Available online at www.sciencedirect.com

SCIENCE DIRECT®

J. Experimental Child Psychology 93 (2006) 95–119

Journal of Experimental Child Psychology

www.elsevier.com/locate/jecp

Relations between vocabulary development and verbal short-term memory: The relative importance of short-term memory for serial order and item information

Steve Majerus [a,b,*], Martine Poncelet [a], Christelle Greffe [a], Martial Van der Linden [a,c]

[a] *Department of Cognitive Sciences, University of Liège, B-4000 Liège, Belgium*
[b] *Belgian National Fund of Scientific Research, Belgium*
[c] *Cognitive Psychopathology Unit, University of Geneva, 1205 Geneva, Switzerland*

Received 25 February 2005; revised 21 July 2005
Available online 9 September 2005

Abstract

Although many studies have shown an association between verbal short-term memory (STM) and vocabulary development, the precise nature of this association is not yet clear. The current study reexamined this relation in 4- to 6-year-olds by designing verbal STM tasks that maximized memory for either item or serial order information. Although empirical data suggest that distinct STM processes determine item and serial order recall, these were generally confounded in previous developmental studies. We observed that item and order memory tasks were independently related to vocabulary development. Furthermore, vocabulary development was more strongly associated with STM for order information in 4- and 6-year-olds and with STM for item information in 5-year-olds. These data highlight the specificity of verbal STM for serial order and item information and suggest a causal association between order STM processes and vocabulary development, at least in 4- and 6-year-olds.

* Corresponding author. Fax: +32 4 3662808.
E-mail address: smajerus@ulg.ac.be (S. Majerus).

0022-0965/$ - see front matter
doi:10.1016/j.jecp.2005.07.005

Keywords: Cognitive development; Verbal short-term memory; Vocabulary; Serial order; Phonological processing; 4- to 6-year-olds

Introduction

Many studies have demonstrated a strong association between verbal short-term memory (STM) capacities and vocabulary development in children. However, many questions remain about the exact cause of this association. In the current article, we argue that a better understanding of this association may be achieved when using STM tasks that make a clearer distinction between the different types of information that must be maintained in STM tasks. In this study, we distinguish two types of information: (a) item information, that is, the phonological, lexical, and semantic content of the verbal items presented for recall, and (b) serial order information, that is, the sequential order in which the items are presented. These two types of information are typically confounded in classical STM measures. However, their distinction is fundamental for understanding associations between verbal STM and vocabulary development because STM for item information and STM for order information might reflect distinct processes that may be differentially related to vocabulary development.

An impressive number of studies have shown that verbal STM performance, such as that measured by nonword repetition and digit span, correlates with receptive vocabulary development in 2- to 13-year-olds (e.g., Avons, Wragg, Cupples, & Lovegrove, 1998; Bowey, 1996; Gathercole, 1995; Gathercole & Adams, 1993, 1994; Gathercole & Baddeley, 1989, 1990, 1993; Gathercole, Service, Hitch, Adams, & Martin, 1999; Gathercole, Willis, & Baddeley, 1991; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994). Despite this highly consistent empirical finding, the reasons for this association are not yet clear. A number of authors consider verbal STM capacity as a causal factor of vocabulary development (e.g., Adams & Gathercole, 1995; Avons et al., 1998; Baddeley, Gathercole, & Papagno, 1998; Gathercole, 1999). This position considers that verbal STM is an obligatory doorway through which any new phonological information entering long-term memory must pass (e.g., Baddeley, 2003; Baddeley et al., 1998). In other words, the better the quality of the STM representation of a new word, the more likely this temporary representation will be accurately rehearsed and eventually transformed into a stable and precise long-term phonological representation. This position is supported by longitudinal correlational data showing that verbal STM performance, as measured by nonword repetition, predicts later vocabulary knowledge. For example, Gathercole and Baddeley (1989) observed that nonword repetition performance measured in 4-year-olds predicts their vocabulary knowledge at 5 years of age.

A second position considers that vocabulary growth itself is also a causal factor responsible for the developmental increase in verbal STM capacity. For example, Metsala (1999) argued that, as a result of increasing vocabulary knowledge, children switch from holistic representations of familiar words to more segmented lexical representations, adopting the phoneme as the basic unit of oral language processing, that is, the "lexical restructuring hypothesis" (see also Fowler, 1991). Brown and Hulme (1996) proposed a similar theoretical framework but added that reading instruction further boosts the development of segmentalized lexical representations. These finer-grained phonological representations would allow a more precise and accurate encoding of nonwords in STM tasks and would facilitate nonword STM performance.

This position is supported by a number of studies showing that verbal STM performance is strongly influenced by language knowledge. Word span is well above nonword span in both younger and older children, showing that lexical knowledge supports storage of verbal information in STM (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Majerus & Van der Linden, 2003; Roodenrys, Hulme, & Brown, 1993). Other lexical and semantic variables, such as word frequency and word imageability, also influence STM performance for word list recall in both children and adults (Majerus & Van der Linden, 2003). Furthermore, even for nonwords, sublexical phonological knowledge about the phonological structure of the native language appears to influence STM performance. Gathercole, Frankish et al. (1999) showed that nonwords containing phoneme combinations that are frequent relative to the phonotactic structure of English yield higher performance levels in an immediate serial recall task than do nonwords containing much less familiar phoneme combinations. Majerus, Van der Linden, Mulder, Meulemans, and Peters (2004) further demonstrated that nonword recall performance can also be influenced by new phonotactic knowledge that has been learned during a 30-min incidental learning session just prior to the nonword recall task. Altogether, these data clearly show that verbal STM performance is strongly dependent on lexical and sublexical knowledge and that the developmental increase in this knowledge base will also have a positive impact on verbal STM capacity.

However, there are a number of reasons to believe that further understanding of the complex relations between vocabulary development and verbal STM capacity is hindered by the fact that developmental studies typically confound item and serial order information in the tasks used to assess STM performance. Nonword repetition and digit span, the most frequently used tasks, require that at least two different types of information be stored: item information (the digits or phonemes presented) and order information (the order in which these different units were presented). A number of studies suggest that STM for item information and STM for order information might reflect distinct cognitive processes. For example, Henson, Hartley, Burgess, Hitch, and Flude (2003) showed that short-term recognition of item and order information in adults is differentially influenced by interfering variables such as articulatory suppression and irrelevant speech presented during the administration of the memory lists. It is also known that phonological similarity of the items to be recalled increases order errors but not item errors (Nairne & Kelly, 2004; Wickelgren, 1965).

With respect to the influence of sublexical and lexical language knowledge, a number of studies suggest that language support is most pronounced for recall of item information. For example, Poirier and Saint-Aubin (1996) found that word frequency increased item recall but not order recall. Nairne and Kelly (2004) also observed a larger influence of word frequency on item recall than on order recall. Furthermore, recall of item and order information might be subtended by distinct STM capacities. Majerus, Van der Linden, Bressand, and Eliez (2005) showed that some children with a chromosome 22q11.2 microdeletion present severe deficits for recall and recognition of serial order information (as measured by serial order reconstruction or probe recognition tasks), whereas their STM performance on item information (single nonword delayed repetition or item probe list recognition) is preserved.

At a theoretical level, many recent connectionist models of verbal STM suggest that item and serial order information are indeed stored in separate, albeit closely connected, systems (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1992, 1999; Gupta, 2003; Gupta & MacWhinney, 1997; Henson, 1998). All of these models contain some form of external signaling mechanism ensuring the encoding of serial order information, whereas the items on which this timing mechanism operates are represented in a separate and often linguistic code. For example, in the model proposed by Burgess and Hitch (1999), serial order information is encoded via a system of context nodes and the fast-changing connection weights between these context nodes and item nodes in the lexical language network. The differential patterns of activation in the context node system, changing for each item as a function of its moment of presentation, underlie the storage and recovery of serial order information. A different set of fast-changing connection weights between the lexical item nodes and input and output phoneme nodes temporarily encodes the lexical and phonological characteristics of item information.

