SHORT-TERM MEMORY PERFORMANCE AND METAMEMORY JUDGMENTS IN PRESCHOOL AND EARLY SCHOOL-AGE CHILDREN: A QUANTITATIVE AND QUALITATIVE ANALYSIS

Laura VISU-PETRA*, Lavinia CHEI, Oana BENGA
Department of Psychology, Babeș-Bolyai University, Cluj-Napoca, Romania

ABSTRACT

The developmental progression in short-term memory (STM) is well-documented throughout childhood. Most research has emphasized the verbal memory domain, and less is known about the visual-spatial systematic improvement. We conducted a cross-sectional study assessing 4 age groups of preschool and school-aged children (N = 223): Age Group 1 (mean age = 50 months), Age Group 2 (mean age = 71 months), Age Group 3 (mean age = 87 months) and Age Group 4 (mean age = 96 months). STM performances across all age groups, as well as preschoolers' metamemory judgments (concerning their visual-spatial memory strategies) were investigated. Regarding response accuracy, we found that span performance increased across the four age groups on all span tasks. School aged children made a better use of verbal recoding of familiar visual stimuli (colors and objects); only on these visual, but verbally-recodable tasks did we also find a gender effect in preschool children, girls outperforming boys. The total number of errors on verbal STM decreased with age. Finally, regarding metamemory, most preschoolers were able to make judgments regarding the strategies they used to better encode the memoranda (i.e. spontaneous rehearsal and verbal coding of visual stimuli).

KEYWORDS: short-term memory, simple span, children, error analysis, metamemory.

* Corresponding author:
E-mail: laurapetra@psychology.ro
INTRODUCTION

Short-term memory (STM) represents the temporarily increased availability of information in memory that can be used to carry out various types of mental tasks (Cowan et al., 1999). The STM store is limited in its capacity: although through the use of mnemonic strategies (e.g. chunking) adults can remember up to seven elements (Miller, 1956), the real capacity limit is of about three or four elements, similar to the amount that can be simultaneously sustained in the focus of attention (Cowan, 1995; Halberda, Simons, & Wetherhold, 2006), or to what Sperling (1960) called “the span of apprehension”. The story of this construct has been inextricably linked to the one of working memory (WM), the latter representing an active memory system that is responsible for the temporary maintenance and simultaneous processing of information that is typically required in complex cognitive tasks (Baddeley, 1986).

A note should be made at this point: in infants and very young children, the distinction between WM and STM is blurred and the perspectives are contradictory; we will present the main arguments of the existing positions since the basic reasoning can be generalized to older preschoolers. On one hand, researchers such as Reznick (2007) argue that short-term retention in infancy is actually an index of WM. He concludes this after a critical analysis of the most widely used testing procedures of short-term retention in infants: the hide-find method (a delayed-response task), observe-perform procedures (action sequence re-enactment after a delay), and the familiarize-recognize procedure. The critical analysis leads to a common caution regarding all the tasks related to the ability of the research design to rule out possible confounds (alternative explanations): long-term memory mechanisms, reactions to violations of expectations, motivation or motor competence. This researcher’s preference for the term working memory (although not identical to the significance of the term in adults) in order to characterize very young children’s short-term retention is based on three motivations: 1) the “naturalistic” request for WM, as opposed to the more artificial STM tasks, 2) the executive processing requirements, specific to WM tasks; 3) the existing proofs for the very early emergence of short-term retention in young children during problem-solving scenarios. On the other hand, researchers such as Oakes, Ross-Sheehy, and Luck (2007) make the opposite claim, suggesting that it is difficult to assess the “workings” of WM in infants and very young children, because in their case the processes might be more bottom-up driven, thus favoring the alternative short-term memory terminology for characterizing their memory processes.

Throughout this paper, we will use in the description of experimental data in the literature the terms WM and STM as they are specified by the authors (inevitably reflecting the state of confusion between these terms in the literature). However, in the presentation of our own work, we will make a distinction based on postulated tasks demands (some derived from the adult literature), and only make inferences regarding the underlying mechanisms. More specific, this paper will deal with simple span tasks that require only the brief maintenance and recall of
stimuli – we refer to this ability as STM; as opposed to complex span tasks, explicitly requiring maintenance and manipulation of information, and eliciting WM. It might be that at an early age, relatively simple STM demands require a much more active processing of information, requesting WM-like abilities.

