Nag, Snowling, & Mirković, 2018; Klem et al., 2015).

The dynamic organization of the memory architecture during development: the role of sentence recall

Interestingly, the longitudinal paths also revealed that sentence recall explained progressive gains in vocabulary, beyond autoregressive effects. This finding provides new insights into the role of sentence recall abilities in the memory architecture over time. If the integrative nature of sentence recall entails the activation of longer memory traces, which, as suggested in the literature, might range from phonological sequences to word sequences (see Alloway et al., 2005, McDonald, 2008; Polišenská et al., 2015), then sentence recall performance might give account of the quality with which structural aspects of language are stored in a child's memory, and of the child's ability to activate and produce such structures.

The direct relation of sentence recall at Time 1 with developmental growth in vocabulary at Time 2 reinforces previous suggestions that an important feature of sentence recall might lie in the specific demands of long-term memory resources to activate and maintain verbal information in memory (Tremblay, Derwing, Libben, & Westbury, 2011). Our results extend previous evidence by showing that sentence recall performance not only depends on the child's lexical level (Mainela-Arnold et al., 2005; Riches, 2012) but also explains an independent source of variance of lexical growth. The predictive relations observed in our model offer a potential explanation of the relation between vocabulary and sentence recall over time, showing that previous lexical knowledge (vocabulary level at Time 1) favours the internalization of complex structures that contain known lexical items (facilitating sentence recall performance at Time 1). At the same time, knowledge about word structures frees cognitive resources to focus on new words (favouring vocabulary growth at Time 2), and to internalize more complex structures with time (favouring sentence recall at Time 2). Thus, the current study adds to the recent theory about how this task involves storage and monitoring resources, as well as knowledge about words and word sequences (see Allen, Hitch, Mate, & Baddeley, 2012; Baddeley et al., 2009) for evidence with adults). Children's efficiency in making use of acquired linguistic knowledge (distinctness of phonological structures embedded in words and of word sequences in the language) could boost lexical formation mechanisms. Our data therefore reveal that sentence recall draws together resources from memory mechanisms and lexical knowledge, supporting its multidimensional nature.

An interesting question is why sentence recall did not predict pSTM longitudinally, since pSTM resources were clearly concurrently involved in sentence recall performance at Time 1. One argument might be that pSTM entails rehearsal and articulation of specific combinations of sounds (note that there was a significant autoregressive effect), while sentence recall might call for a greater effort in terms of monitoring long-term memory resources, enhancing long-term lexical knowledge longitudinally. Interestingly, this assumption also finds support in clinical samples. The fact that sentence recall shows a strong sensitivity to predict language development in SLI with and without verbal WM impairments (Archibald & Joanisse, 2009; Bishop et al., 2006; Conti-Ramsden et al., 2001) reveals that the value of this task in predicting language difficulties might lie in its integrative demands.

The present findings support the assumption that sentence recall fits well with the role attributed to the episodic buffer (Baddeley, 2003). Although Baddeley (2012) suggested that the binding of words into chunks can be performed automatically in long-term memory, the executive buffer is regarded as a structure where these chunks are available for further manipulation, sustaining language growth. Our data reinforce the idea that sentence recall taps not only into knowledge about word sequences, but also into general aspects of language, such as phonological coding and lexical processing abilities, as suggested in previous works (Klem et al., 2015; Komeili & Marshall, 2013). This specific issue has been explored in experimental paradigms in which recall performance in correct sentence conditions is compared to conditions in which phonological, lexical, syntactic, prosodic and semantic correctness are manipulated.

The fact that typically developing children's errors are significantly greater in the first three conditions with respect to the control condition, suggests that the ability to reorder the information into a syntactic "frame" poses high phonological and lexical processing demands on the child (Riches, Loucas, Baird, Charman, & Simonoff, 2010; Conti-Ramsden et al., 2001; Polišenská et al., 2015). These findings are consistent with those of Alloway and Gathercole (2005), who found that the type of errors committed by 5-year-olds in a sentence recall task depended on their pSTM skills. Those with low pSTM made more phonological and serial order errors, while those with high pSTM skills committed lexical-semantic errors.

We explored this issue further by examining the type of errors made by our children, who showed relatively good levels of pSTM. Of the total number of errors, the most frequent ones were grammatical (omission of function word or verb, 56% and 55% at T1 and T2, respectively), followed by lexical (omission, addition of noun, 23.4% and 24%), lexical-semantic (noun substitution, 10.4% and 10.2%), serial order errors (6.5% and 7.2%), and finally phonological errors (0.9% and 0.14%). Our pattern of results favours the view that sentence recall performance is driven not only by the child's knowledge about syntactic frames, but also by the extent to which lexical representations and their phonological forms have been consolidated in long-term memory. All this evidence supports certain authors' claims that sentence recall draws on cognitive resources that facilitate the transition from the construction of structural representations in root memory to an abstract and decontextualized use of language (Devescovi & Caselli, 2006; McCauley & Christiansen, 2015). Although this claim deserves further study, it could explain the strong sensitivity of this task to measuring general language processing abilities in children with and without language difficulties.

Summary and conclusions

In sum, our results point to a dynamic interaction of the memory processes involved in language development. These findings have important theoretical and practical implications.

Theoretically, they provide support for the model suggested by Baddeley (2003), which conceptualizes the episodic buffer as a memory component acting as a temporal interface between long-term memory and language processing subsystems (the central executive and phonological loop). On practical grounds, the most obvious implication is for verbal WM and pSTM as early markers of a child's potential to develop linguistic abilities, and of sentence recall as a method to identify and train language-processing abilities that involve knowledge about words and word order. Structured sentence recall training programs have already demonstrated their efficacy in improving language measures as well as verbal WM in aphasic patients (Berthier, Dávila, Green-Heredia, Moreno-Torres et al., 2014; Eom & Sung, 2016). Our data with typically developing children reveal that such programs could be proposed as a method of choice in the intervention of verbal monitoring and lexical abilities in the middle school years. Future studies are required to examine the effect of different manipulations –phonological, grammatical, lexical and semantic– and levels of complexity on children´s performance at different ages in order to explore the specific processes in play, as well as to understand what such performance tells us about a child's language-learning processes.

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