With respect to vocabulary development, some of these models further predict that it is specifically the serial order component that determines the relation between verbal STM performance and vocabulary development. For example, like Burgess and Hitch (1992), Gupta (2003) postulated the existence of an STM system solely dedicated to the storage of serial order information. This STM system is connected to a lexical system where familiar word forms are stored and to a sublexical system where sublexical phonological information, such as phonemes and syllables, are represented. When a new word form is presented, the corresponding phonemes will be activated in the sublexical system, as will a new lexical node in the lexical system. At the same time, the STM system encodes and temporarily stores the order of activation of the phonemes in the sublexical system. This enables the language system to "replay" the new phoneme sequence with each phoneme in correct serial position and to build up a more stable long-term lexical representation by progressively strengthening the connection weights between the new lexical node and the corresponding phonemes after each "replay." If the capacity of the STM system is weak, the ordered replay of the new phoneme sequence will be more error prone, slowing down the learning process. In that way, verbal STM capacity is clearly related to the ability to temporarily maintain and reproduce serial order information, and it is this capacity that is assumed to be a critical building block for new word learning. In contrast, the storage of item information is closely related to the quality of the language network itself because it is represented via temporary activation of lexical and sublexical language representations.

In the light of these theoretical developments, the aim of the current study was to reexamine the relation between STM capacities and vocabulary development in young children (4–6 years of age) by designing tasks that maximize retention requirements for either serial order or item information. According to Gupta (2003) and Gupta and MacWhinney (1997), we should observe strong correlations between measures maximizing retention of serial order information and vocabulary development. This would further strengthen the hypothesis that verbal STM capacity is causally related to vocabulary development. With respect to the studies suggesting that vocabulary knowledge and its level of segmentation are exerting a strong influence on verbal STM performance, we should also observe significant associations between vocabulary development and STM measures maximizing retention of item information because these measures supposedly are more influenced by lexical knowledge than are order STM measures. Most important, according to the theoretical models presented here, there should be independent associations between vocabulary development and STM measures maximizing retention of either serial order or item information.

Finally, some authors also predict that common mechanisms underlie recall of serial order and item information in memory tasks with either short-term or longer term retention delays. Nairne (1990) showed that serial order reconstruction of verbal lists after a delay of several minutes yielded very similar serial position curves as immediate serial recall tasks and serial order reconstruction tasks in STM conditions. Similarly, Whiteman, Nairne, and Serra (1994) observed that effects of word frequency in long-term memory tasks yielded effects comparable to those observed in STM tasks: these effects enhance recall of item information but not of order information. Given these findings, the pattern of correlation between tasks maximizing retention requirements for serial order or item information and vocabulary development may be independent of the length of the retention interval. This was explored in the current study by presenting the item and order memory tasks in two different versions, that is, with either short or longer retention delays (30 s).

We chose to study relatively young children, 4- to 6-year-olds, because previous studies have shown that the relation between verbal STM measures and vocabulary development is strongest at these ages. This association tends to be less reliable at later ages when vocabulary growth will be more influenced by external factors such as school instruction and reading experience (Cunningham & Stanovich, 1991; Gathercole & Baddeley, 1993; Gathercole, Service et al., 1999).

The current experiment

The STM task designed to maximize retention requirements for serial order information was a serial order reconstruction task. In this task, children were presented with a short auditory list of animal names. At the end of the list, children were given cards depicting the animals that had been presented. Children were asked to rearrange the cards in the order that the animal names had been presented. This task was similar to serial order reconstruction tasks used by a number of authors to measure the reconstruction of serial order information after either short- or long-term retention delays (e.g., DeLosh & McDaniel, 1996; Nairne, 1990). This task generally yields U-shaped serial order position curves similar to those of standard immediate serial recall tasks. It appears to be highly sensitive to serial order information and minimizes the retention of item information because all items are represented at recall, when only order information must be reconstructed.

It should be noticed that this task does not completely eliminate retention requirements for item information; for example, Neath (1997) showed that variables that usually affect item recall, such as concreteness, also affect serial order reconstruction tasks. However, the important point here is that, relative to the item STM tasks presented subsequently, retention requirements for serial order information are maximized in this serial order reconstruction task, whereas requirements for processing of phonological item information are minimized. The animal names used in the current study were in fact sampled from a limited pool of seven highly familiar animal names with a very low age of acquisition and a simple phonological structure. In this way, phonological analysis and segmentation processes for item information are highly facilitated in this task. Furthermore, at the time of recall, item information was fully available because the cards representing the presented animal names were given to the children and they simply had to arrange them in correct serial position.

To make the task requirements as straightforward as possible for very young children, the task was presented as a game. Children were told that several animals were participating in a race and that they would hear the order of arrival of the animals at the finish line. Their task would be to put the winning animal, the animal finishing second, the animal finishing third, and so forth on the winner's podium.

STM tasks maximizing retention requirements for item information were simple delayed single word or nonword repetition tasks. In these tasks, a single word or nonword was presented, followed by a delay of 3 s during which the child had to perform a distractor task preventing rehearsal of the information to be recalled. To maximize processing requirements for item information, the items were new on any trial. Serial order requirements were kept to a minimum in that only a single item had to be repeated; however, they were not completely abolished given that retention of order information at the phoneme level was necessary. They nevertheless were minimized in the sense that the phoneme sequence was predictable because all items had the same monosyllabic CVC structure—beginning with a consonant, followed by a vowel, and ending with another consonant—so mainly phoneme identity had to be retained to "fill in" the different consonant and vowel positions. By comparing STM for word and nonword items, we were also able to explore whether lexical knowledge was influencing STM for item information in very young children. According to some of the theoretical models described previously, coding of item information depends strongly on activation of the language network and will be sensitive to any verbal knowledge that is available, even if this knowledge is not yet fully developed. However, with respect to empirical data, consistent lexicality effects in verbal STM tasks have been observed in children age 6 years or older but not yet in younger children (Gathercole, Pickering, Hall, & Peaker, 2001; Henry & Millar, 1991; Roodenrys et al., 1993; Turner, Henry, & Smith, 2000). Only Brock and Jarrold (2004) showed evidence of lexicality effects in 4-year-olds using item and order probe recognition tasks.

In the current study, the item STM tasks were presented as a game like the serial order STM tasks. Children were told that they were in a castle and that they had to find their way out. To get out, they had to cross different rooms, each of which could be opened by correctly repeating, after a short delay, a password that was presented on arrival at the door of the room.

As mentioned previously, this study also aimed to investigate whether possible differential relations between vocabulary knowledge and STM tasks maximizing retention for either serial order or item information can be reproduced for tasks with longer term retention intervals. Therefore, we administered long-term versions of the item and serial order STM tasks, including a filled delay of 30 s between presentation of the target stimulus/sequence and the response. Furthermore, for the item long-term memory version, only word stimuli were used because pilot testing had shown that performance dropped severely for nonword stimuli after a retention delay longer than 3 s.

Method

Participants

A total of 60 children from three age groups participated in this study. There were 20 4-year-olds (9 girls and 11 boys; mean age: 55 months; range: 49–59), 20 5-year-olds (10 girls and 10 boys; mean age: 65 months; range: 60–71), and 20 6-year-olds (9 girls and 11 boys; mean age: 78 months; range: 73–83). When collapsing the three age groups, the mean age of the entire sample was 66 months. The children were selected from kindergarten and first grade-level classes in two localities of the province of Liege in Belgium. Parental consent was obtained for each child. Parents were also administered a questionnaire ensuring that the children's native language was French, that the children had no history of neurological disorders or neurodevelopmental delay, that the children's auditory and visual acuity were normal, and that the children had normal language development and no learning difficulties. All of the children came from families with middle-class socioeconomic backgrounds. The children were seen in their respective schools or at home.