The most influential model of WM for adult age belongs to Baddeley and Hitch (1974) (for a review of the research generated by this model, see Baddeley, 2007); this model has proved to be a fruitful framework for characterizing the development of STM (see Gathercole, 2002, for a review). Within this model, the central executive (CE) supervises and controls the flow of information from two short-term storage systems dedicated to a content domain (verbal and visuo-spatial, respectively). The tripartite model of WM has received extensive neuropsychological (comprehensive reviews: Baddeley & Logie, 1999; Vallar & Papagno, 2002, 2003), and neuroimaging support (see Henson, 2001; Jonides, Lacey, & Nee, 2005, for reviews). At this point, we have to note that this model of WM is not singular (see Cowan, 1995; Engle, Tulowski, Laughlin, & Conway, 1999; Kane et al., 2004; Shah & Miyake, 1996; Jones, Beaman, & Macken, 1996, for alternative accounts), and is definitely not without criticism (Lovatt, Avons, & Masterson, 2000). However, as will be noted below, it has provided the most fruitful terrain for developmental investigations of STM development during early childhood. A more recent trend, underlying the shift in memory research from “a chunk limit to a time limit” (Cowan, 2007) is to extract information regarding the underlying strategies from the microanalysis of response-timing patterns during the child’s overt recall (Cowan et al., 1992; Cowan et al., 1994; Cowan et al., 1998; Cowan, Saults, Nugent, & Elliot, 1999; Hulme, Newton, Cowan, Stuart, & Brown, 1999). As supported by our own investigations (Visu-Petra, Benga, & Cheie, 2008), the information that these measures provide is not only complementary with the accuracy analysis, but actually provides a more developmentally-sensitive measure of recall processes.

**Short-term memory development**

Only about two decades ago has research on memory processes begun to seriously reflect upon the early precursors of working memory development. There are several plausible reasons for this delay: in infants and young children both anecdotal and empirical evidence points out to information slips from the focus of attention, vulnerability to interference and less efficient (if even existing) rehearsal processes (Bauer, Abbema, & de Haan, 1999). However, recent nonverbal techniques, such as elicited (deferred) imitation, point to long-term recall during the first year of life (Carver & Bauer, 1999), although there is evidence for massive loss of information over short intervals (Hanna & Meltzoff, 1993). It appears that even infants a few hours old can encode and remember a visually presented stimulus (Slater & Morison, 1991), and that they can remember this information for hours, and even days (Rose, 1981).

Most studies investigating the development of STM span in children have been cross-sectional; few longitudinal studies have followed usually one or two
simple span tasks (i.e. word and non-word span) and related them to language outputs such as vocabulary acquisition (Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1991; Bowey, 2001). However, to our knowledge, there are two studies relating verbal STM in preschoolers to reading ability during early school age (Näslund, 1990; Parrila, Kirby, & McQuarrie, 2004). As for longitudinal studies that would investigate the development of verbal and visual-spatial STM during the preschool years, we identified a microgenetic study involving 196 preschool children (although they were 6 years and 6 months old at the time of their first assessment, therefore much older than our initial preschool sample) in a study related to the development of memory strategies (Schneider, Kron, Hünnerkopf, & Krajewski, 2004).

Looking at the results of these studies, it appears that almost all measures of short-term memory present a steady increase from the preschool years through adolescence (Case, Kurland, & Goldberg, 1982; Isaacs & Vargha-Khadem, 1989; Gathercole, Pickering, Ambridge, & Wearing, 2004; Alloway, Gathercole, & Pickering, 2006). Generally, memory performance increases steeply up to eight years of age, and shows more gradual improvement thereafter to asymptotic levels at 11 or 12 years (Gathercole, 1999). The memory components corresponding to the CE, the phonological loop and the visuospatial sketchpad appear to resemble the adult tripartite distinction and to be functioning as early as 6 years of age (Gathercole et al., 2004). However, one should take into account both indexes of STM improvement, (although few studies do so): 1) the number of items or locations that the child can remember, and 2) the length of delay that the child can tolerate. In the WM model proposed by Cowan (1988), activated memory is limited by temporal decay, and the focus of attention is limited by the number of chunks that can be simultaneously maintained (about 4 chunks in adults: Cowan, 2001); both dimensions are also limited by their vulnerability to different types of interference.

But what are the mechanisms responsible for this increase? One theoretical position suggests that, following maturation and task practice, older children increase their capacity available for information storage (Case, 1985; Pascual-Leone, 1970; Halford, Mayberry, O’Hare, & Grant, 1994; Cowan et al., 1999; but see Towse, Hitch, & Skeates, 1999). Other views emphasize the crucial changes occurring in the knowledge structures which can be used in the service of encoding and recall (Chi, 1978; Hulme, Maughan, & Brown, 1991). A third focus of interest has been children’s memory strategies, especially with respect to the use of rehearsal to maintain or strengthen memory traces for subsequent recall (Case, Kurland, & Goldberg, 1982; Flavell, Beach, & Chinsky, 1966).

A rigorous task analysis is necessary in order to avoid over-generalizing or over-simplifying explanations. Different types of improvements could occur at different stages of a STM task, and this progress could unfold at distinct developmental rates. Just like the verbal WM, the capacity of the phonological loop follows a constant development path starting with early childhood through early adolescence, maturing towards the age of 15 (Gathercole & Alloway, 2006).
Gathercole (1999) proposes a detailed process analysis for the verbal short-term recall. The temporarily storing of auditory stimuli involves the following components: acoustic storage (in a sensory form vulnerable to subsequent encodings), phonological analysis and storage (perceptual analysis and segmentation), temporal order encoding, rehearsal, retrieval (through rapid serial scanning processes), and sometimes a process called redintegration (the use of stored knowledge related to the lexical, semantic and phonological properties of specific items and of the language more generally in order to reconstruct incomplete phonological traces). The author presents evidence for developmental improvements in sensory memory (Gomes et al., 1991), phonological storage (changes in rates of decay and quality of encoding – Gathercole & Baddeley, 1993), sequential ordering (Pickering, Gathercole, & Peaker, 1998; Brown, Vousden, McCormack, & Hulme, 1999), subvocal rehearsal via subvocal articulation, but only after the age of 7 (Baddeley, Gathercole, & Papagno, 1998; Cowan et al., 1998), and in the process of redintegration (Roodenrys, Hulme, & Brown, 1993). The conclusion is that there are multiple parallel or successive components that could account for the observed progress on short-term memory recall tasks.

The STM for visual material undergoes an important developmental shift during early school years (Gathercole et al., 2004). Children progress from relying solely on the visuospatial sketchpad to the parallel use of visual codes and to verbal re-coding, finally reaching a mature stage, where verbal encoding is preferred (Hitch & Halliday, 1983). A still puzzling phenomenon is the steady increase across childhood years in performance on tests that employ visual material that is not phonologically recodable (Pickering, Gathercole, Hall, & Lloyd, 2001). A storage hypothesis has been proposed (Logie & Pearson, 1997), suggesting the increase in the capacity of the visuospatial sketchpad; alternatively, an increasing involvement of CE via more effective strategies or long-term memory knowledge (Pickering et al., 2001) deployment has been suggested. Additionally, a better rate of attention shifting between locations could also be responsible for the increase in spatial span (Smith & Jonides, 1997).

As for the documented visual vs. spatial distinction in the adult literature, this seems to be confirmed by developmental data; additionally, a static vs. dynamic distinction has been identified (Pickering et al., 2001). Logie and Pearson (1997) pointed out the distinctiveness of visual and spatial working memory in a study with children in three age groups, ranging from 5 to 12 years. They found that although performance increased with age for both tasks, there was a much steeper age-related increase for the visual patterns task than for the spatial (Corsi tapping) task, suggesting the visual subcomponent as a distinct component of the visual-spatial sketchpad that develops faster in children than the spatial counterpart. The subcomponent dealing with visual patterns is termed “visual cache” and is closely related to the visual perceptual system, while the component dealing with motion and dynamic sequences is called “inner scribe” (Logie, 1995);
in order to increase the analogy with the phonological loop model, the “inner scribe” is also considered to refresh the contents of the visual cache.

Both visual and verbal codes, required by the visual and verbal STM, are available from an early age, and continue to be available throughout the developmental course. However, their dissociation has been revealed in short-term storage tasks in children as young as 5 (Pickering, Gathercole, & Peaker, 1998), although error patterns were found to be similar. This is interpreted as evidence for a possible common reconstructive mechanism (Alloway, Gathercole, & Pickering, 2006). During the developmental course of WM, it appears that domain-general processing mechanisms interact with domain-specific storage components (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Bayliss, Jarrold, Baddeley, & Gunn, 2005); the presence of both types of mechanisms being pointed out as early as 6 years of age (Gathercole et al., 2004), or even earlier – at 4 years (Alloway, Gathercole, & Pickering, 2006).