Materials and procedure

Serial order reconstruction (the animal race task): Short-term retention interval

The stimuli used for this task were seven monosyllabic animal names: *chien*, *chat*, *loup*, *ours*, *lion*, *coq*, and *singe* (dog, cat, wolf, bear, lion, cock, and monkey). The mean age of acquisition for the seven names was 1 year 8 months (range: 13–24 months) (Alario & Ferrand, 1999; Ferrand & Alario, 1998). The mean lexical frequency, based on a database derived from texts from schoolbooks and general books for children of primary school age, was very high (mean lexical frequency: 50,631; range: 16,423–90,926) (Lambert & Chesnet, 2001). These selection parameters ensured that all items were highly familiar to the children. These seven stimuli were used to form lists with lengths ranging from two to seven items, and there were four trials for each list length. For each list, the items were randomly selected from the pool of seven items, and no item could occur twice in the same list.The individual items were recorded by a female voice and stored on computer disk. Mean duration of the items was 549 ms (range: 371–696). The different prerecorded items were used to assemble the 24 stimulus lists with an interstimulus interval of 650 ms.

The stimuli were presented by increasing list length, beginning with list length 2. All 24 trials were presented to each child. The procedure was as follows. The stimulus list was presented via headphones connected to a portable PC. The experimenter activated the presentation of each stimulus list. After the auditory presentation of the list of animal names, the child was given cards with a dimension of 6.5×6.5 cm. On each card, one of the animals whose oral names the child had heard was depicted. Only the cards for the animals actually presented were given to the child. Thus, for list length 2, the child received two cards; for list length 3, the child received three cards; and so forth for subsequent list lengths. The child then had to arrange the cards (given in alphabetical order) following the order of presentation of the auditory sequence by putting them on a 50×50-cm cardboard sheet on which a staircase-like figure with seven steps was depicted. The child had to put the first animal of the list at the highest step, the second animal at the second-highest step, and so forth for the subsequent trials. However, the child could begin order reconstruction at any serial position (i.e., free reconstruction of order). For list lengths less than seven items, the unneeded steps were covered by a blank sheet. The experimenter wrote down the order in which the child had reordered the cards, removed the cards, and activated the auditory presentation of the next list. The child was told the following story for task description:

> Every year, the animals from all over the world gather to have a huge race. This year, seven animals are participating: a dog, a cat, a lion, a bear, a wolf, a monkey, and a cock [the experimenter shows the cards of the corresponding animals]. Several races take place. Sometimes only two animals are participating. Sometimes there are three, four, or five animals. At other times, there are big races with six or seven animals. Through the headphones, you will hear someone announce the animals' order of arrival at the finish line, from the first to the last animal. Immediately after, you have to put the pictures of the animals on the podium in their order of arrival. The animal arriving first has to be put on the highest step and the last one on the lowest step. Okay?

The child was informed when the list length increased. We determined the number of sequences correctly reconstructed out of a total of 24 trials.

Serial order reconstruction (the animal race task): Long-term retention interval

For the long-term retention interval, the task was exactly the same. A new set of 24 trials was sampled from the seven animal names and consisted of lists ranging from two to seven items with four trials for each sequence length. Stimulus preparation, presentation, and task procedure were exactly the same as described in the previous task except that there was a retention interval lasting 30 s beginning at the offset of presentation of the stimulus list. During the retention interval, the child performed parts of a vocabulary task or other filler tasks to prevent rehearsal of the list to be remembered (described subsequently).

Delayed item repetition (the castle task): Short-term retention interval

This task consisted of 30 monosyllabic words and 30 monosyllabic nonwords. The 30 words had a CVC syllabic structure with a low age of acquisition (mean: 1 year 11 months; range: 15–37 months) (Alario & Ferrand, 1999) and high lexical frequency (mean: 15,566; range: 1190–85,452) (Lambert & Chesnet, 2001). All words represented concrete objects. The 30 nonwords also had a CVC syllabic structure, and all were legal with respect to French phonotactic rules. The diphone frequencies of the CV segments (mean: 149; range: 3–524) and VC segments (mean: 129; range: 7–728) were nevertheless chosen to be low relative to the phonological structure of French, according to the database of French phonology by Tubach and Boë (1990). The word and nonword stimuli were recorded by a female human voice and stored on a computer disk. The word stimuli had a mean duration of 621 ± 148 ms, and the nonword stimuli had a mean duration of 738 ± 95 ms.

The word and nonword stimuli were presented in separate lists. Further details of the procedure are as follows. The experimenter activated the auditory presentation of an individual stimulus that the child heard through headphones connected to a portable PC. At the end of the stimulus, the child was instructed to continuously repeat the syllable "bla" during 3 s. Then the experimenter instructed the child to repeat the stimulus. Furthermore, the task was also presented as a game. The child was told the following:

> You are an adventurer [for a boy]/a princess [for a girl] locked up in the tower of a castle [a drawing of the castle is shown to the child on the computer screen]. The castle has many doors. You have to find your way out of the castle. In order to do so, you have to open the doors by remembering passwords. More precisely, when you see a closed door [the experimenter shows the next computer slide depicting a closed door], you will hear through the headphones a password [for a word]/word from a magic language [for a nonword] which opens the door and which you have to remember. The door opens if you repeat "blablabla …" during a short time and if afterward, on my order, you repeat the password you just heard. Okay?

To avoid excessive frustration in case the child did not remember the nonword, the examinator opened the door for him or her by using a golden key. However, the child was told that there was only a limited number of keys available and that the child had to do the best he or she could to remember the password/magic word.

For the word and nonword conditions, we counted the number of items correctly repeated. For the nonword condition, the child additionally had to repeat the nonword once immediately after presentation to confirm that the child had correctly perceived the item and was able to reproduce it accurately. However, no corrective feedback was given to the child.

Delayed item repetition (the castle task): Long-term retention interval

This task was very similar to the single word delayed repetition task as described in the previous paragraph. A new set of 20 monosyllabic and concrete words was selected. The age of acquisition (mean: 1 year 11 months; range: 15–35 months) (Alario & Ferrand, 1999), lexical frequency (mean: 18,033; range: 476–44,035) (Lambert & Chesnet, 2001), and duration (620 ± 153 ms) were similar to those for the previous word list of the short-term retention condition. The stimulus preparation, presentation, and task procedure were exactly the same as in the previous task. The only difference was that the retention interval was increased to 30 s, during which the child performed filler tasks (described subsequently) to prevent rehearsal of the word to be recalled. As noted previously, no nonword stimuli were used for this task because pilot testing had shown that nonword delayed repetition after more than 3 s yielded floor effects.

Receptive vocabulary knowledge

Vocabulary knowledge was measured using the EVIP (*Echelle de vocabulaire en images Peabody*) (Dunn, Thériault-Whalen, & Dunn, 1993), a French adaptation of the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981). As a dependent variable, we used raw vocabulary scores.

Nonverbal intelligence

Raven's colored progressive matrices (Raven, Court, & Raven, 1998) were administered during the long-term retention intervals and estimated general nonverbal reasoning abilities. Raw scores were used in the analyses presented later in Results.

Filler tasks

Other tasks were administered during the retention delay of the memory tasks with a long-term retention interval. These tasks were the ECOSSE (*Épreuve de compréhension syntaxico–sémantique*) (Lecocq, 1996), a French adaptation of the Test for the Reception of Grammar (TROG) (Bishop, 1983), and the Block Design subtest of the WPPSI-R (échelle d'intelligence de *Wechsler pour la période préscolaire et primaire–forme révisée*) intelligence scales (Wechsler, 1995). However, these tasks served mainly as fillers for the retention interval of the memory task, and performance on these tests was not further analyzed.

General procedure and task order

The different tasks were administered in two different sessions lasting approximately 1 h, with a short break at the middle of each session. To obtain the most valid estimate possible of a given child's performance level on a given task, each memory task was split into two parts having exactly the same number of trials and being of equivalent sequence length (for the serial order reconstruction tasks), with one part being presented during Session 1 and the other during Session 2. The scores obtained for the two parts were then combined. Our reasoning was that performance measures at two time points for the same task give a more valid estimate of general performance capacity for a given task than does a unique measure at a single time point. This allowed us to obtain estimates for test–retest reliability of our experimental measures. More precisely, during each session, we presented 12 trials (2 trials for each sequence length) of the serial order reconstruction task (short term), followed by the 15 trials of the single word delayed repetition task (short term), followed by 12 trials of the long-term serial order reconstruction task. During the retention intervals, the vocabulary task (Session 1) or the sentence comprehension task (Session 2) was concurrently administered. At the end of the 12 memory trials, administration of the vocabulary or the sentence comprehension task continued until completion. After a short break, the short-term single nonword delayed repetition task was presented. The session ended with the administration of 10 trials of the long-term single word delayed repetition task. Raven's matrices or the block design task was administered during the retention interval. No verbal filler tasks (vocabulary development or sentence comprehension) were presented during the retention delay for the long-term word delayed repetition task because the different word stimuli contained in these verbal filler tasks could have either facilitated (cued) recall or caused interference with the target word. This was not the case for the long-term serial order reconstruction task, where the verbal items came from a highly restricted set, were known in advance, and were represented at recall.

Outline of analyses

First, reliability estimates of the experimental tasks were examined. A set of analyses of variance (ANOVAs) then assessed age effects for the different tasks. If verbal STM for item and serial order information rely on different cognitive components, then these components might present differential maturation rates and lead to differential age effects for the item and order tasks. A second set of ANOVAs assessed lexicality effects for the delayed repetition tasks. Next, partial correlation analyses were conducted to determine the extent to which the different item and serial order memory tasks correlate with vocabulary development. Finally, multiple regression analyses were conducted to determine the unique impact on vocabulary scores of the different item and order memory tasks. For all of the memory tasks presented here, we had taken special care in designing STM measures that were equated with respect to task difficulty. However, this was not possible for each task. Pilot testing had shown that for the nonword repetition task, a retention delay of 3 s ensured levels of performance similar to those for the short-term serial order reconstruction task. Because we also wanted to compare the word and the nonword stimuli in the delayed repetition task, we had to keep the same retention interval for the word condition. However, this inevitably increased the risk of obtaining higher performance levels for the word condition, especially if there are significant lexicality effects.

Results

Reliability analyses

Descriptive statistics for the entire sample are given in Table 1. As can be seen from proportionalized scores, performance levels were very similar between the long- and short-term serial order reconstruction tasks and the nonword delayed repetition task. As expected, performance for the word delayed repetition tasks (both the short- and long-term versions) was higher. Reliability estimates for the different measures were obtained by computing correlations between the first and second administrations of each task (see last column of table). Highly significant and large test–retest reliability estimates were obtained for most measures except for the short-term delayed word repetition task, where the test–retest correlation, although significant, rose to only .55. This was probably due to the very high performance levels, which were close to ceiling in this task. A set of t tests determined whether there was an effect of task repetition; all t tests were less than 1.15 and nonsignificant, suggesting the absence of any significant increase or decrease of performance between the two test sessions.

As a further measure of reliability, we also computed simple correlations between the different short- and long-term versions of our measures. As shown in Table 2, correlations between short- and long-term measures for serial order reconstruction, as well as correlations between short- and long-term measures for delayed item repetition, were high, whereas correlations between the different order and item memory tasks were smaller and less consistent. More specifically, although the short-term serial order reconstruction task correlated with all three item (short- or long-term) memory measures, these correlations were smaller than the correlation with the long-term serial order reconstruction task. The long-term serial order reconstruction task further showed a small correlation with the short-term nonword delayed repetition task but not with any other item (short- or long-term) memory measure. This pattern of correlation is compatible with our task

Table 1
Descriptive statistics and test–retest reliability for the different measures administered in this experiment

	Maximum possible score	Mean (raw)	*SD*	Mean (proportion)	$R_{(t1*t2)}$
ST serial order reconstruction	24	11.05	3.38	.46	.82*
LT serial order reconstruction	24	9.10	2.97	.38	.71*
ST nonword repetition	30	15.32	6.09	.51	.74*
ST word repetition	30	26.97	2.82	.90	.53*
LT word repetition	20	15.98	1.96	.80	.63*
EVIP	na	70.23	15.74	na	na
RPCM	na	20.05	5.36	na	na

Note. ST, short-term; LT, long-term; EVIP, French version of Peabody Picture Vocabulary Test; RCPM, Raven's colored progressive matrices; na, not available.

* $p < .05$.

Table 2
Correlation matrix between different short- and long-term memory measures

	LT serial order	ST nonword repetition	ST word repetition	LT word repetition
ST serial order	.677**	.514**	.473**	.335*
LT serial order		.264*	.227	.236
ST nonword repetition			.645**	.426**
ST word repetition				.435**

Note. ST, short-term; LT, long-term.
* $p < .05$ ($df = 58$).
** $p < .001$ ($df = 58$).

design; we expected that tasks maximizing retention capacities for the same type of information would show higher intercorrelations than would tasks maximizing retention capacities for different types of information.

Age effects on item and order memory

We used simple ANOVA designs to investigate effects of age for the different order and item memory tasks using proportionalized scores to eliminate scaling effects. Significant age effects were observed for the short-term serial order memory task, $F(2, 57) = 24.07$, $MSE = .01$, $p < .001$, for the long-term serial order memory task, $F(2, 57) = 7.55$, $MSE = .01$, $p < .001$, for the short-term nonword item delayed repetition task, $F(2, 57) = 8.49$, $MSE = .03$, $p < .001$, and for the long-term word item delayed repetition task, $F(2, 57) = 7.67$, $MSE = .01$, $p < .01$. Newman–Keuls post hoc comparisons showed that for both short- and long-term item memory measures, no difference was observed between 4 and 5 years of age, but a highly significant difference occurred between 5 and 6 years of age (short-term item measure: $M_{\text{age 4}} = .45$, $M_{\text{age 5}} = .44$, $M_{\text{age 6}} = .65$; long-term item measure: $M_{\text{age 4}} = .77$, $M_{\text{age 5}} = .77$, $M_{\text{age 6}} = .86$). This result contrasted with post hoc comparisons for the short- and long-term serial order memory measures; significant differences were observed among 4, 5, and 6 years of age, although only marginally ($p = .08$) for the long-term serial order measure between 4 and 5 years of age (short-term serial order reconstruction measure: $M_{\text{age 4}} = .34$, $M_{\text{age 5}} = .46$, $M_{\text{age 6}} = .57$; long-term serial order reconstruction measure: $M_{\text{age 4}} = .31$, $M_{\text{age 5}} = .37$, $M_{\text{age 6}} = .45$). As can be seen in Figs. 1A and B, performance increased steadily for the serial order reconstruction tasks but not for the item delayed repetition tasks, where performance levels for 4- and 5-year-olds were identical and then sharply rose between 5 and 6 years of age.

Performance for the short-term word delayed repetition task was very near ceiling. Because of this ceiling effect, no ANOVA testing for age effects was conducted given that any differential age effects would be difficult to interpret. In fact, the high level of performance for the short-term word delayed repetition task reveals the presence of a large lexicality effect. When comparing the short-term nonword and word delayed repetition tasks, we observed a highly significant lexicality effect, $F(1, 57) = 407.18$,