However, diverging from an exclusively componential perspective, we can identify relevant changes not only in the operants, but also in the operations themselves. Alternative, process-oriented accounts - which will be emphasized in our research - reveal changes in different processes that accompany (and might be causally related to) the increase in STM ability.

An initial account of how (phonological) STM span functions stemmed from evidence that both adults and children can recall about as many items as they can pronounce in about 2 seconds (Baddeley, Thomson, & Buchanan, 1975; Hulme & Tordoff, 1989). This was seen as a proof of a strong link between articulation rate, covert rehearsal speed and memory span, a relation reinforced by subsequent research (Case, Kurland, & Goldberg, 1982; Cowan et al., 1992; Hulme, Thomson, Muir, & Lawrence, 1984; Nicolson, 1981, etc.) although the relation is not straightforward (Hulme & Muir, 1985; Hitch, Halliday, & Littler, 1993). An increase in articulation rate would be accompanied by an increase in the rate of subvocal rehearsal, enabling a larger verbal span by preventing items from decaying (Hitch & Halliday, 1983). A similar mechanism was postulated for the spatial span, either through more rapid shifts in spatial attention (Smyth & Scholey, 1994), or through attention shifting between locations representations (Smith & Jonides, 1997). However, the causal mechanisms behind this relation were far from being elucidated.

An alternative account derived from the unitary model proposed by Jones, Beaman, and Macken (1996); in contrast to the WM model, all types of stimuli (verbal and spatial, auditory and visual) were thought to share a common level of representation (the modality-invariant-hypothesis). The limits of memory span stemmed from the difficulty to handle changing-state information (a sequence composed from different items) in the to-be-remembered sequences (the changing-state hypothesis). Chuah and Maybery (1999) took this hypothesis and applied it to the developmental context, suggesting that “it may be the development in the efficiency of a mechanism for processing changing-state sequences that is responsible for verbal and spatial span growth” (p. 10).

A third and more general account is based simply on a development in processing speed, proved to change systematically as a function of age (Cerella & Hale, 1994; Kail, 1991; Kail & Salthouse, 1994), irrespective of the identity of processes that it characterizes and related to global changes in neural transmission rates (Cerella & Halle, 1994). Chuah and Maybery (1999) suggested two ways in which speed of processing could determine the developmental increase in memory span: by preventing the rapid decay of memory traces or by influencing the rate of activation of information during list presentation. Their own results favored a joint contribution of articulation rate (and its visual-spatial “equivalent” – a tapping measure) and processing speed on the age-related variance in verbal and spatial span. It also supported the unitary model of WM, in that the verbal and the spatial predictors (articulation rate and tapping rate) did not differentially relate to the same-modality spans. In conclusion, some modality-irrelevant indexes related to speed of processing could account for the development in span: speed of item identification (Case, 1985), speed of covert memory search during the recall of successive items (Cowan, 1992). This last line of research favors the idea of multiple processing rates, developing at different paces during the ontogenetic trajectory of the individual, instead of a global increase in an underlying “processing speed” mechanism.

An important source of information regarding the development of short-term memory has been represented by the children’s own metamemory reports. Children’s understanding of their own memory processes has been investigated as a reflection, but also as a source in itself of short-term memory development. Flavell and Wellman (1997) divided metamemory variables into those concerning the person, the task, and strategies. Metamemory research has almost exclusively targeted school-age children, several studies conducting interviews in which children were asked to report on their memory strategies and/or to estimate their memory ability (Fabricius & Hagen, 1984; Kreutzer, Leonard, & Flavell, 1975; Leijenhorst, Crone, & Van der Molen, 2007). DeMarie and Ferron (2003) used a latent variable approach to see the influence of capacity, strategies, and metamemory factors on memory development. The results revealed that younger children (5-7 years) did not have a consistent metamemory factor, but that for older children, a three-factor model was better than a unitary model, suggesting the relative independence of the three domains. Leijenhorst, Crone, and Van der Molen (2007) found that children who reported having used a verbal recoding strategy performed better than those who didn’t on a spatial and an object working memory task.