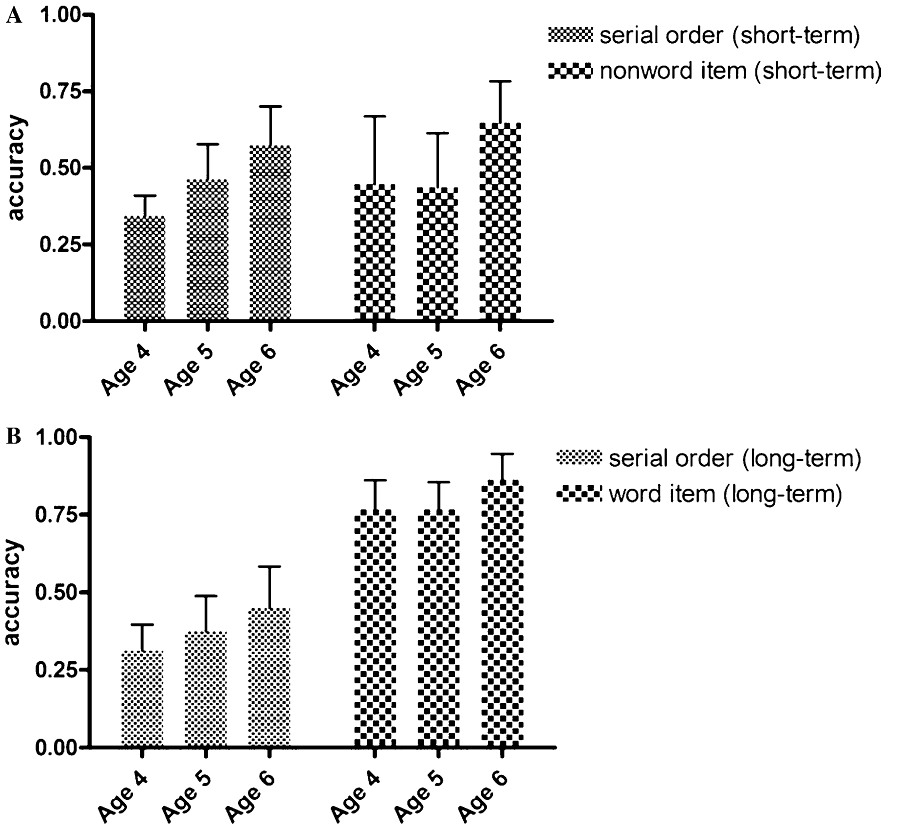

Fig. 1. Means and standard deviations (error bars) for short-term (A) and long-term (B) item and serial order memory tasks as a function of age group.

$MSE = 0.01$, $p < .00001$, remaining significant for each age group considered separately (Tukey post hoc comparisons, $p < .05$) (Fig. 2). Given the ceiling effect of the short-term delayed word repetition task, this task was not considered further in the subsequent correlation analyses.

Correlations between vocabulary development and item and order memory

When considering the short-term versions of the item and order memory tasks, we observed that both the serial order reconstruction task and the delayed nonword repetition task significantly correlated with vocabulary knowledge (Table 3). With respect to the long-term versions of the memory tasks, the long-term serial order reconstruction task, but not the long-term delayed word repetition task, correlated significantly with vocabulary knowledge after controlling for age and nonverbal intelligence (Table 3). We must remain cautious with respect to the absence of correlation between vocabulary knowledge and the long-term word delayed repetition

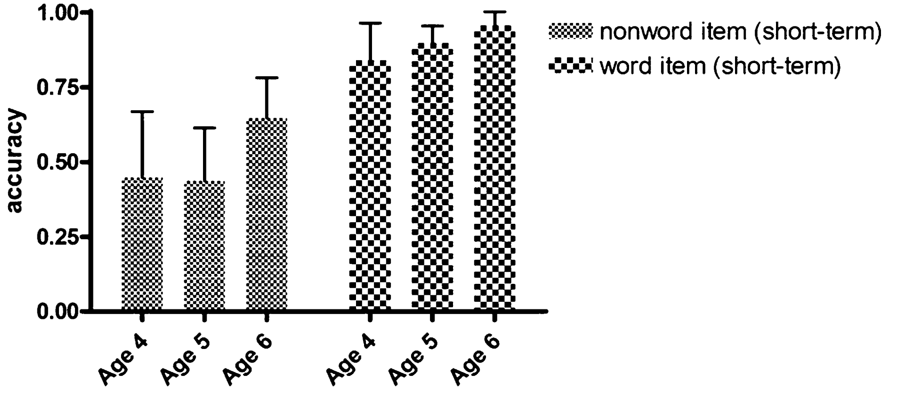

Fig. 2. Means and standard deviations (error bars) for the short-term word and short-term nonword delayed repetition tasks.

Table 3
Partial correlations between vocabulary knowledge and different item and order memory tasks with age and nonverbal intelligence (Raven's colored progressive matrices) partialled out

	Partial correlation
ST serial order reconstruction–EVIP	.353**
ST nonword repetition–EVIP	.362**
LT serial order reconstruction–EVIP	.264*
LT word delayed repetition–EVIP	.097

Note. ST, short-term retention delay; LT, long-term retention delay; EVIP, French version of Peabody Picture Vocabulary Test.
* $p < .05$ ($df = 56$).
** $p < .001$ ($df = 56$).

tasks because the latter task yielded higher performance levels (80%) than did the long-term serial order reconstruction task (38%). Hence, any differential pattern of correlations implicating these two measures might be at least partly related to the different levels of task difficulty.

Multiple regression analyses

Next, using multiple regression analysis, we determined which of the two STM tasks, the short-term serial order recognition task or the short-term nonword delayed repetition task, was the strongest predictor of vocabulary development. As can be seen in Table 4, both tasks predicted independent variance in vocabulary scores after controlling for age and nonverbal intelligence. Furthermore, the proportion of independent variance explained by the serial order reconstruction task (.017) or the short-term nonword delayed repetition task (.018) was equal to or greater than the proportion of shared variance (.016). However, it must be noted that these amounts of independent

Table 4
Multiple regression analyses predicting vocabulary development by short-term serial order reconstruction and short-term nonword delayed repetition after controlling for age and Raven's colored progressive matrices scores

Variable introduced	ΔR^2	p	F	p	df
All age groups confounded ($N = 60$)					
1. Age	.702	<.0001	136.36	<.0001	1, 58
2. RCPM	.032	<.05	78.65	<.0001	2, 57
3. ST serial order reconstruction	.033	<.01	61.52	<.0001	3, 56
4. ST nonword repetition	.018	<.05	50.06	<.0001	4, 55
3. ST nonword repetition	.034	<.01	62.07	<.0001	3, 56
4. ST serial order reconstruction	.017	<.05	50.06	<.0001	4, 55

Note. ST, short-term retention delay; RCPM, Raven's colored progressive matrices.

variance, even if significant, were relatively small.[1] One possible explanatory factor is the large age range of our group (4–6 years); the proportion of age-related variance in vocabulary scores was more than .70. Therefore, we decided to look at partial correlations between vocabulary development and the short-term serial order reconstruction task or the short-term nonword delayed repetition task separately in each of the three age groups (after partialling out residual age effects and nonverbal intelligence). We observed that the serial order reconstruction task correlated independently with vocabulary scores in 4- and 6-year-olds but not in 5-year-olds (Table 5). The 5-year-old group was the only age group where the partial correlation between vocabulary scores and short-term nonword delayed repetition was significant. These differential patterns of correlations, as a function of age group, further explain the relatively small amount of independent variance in vocabulary scores predicted by the serial order reconstruction and nonword delayed repetition tasks when the three age groups are collapsed; although both STM tasks are independent predictors of vocabulary development, they are not equally strong predictors in each of the three age groups. Hence, their predictive power will be lower in the whole sample than when considering only those age groups where their predictive power is strongest.

A final multiple regression analysis (collapsing the three age groups) compared the predictive power of the short- and long-term versions of the serial order reconstruction task for vocabulary development. As shown in Table 6, the short-term serial order reconstruction task predicted independent variance in vocabulary scores after the long-term serial order reconstruction task had been introduced, but the reverse was not true. Furthermore, the proportion of shared variance predicted by the short- and long-term serial order reconstruction measures (.017) was not much larger than the proportion of independent variance predicted by the short-term measure (.016).

[1] Although these amounts of independent variance are small, their size is comparable to that obtained in other studies that have predicted vocabulary scores by verbal short-term memory measures using child populations with similar age ranges and when controlling for chronological and nonverbal mental age (e.g., Gathercole & Baddeley, 1993).

Table 5
Partial correlations between short-term serial order reconstruction task, short-term nonword delayed repetition task, and vocabulary knowledge in the three age groups considered separately

	Partial correlation	Variables partialled out
4-year-olds		
ST serial order reconstruction	.468*	Age, RCPM, ST nonword repetition
ST nonword repetition	.060	Age, RCPM, ST serial order reconstruction
5-year-olds		
ST serial order reconstruction	.218	Age, RCPM, ST nonword repetition
ST nonword repetition	.653**	Age, RCPM, ST serial order reconstruction
6-year-olds		
ST serial order reconstruction	.560*	Age, RCPM, ST nonword repetition
ST nonword repetition	.245	Age, RCPM, ST serial order reconstruction

Note. ST, short-term retention delay; RCPM, Raven's colored progressive matrices.
* $p \leqslant .05$ ($df = 15$).
** $p < .01$ ($df = 15$).

Table 6
Multiple regression analyses predicting vocabulary development by short- and long-term versions of serial order reconstruction task after controlling for age and performance on Raven's colored progressive matrices

Variable introduced	ΔR^2	p	F	p	df
1. Age	.702	<.0001	136.36	<.0001	1, 58
2. RCPM	.032	<.05	78.65	<.0001	2, 57
3. ST serial order	.033	<.01	61.52	<.0001	3, 56
4. LT serial order	.002	*ns*	45.88	<.0001	4, 55
3. LT serial order	.019	<.05	62.07	<.0001	3, 56
4. ST serial order	.016	<.05	50.06	<.0001	4, 55

Note. RCPM, Raven's colored progressive matrices; ST, short-term retention delay; LT, long-term retention delay; *ns*, nonsignificant.

Discussion

The current study explored the relation between memory for item and serial order information and vocabulary development. Vocabulary development was independently associated with STM for both serial order information and item information. A long-term version of the serial order memory task did not predict vocabulary development after controlling for those processes shared with the short-term version of this task. Furthermore, differential age effects were observed for item and order memory tasks; steady performance increases were observed for short- and long-term order memory tasks between 4 and 6 years of age, whereas performance for short- and long-term item memory tasks did not differ between 4 and 5 years of age and then suddenly increased between 5 and 6 years of age. Further age effects were observed for correlations between vocabulary development and the different item and serial order memory measures; the short-term serial order reconstruction task predicted vocabulary development more strongly in 4- and 6-year-olds than it did in

5-year-olds, whereas the reverse was true for the short-term nonword delayed repetition measure.

The current data suggest the presence of a significant link between capacities for storage and retrieval of serial order information and the development of vocabulary in 4- and 6-year-olds. Our findings are in agreement with previous developmental studies showing a strong link between verbal STM capacity, as measured by nonword repetition and digit span, and vocabulary development in young children (e.g., Gathercole et al., 1991, 1992). Our findings can also be compared to a related result observed by Gathercole et al. (2001), who showed that in adolescents there was an association between vocabulary knowledge and verbal STM when a nonword sequence recognition probe task was used to measure STM capacity. In this task, sequences of three nonwords were presented, followed by a new sequence containing the same three nonwords either in the same order or in a different order (for similar findings in individuals with learning disability, see also Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). Although the study by Gathercole et al. (2001) was not intended to dissociate item and serial order STM, the task used by those authors appears to measure, to a large extent, serial order retention capacities. However, because this task used nonwords, it is difficult to determine whether the association between performance on this task and vocabulary development was related to the serial order retention requirements of the task or to phonological segmentation abilities required for accurately processing the nonwords in the different STM lists. The current findings extend these previous results by showing that it is specifically the capacity to retain and reproduce ordered sequence information that explains this link.[2]

Moreover, with respect to the reverse relation (i.e., the influence of vocabulary knowledge on verbal STM performance), we showed the presence of large lexicality effects in delayed item repetition for word and nonword lists in the three age groups. These findings complement previous results obtained by Brock and Jarrold (2004), who observed lexicality effects in 4-year-olds using item probe recognition tasks.

Our data support the theoretical position that verbal STM capacity, such as that measured by tasks maximizing retention capacities for serial order information, is a determinant of vocabulary development and cannot be merely considered as an epiphenomenon of vocabulary development itself and ongoing segmentation of the lexical network. In the current study, we observed a significant link between vocabulary development and a verbal STM task where it is difficult to see how these segmentation processes could intervene. All of the items used had a very simple syllabic structure and were highly familiar (animal names); furthermore, they were sampled from the same limited pool of items and known in advance, further minimizing requirements for phonological item segmentation processes during the presentation of the

[2] In other experiments with adult participants, we explored the relation between novel word learning capacities and STM serial order reconstruction tasks as well as multiple STM item recall and recognition tasks. We obtained quite similar results; a strong association was observed between the serial STM tasks and novel word learning capacities, but not between novel word learning capacities and the different item STM measures (Majerus, Poncelet, Elsen, & Van der Linden, 2005).

verbal sequence. More generally, it is difficult to see how an increase in vocabulary knowledge could lead to increased performance in storage and reproduction of serial order information for highly familiar words. However, STM for serial order information is not the only measure that is related to vocabulary development. Phonological item information was also independently related to vocabulary development, and this most strongly the case in 5-year-olds, whereas serial order STM measures made no significant independent contribution to vocabulary development anymore.[3]

At first glance, these results might seem surprising. However, this developmental change in relations between vocabulary knowledge and verbal STM measures coincides with previous results obtained by Gathercole et al. (1992). Using a longitudinal study design, those authors showed that a nonword repetition task (in this case measuring retention of both item and serial order information) at 4 years of age predicted vocabulary knowledge at 5 years if age, whereas vocabulary knowledge at 5 years of age predicted nonword repetition at 6 years of age. This suggests that at 4 years of age, verbal STM capacity is a causal factor of vocabulary development, whereas at 5 years of age and later, verbal STM performance is itself strongly dependent on vocabulary development. The results obtained in the current study mirror these findings; the correlation observed between vocabulary development and delayed nonword repetition, but not serial order reconstruction, at 5 years of age might reflect this developmental shift that had been already observed by Gathercole et al. (1992).

These results could be interpreted in the following way. At 5 years of age, vocabulary knowledge has increased substantially (partly as a result of good serial order STM capacities at 4 years of age or younger), leading to more segmentalized phonological representations, which in turn will now begin to facilitate processing of phonological item information in verbal STM tasks (see also Fowler, 1991, and Metsala, 1999). This interpretation must also be related to the age effects that we observed for the item STM tasks; there was a highly important increase in performance levels for these tasks from 5 to 6 years of age but not from 4 to 5 years of age. This increase could be the consequence of ongoing phonological segmentation processes, further boosted by the beginning of reading instruction, which will favor processing of nonwords in verbal STM tasks (e.g., Morais, Alegria, & Content, 1987; Morais & Mousty, 1992; Snowling & Hulme, 1994). At the same time, our results also suggest that at around 6 years of age, verbal STM capacity specific to serial order information is once again a determining factor of vocabulary development. This might be related, albeit speculatively, to the fact that the learning of various new matters at primary school will put renewed pressure on vocabulary development. The child will be confronted with much higher rates of new words than ever before. The long-term acquisition of the phoneme sequences that characterize these multiple new words will be facilitated if the child has a good memory for verbal sequence information, as

[3] We should note that traditional immediate serial recall tasks also have an advantage in that they capture capacities for both item and order recall at once and provide a summary measure of both capacities. However, if our aim is to determine the causal relation between verbal STM capacities and vocabulary development, we need to use less confounded measures that distinguish memory for both types of information.

measured by serial order reconstruction tasks. This possible explanation of developmental shifts in STM–vocabulary relations, however, needs to be further examined using a longitudinal study design distinguishing STM measures for item and serial order at each timepoint of longitudinal assessment. Furthermore, the limited sample size ($n = 20$) when the sample was split by age also urges us to remain very cautious about our interpretation of possible developmental shifts in associations between item and order STM and vocabulary development. Although our data clearly show the involvement of serial order memory in vocabulary development, they cannot be taken as a strong argument against the association of item memory and vocabulary development in 4- and 6-year-olds.