Our investigation uses a quantitative and a qualitative approach to short-term memory development across the preschool and early school years (with an emphasis on the insufficiently investigated visual-spatial field), analyzing both memory span per se, but also types of errors and metamemory judgments (the last construct is only investigated in the preschool group, since it represents an under-researched area).
AIMS AND HYPOTHESES

The memory span procedure, evaluating how many items a person can repeat back in sequence, has been widely used both in adult and in developmental studies as a prototype for investigating STM development. There are several reasons to justify this preference: first, it is simple enough to be comprehensible for very young children, as young as 2 years of age (Gathercole & Adams, 1993). Second, it is a developmentally-sensitive index, considering that it increases steadily during the ages of 3 to 10 years (Dempster, 1985; Gathercole & Adams, 1993; Alloway, Gathercole, & Pickering, 2006). Finally, research into the mechanisms involved in performing this task is ecologically relevant, taking into account its relation to performance on complex tasks involving comprehension and problem-solving (Dempster, 1985), or to academic achievement (Alloway et al., 2005; Swanson, 1994), and its widespread use in intelligence testing (Hutton & Towse, 2001).

Our study uses a cross-sectional design in order to investigate several aspects in the development of STM performance on simple span tasks (verbal and visual-spatial) during preschool and early school age. The novelty in this approach resides in extensively investigating different aspects of memory development in a broad age group (3-10 years), using both traditional and novel tasks, designed to reveal the relations between the development of verbal and visual-spatial STM. Additionally, in the visual-spatial domain, memory for verbally-recodable and verbally not recodable (or less plausibly recodable) items was contrasted in order to reveal the emergence of early memory coding strategies.

Based on the literature findings, we expect to find:
1) An increase across the four age groups in their span performance on all the tasks.
2) Higher associations among tasks from the same modality (verbal vs. non-verbal), corresponding to the subslave systems in the Baddeley and Hitch (1974) model.
3) A greater age-related increase in performance on the abstract visual patterns task than on the spatial (Corsi tapping) task. The comparison of performance on the abstract shape task as compared to the Corsi span task will help distinguish if it’s a true visual vs. spatial distinction in developmental pace, and not just a development of verbal recoding strategies for visual patterns.
4) A similar pattern of errors (omission errors, commission errors, and order reversal errors) across age groups.
5) Better performance accuracy on the verbally-recodable tasks in children who report having used a verbal recoding strategy in the metamemory interview.
METHOD

Participants

The participants (N = 223) were recruited from two local kindergartens and two local schools. The mean age of the total sample was 75 months, SD = 17 months. In all subsequent analyses, the sample will be divided into four subsamples, two including preschoolers, and two including early school age (see Table 1 for data on the four age groups).

Table 1
Demographic Data for the Participants According to Age group

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>Age range (months)</th>
<th>Mean age (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preschoolers</td>
<td>47</td>
<td>37 - 60</td>
<td>50 (8.1)</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>61 - 88</td>
<td>71.3 (7.3)</td>
</tr>
<tr>
<td>School-age</td>
<td>50</td>
<td>73 - 91</td>
<td>87.4 (4.4)</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>92 - 110</td>
<td>96 (4.7)</td>
</tr>
</tbody>
</table>

Measures

1) Verbal Digit Span

The digit span procedure was derived from the standardized administration of the Digits Forward subtest of the Digit Span test, as described in the WISC-III manual (Wechsler, 1991). Digit span was assessed by the experimenter reading aloud series of digits at the rate of one item per second; the child was instructed to repeat them back immediately in the correct sequence. In Romanian, the words denoting these digits varied from monosyllabic (4 items) to bisyllabic (5 words). Three trials (lists of random digits from 1 to 9) were given at each list length (LL), beginning with a list length of 2 items. If recall was correct on two or more of the three trials for each LL, the sequence length was increased by one. If the child failed more than one list in a list length, testing was discontinued.

Word Span

A list of common 9 two-syllable words was chosen to provide a test of word repetition directly comparable to the other span measures. The selection of a constant number of syllables was made in order to avoid the word length effect, which was not analyzed in the present study. The testing procedure corresponds to the one used for the Digit Span Task.