A related aim of the current study was to determine whether order memory tasks are equally strong predictors of vocabulary development independent of the length of the retention delay. Our study provided partial support for this hypothesis; both the short- and long-term serial order reconstruction tasks correlated significantly with vocabulary development. However, the partial correlation between the long-term condition and vocabulary development was no more significant after partialling out performance on the short-term condition. Differences in task sensitivity are not likely to be responsible for this finding given that the short- and long-term serial order reconstruction tasks had similar levels of difficulty (mean performance: .46 and .38, respectively) and similar reliability (.82 and .71, respectively). A second possibility is that the short-term condition put more weight on phonological retention capacities than did the long-term condition because over long-term retention delays phonological information has decayed too much and will be of no use for serial order reconstruction. This explanation is also unlikely; we have shown that, at least in 4- and 6-year-olds, the short-term serial order reconstruction task is independently related to vocabulary development after controlling for phonological retention capacities as measured by nonword delayed repetition. Furthermore, phonological item retention capacities did not appear to be strongly related to vocabulary development at these ages (even if we must remain cautious for the reasons of limited sample size discussed in the previous paragraph). This differential association with vocabulary development for the short-term serial order reconstruction and nonword delayed repetition tasks cannot be attributed to differences in task sensitivity (mean performance: .46 and .51, respectively) or reliability (.82 and .74, respectively). Hence, the short-term serial order reconstruction task made a stronger contribution to vocabulary development than did the long-term version of this task, independent of the possible differential contribution of phonological retention capacities.

It might be possible that the long-term serial order reconstruction task captures additional processes related to cue-based retrieval; although for the short-term condition passive read-out of the entire sequence information might be possible for recalling most trials, this will be less likely in the long-term condition, where this information will have decayed to a much greater extent. Although the entire sequence information is no more available at once, sequence information might be retrieved by reconstructing order via item-by-item associative cueing mechanisms (i.e., for a given item, the child might try to determine which item was next and so forth for the subsequent items), leading to overall performance levels that will not be much lower than those observed for the short-term serial order reconstruction condition (e.g., .46 vs. .38 in this study). This capacity for cue-based item-by-item retrieval of serial order information might be less related to learning new phonological information than are short-term capacities for storing complete and instantly available sequence information. This could explain the differential associations observed in this study between vocabulary development and the short- and long-term versions of serial order reconstruction. Finally, with respect to item memory, a similar pattern of results was observed; although the short-term item delayed repetition task showed a consistent correlation with vocabulary development (when collapsing the three age groups), this was not the case for the long-term version of this task. However, because of clear differences in task difficulty here (.51 vs. .80), we cannot rule out that, in this particular case, these differential patterns of correlation are related to different levels of task sensitivity.

Although our data show that developmental increases in STM capacity for serial order information are a determining factor of vocabulary development (at least in 4- and 6-year-olds), it is not yet clear what the underlying mechanisms of such an increase in serial order STM capacity are. Our results echo those observed by McCormack, Brown, Vousden, and Henson (2000), who showed that movement errors in immediate serial recall (i.e., exchanges of serial position for a given item) were closer to the original serial position in adults and older children, whereas younger children (<9 years of age) exchanged serial positions across larger distances. Thus, their data also suggest that the encoding and retrieval of serial order information improves with age. A related factor must also be considered, namely that greater efficiency in serial rehearsal strategies could further underlie improved retention and output of serial order information, at least for children 7 years of age or older. Children younger than 7 years of age do not seem to use rehearsal strategies spontaneously, and correlations between STM span and speed of articulation (used as an estimate of rehearsal speed) are inconsistent in this age group (e.g., Cowan, Keller, Hulme, & Roodenrys, 1994; Flavell, Beach, & Chinsky, 1966; Gathercole, Adams, & Hitch, 1994; Hulme, Muir, Thomson, & Lawrence, 1984; Palmer, 2000).

A number of current STM models assume the existence of a specialized STM system that encodes serial order information, although these models differ with respect to the precise mechanisms that implement representations for serial order (Brown et al., 2000; Burgess & Hitch, 1992, 1999; Gupta, 2003; Gupta & MacWhinney, 1997; Henson, 1998). Many of these models would endorse the possibility of developmental changes in the efficiency of processing of these specialized serial order STM systems (e.g., Brown, Vousden, McCormack, & Hulme, 1999; Maylor, Vousden, & Brown, 1999). In the model of Gupta and MacWhinney (1997), a very explicit association was established between the capacities of a serial order STM system and vocabulary development, as described in Introduction to the current article. Age-related increases in processing efficiency of this system may ensure the creation of a more accurate temporary representation of new phoneme sequences and a more accurate reactivation of this temporary representation, leading to more efficient learning of new words and eventually to a larger and more precise network of long-term lexical representations. Developmental increases in both the precision of positional coding in STM and serial rehearsal are compatible with this type of model.

To conclude, the current study extends previous findings of a strong association between verbal STM capacity and vocabulary knowledge in young children by highlighting the distinct roles of processes involved in memory for serial order and item information. Although verbal STM tasks are clearly determined by vocabulary knowledge, especially for STM tasks maximizing retention capacities for item information, there are specific serial order STM processes that cannot be influenced by vocabulary knowledge but that are themselves important determinants of vocabulary development in 4- and 6-year-olds. At 5 years of age, the balance appeared to be reversed, with STM for item information being specifically associated with vocabulary development. The purpose of this study was to highlight the specificity and importance of these serial order STM capacities for the development of vocabulary. Future studies need to address the precise cognitive processes that underlie STM for serial order information, how they change across development, and how exactly developmental increases in processing efficiency for both item and serial order information interact with vocabulary development.

Acknowledgments

Steve Majerus is a postdoctoral researcher at the Fonds National de la Recherche Scientifique, Belgium. The authors thank the children, their teachers, and their parents for the time they readily agreed to devote to the participation in this study. We also gratefully acknowledge Chris Jarrold, Ian Neith, and John Towse for comments on an earlier version of this manuscript.

References

Adams, A. M., & Gathercole, S. E. (1995). Phonological working memory and speech production in preschool children. *Journal of Speech and Hearing Research, 38*, 403–414.

Alario, F. X., & Ferrand, L. (1999). A set of 400 pictures standardized for French: Norms for name agreement, image agreement, familiarity, visual complexity, image variability, and age of acquisition. *Behavior Research Methods, Instruments, and Computers, 31*, 531–552.

Avons, S. E., Wragg, C. A., Cupples, L., & Lovegrove, W. J. (1998). Measures of phonological short-term memory and their relationship to vocabulary development. *Applied Psycholinguistics, 19*, 583–601.

Baddeley, A. D. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*, 189–208.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*, 158–173.

Bishop, D. V. M. (1983). *TROG: Test for reception of grammar*. Manchester, UK: University of Manchester, Chapel Press.

Bowey, J. A. (1996). On the association between phonological memory and receptive vocabulary in five-year-olds. *Journal of Experimental Child Psychology, 63*, 44–78.

Brock, J., & Jarrold, C. (2004). Language influences on verbal short-term memory performance in Down syndrome: Item and order recognition. *Journal of Speech, Language, and Hearing Research, 47*, 1334–1346.

Brown, G. D. A., & Hulme, C. (1996). Nonword repetition, STM, and age-of-acquisition: A computational model. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 129–148). Hove, UK: Psychology Press.

Brown, G. D. A., Preece, T., & Hulme, C. (2000). Oscillator-based memory for serial order. *Psychological Review, 107*, 127–181.

Brown, G. D. A., Vousden, J. I., McCormack, T., & Hulme, C. (1999). The development of memory for serial order: A temporal–contextual distinctiveness model. *International Journal of Psychology, 34*, 389–402.

Burgess, N., & Hitch, G. J. (1992). Toward a network model of the articulatory loop. *Journal of Memory and Language, 31*, 429–460.

Burgess, N., & Hitch, G. J. (1999). Memory for serial order: A network model of the phonological loop and its timing. *Psychological Review, 106*, 551–581.

Cowan, N., Keller, T. A., Hulme, C., & Roodenrys, S. (1994). Verbal memory span in children: Speech timing clues to the mechanisms underlying age and word length effects. *Journal of Memory and Language, 33*, 234–250.

Cunningham, A. E., & Stanovich, K. E. (1991). Tracking the unique effects of print exposure in children: Associations with vocabulary, general knowledge, and spelling. *Journal of Educational Psychology, 83*, 264–274.

DeLosh, E. L., & McDaniel, M. A. (1996). The role of order information in free recall: Application to the word-frequency effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1136–1146.

Dunn, L. M., & Dunn, L. M. (1981). *Peabody picture vocabulary test–revised: Manual for forms L and M*. Circle Pines, MN: American Guidance Service.

Dunn, L. M., Thériault-Whalen, C. M., & Dunn, L. M. (1993). *Echelle de vocabulaire en images Peabody: Adaptation française du Peabody Picture Vocabulary Test*. Toronto, Canada: Psycan.

Ferrand, L., & Alario, F. X. (1998). Normes d'associations verbales pour 366 noms d'objets concrets. *L'Année Psychologique, 98*, 659–670.

Flavell, J. H., Beach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development, 37*, 283–299.

Fowler, A. E. (1991). How early phonological development might set the stage for phonological awareness. In S. Brady & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97–117). Hillsdale, NJ: Lawrence Erlbaum.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition, 23*, 83–94.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3*, 410–419.

Gathercole, S. E., & Adams, A. M. (1993). Phonological working memory in very young children. *Developmental Psychology, 29*, 770–778.

Gathercole, S. E., & Adams, A. M. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language, 33*, 672–688.

Gathercole, S. E., Adams, A. M., & Hitch, G. J. (1994). Do young children rehearse? An individual-differences analysis. *Memory & Cognition, 22*, 201–207.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28*, 200–213.

Gathercole, S. E., & Baddeley, A. D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology, 81*, 439–454.

Gathercole, S. E., & Baddeley, A. D. (1993). Phonological working memory: A critical building block for reading development and vocabulary acquisition?. *European Journal of Psychology of Education, 8*, 259–272.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Human Learning and Memory, 25*, 84–95.

Gathercole, S. E., Pickering, S. J., Hall, M., & Peaker, S. (2001). Dissociable lexical and phonological influences on serial recognition and serial recall. *Quarterly Journal of Experimental Psychology A, 54*, 1–30.

Gathercole, S. E., Service, E., Hitch, G. J., Adams, A. M., & Martin, A. J. (1999). Phonological short-term memory and vocabulary development: Further evidence on the nature of the relationship. *Applied Cognitive Psychology, 13*, 65–77.

Gathercole, S. E., Willis, C., & Baddeley, A. D. (1991). Differentiating phonological memory and awareness of rhyme: Reading and vocabulary development in children. *British Journal of Psychology, 82*, 387–406.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*, 887–898.

Gupta, P. (2003). Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *Quarterly Journal of Experimental Psychology A, 56*, 1213–1236.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59*, 267–333.

Henry, L. A., & Millar, S. (1991). Memory span increases with age: A test of two hypotheses. *Journal of Experimental Child Psychology, 51*, 459–484.

Henson, R. N. A. (1998). Short-term memory for serial order: The start–end model. *Cognitive Psychology, 36*, 73–137.

Henson, R., Hartley, T., Burgess, N., Hitch, G., & Flude, B. (2003). Selective interference with verbal short-term memory for serial order information: A new paradigm and tests of a timing-signal hypothesis. *Quarterly Journal of Experimental Psychology A, 56*, 1307–1334.

Hulme, C., Muir, C., Thomson, N., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38*, 241–253.

Jarrold, C., Baddeley, A. D., Hewes, A. K., Leeke, T., & Phillips, C. (2004). What links verbal short-term memory performance and vocabulary level? Evidence of changing relationships among individuals with learning disability. *Journal of Memory and Language, 50*, 134–148.

Lambert, E., & Chesnet, D. (2001). Novlex: Une base de données lexicales pour les élèves de primaire. *L'Année Psychologique, 101*, 277–288.

Lecocq, P. (1996). *ECOSSE: Une épreuve de compréhension syntaxico–sémantique*. Villeneuve d'Ascq, France: Presses Universitaires du Septentrion.

Majerus, S., Poncelet, M., Elsen, B., & Van der Linden, M. (2005). *Exploring the relationship between new word learning and short-term memory for serial order recall, item recall, and item recognition.* Unpublished manuscript, University of Liège, Belgium.

Majerus, S., & Van der Linden, M. (2003). Long-term memory effects on verbal short-term memory: A replication study. *British Journal of Developmental Psychology, 21*, 303–310.

Majerus, S., VanderLinden, M., Bressand, V., & Eliez, S. (2005). *An investigation of verbal short-term memory in children and adults with a chromosome 22q11.2 deletion: A specific deficit in serial order retention capacities?* Unpublished manuscript, University of Liège, Belgium.

Majerus, S., Van der Linden, M., Mulder, G., Meulemans, T., & Peters, F. (2004). Verbal short-term memory reflects the sublexical organization of the phonological language network: Evidence from an incidental phonotactic learning paradigm. *Journal of Memory and Language, 51*, 297–306.

Maylor, E. A., Vousden, J. I., & Brown, G. D. (1999). Adult age differences in short-term memory for serial order: Data and a model. *Psychology and Aging, 14*, 572–594.

McCormack, T., Brown, G. D., Vousden, J. I., & Henson, R. N. A. (2000). Children's serial recall errors: Implications for theories of short-term memory development. *Journal of Experimental Child Psychology, 76*, 222–252.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology, 91*, 3–19.

Michas, I. C., & Henry, L. A. (1994). The link between phonological memory and vocabulary acquisition. *British Journal of Developmental Psychology, 12*, 147–164.

Morais, J., Alegria, J., & Content, A. (1987). The relationships between segmental analysis and alphabetical literacy: An interactive view. *Cahiers de Psychologie Cognitive [European Bulletin of Cognitive Psychology], 7*, 415–438.

Morais, J., & Mousty, P. (1992). The causes of phonemic awareness. In J. Alegria, D. Holender, J. Morais, & M. Radeau (Eds.), *Analytic approaches to human cognition* (pp. 193–212). Amsterdam, Netherlands: Elsevier.

Nairne, J. S. (1990). Similarity and long-term memory for order. *Journal of Memory and Language, 29*, 733–746.

Nairne, J. S., & Kelly, M. R. (2004). Separating item and order information through process dissociation. *Journal of Memory and Language, 50*, 113–133.

Neath, I. (1997). Modality, concreteness, and set-size effects in a free reconstruction of order task. *Memory & Cognition, 25*, 256–263.

Palmer, S. (2000). Working memory: A developmental study of phonological recoding. *Memory, 8*, 179–193.

Poirier, M., & Saint-Aubin, J. (1996). Immediate serial recall, item identity, and item position. *Canadian Journal of Experimental Psychology, 50*, 408–412.

Raven, J. C., Court, J. H., & Raven, J. (1998). *Progressive matrices couleur*. Oxford, UK: Oxford Psychologists Press.

Roodenrys, S., Hulme, C., & Brown, G. (1993). The development of short-term memory span: Separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology, 56*, 431–442.

Snowling, M., & Hulme, C. (1994). The development of phonological skills. *Philosophical Transactions of the Royal Society of London B, 346*, 21–27.

Tubach, J. L., & Boë, L. J. (1990). *Un corpus de transcription phonétique*. Moulineaux, France: Telecom.

Turner, J. E., Henry, L. A., & Smith, P. T. (2000). The development of the use of long-term knowledge to assist short-term recall. *Quarterly Journal of Experimental Psychology A, 53*, 457–478.

Wechsler, D. (1995). *WPPSI-R: Echelle d'intelligence de Wechsler pour la période préscolaire et primaire (forme révisée)*. Paris: Editions du Centre de Psychologie Appliquée.

Whiteman, H. L., Nairne, J. S., & Serra, M. (1994). Recognition and recall-like processes in the long-term reconstruction of order. *Memory, 2*, 175–194.

Wickelgren, W. A. (1965). Acoustic similarity and intrusion errors in short-term memory. *Journal of Experimental Psychology, 70*, 102–108.