2) Visual-spatial Corsi blocks

A widely known measure of spatial STM was used: the Corsi blocks test (Corsi, 1972). The display was taken from the WAIS-R Neuropsychological Inventory (Kaplan, Fein, Morris, & Delis, 1991) that uses 10 blue blocks, with five blocks on each half of the board, so as to permit an assessment of visual field neglect. The examiner used the index finger to point the Corsi sequences but
moved it from one block to the next without lifting the hand, at the rate of one block per second.

**Color span**

The nine cards (6.5 x 7 cm) used in this task represent colored, equally-sized circles; the colors being used were: red, yellow, blue, pink, grey, violet, brown, orange, green.

**Object span**

The cards, similar to the ones used for circles, represented objects extracted from the Snodgrass (revised, colored) inventory (Rossion & Pourtois, 2004); in order to ensure color equivalence, only red stimuli were selected.

**Abstract shape span**

Nine abstract shapes were created for this task, with the same color (green), so as to be not (or at least difficult) verbally recodable.

**Procedure**

One testing session was sufficient for the administration of all tasks. The procedure was similar for each task, in order to ensure a direct match of their results and a similar degree of familiarity with the items throughout the different tasks. The common requirement of all tasks was to reproduce (verbally or non-verbally) a gradually increasing series of presented elements in the exact order as they had been presented by the examiner. Each task was based on 9 items, with a possible maximum of 8 to-be-remembered items. Each list length had 3 trials of items of that particular length, beginning with a 2-items list (and adding an element with each list length). The order in which the items were presented was different for each trial. Each item, irrespective of content, was represented from the beginning with a number, so that the actual sequences were identical across tasks (item no. 1 was a word: “desk”, a digit “three”, a colored circle “red”, an abstract shape, an object “clock”, and a position on the Corsi display). The child went through the three trials from each list length; after three consecutive wrong trials (i.e. omitting, distorting, adding an item, or not reproducing the words in the exact order), testing was stopped. Following the procedure presented by Cowan et al.(1994, 2003), a sensitive measure, termed *aggregate span* was calculated to reflect performance across lists. After determining a base span as the highest list length at which all three trials were passed correctly, a score of 0.33 was added to this base span for every list of a higher length that was correctly recalled. For example, if a child correctly recalled 3 two-word lists, 2 three-word lists and 1 four-word list, an aggregate span of $2 + 0.66 + 0.33 = 3$ would be awarded (for more details on the scoring procedure see Cowan et al., 2003).

After each span task, a short *metamemory* interview took place, the child being required to evaluate how difficult the task has been, and to explain how he/she memorized the items. The purpose was to extract some of the strategies they might have used, considering that preschoolers already present signs of metacognitive vocabulary and metamemory knowledge (Lockl & Schneider, 2006).
PERFORMANCE RESULTS

Descriptive data

Figures 1-3 present the means and standard deviations for all the span tasks, across age groups and gender groups. From the visual inspection of these graphs, it is clear that children progress in their span capacity with age; however, this progress is differential according to the tasks investigated. The verbal tasks appeared to present a gradual improvement; in the non-verbal, non-verbally recodable tasks (Corsi and abstract shape) the performance remained at a low level (less than 4 elements) even at school age. In the visual, verbally-recodable tasks, it appeared to be an abrupt improvement from preschool to school-age. These final two tasks (object and color span) also represented the only ones which showed some gender differences, with girls apparently outperforming boys, but only in the preschool age groups. All these visual intuitions will be supported by the statistical analysis in the following sections.

Figure 1
Performance on verbal span tasks (Word span – left and Digit span – right) across age groups and gender.

Figure 2
Performance on spatial and visual, verbally non-recodable span task (Corsi blocks – left; Abstract shape – right) across age groups and gender.
The differences among the four age groups were investigated with one-way ANOVAs conducted with aggregated scores on span tasks as dependent variables and with age group (1/2/3/4) as between-subject variable. The results pointed to a strong effect of age on all span tasks, p < .001. However, post-hoc Tuckey tests revealed that in the case of word span and digit span this difference was not significant between age groups 1 and 2 or between age groups 3 and 4. In the case of Corsi span, object span and color span, no significant increase in performance was revealed between age groups 3 and 4, all the other progressions being significant. In the case of abstract shape span (not applied to the Age group 1), there was a significant progression in performance from age group 2 to age group 3, the progression to age group 4 no longer being significant.

Looking closer at the “critical” shift between late preschool and early school years, the steepest increase took place at the level of color and object memory span, as revealed by independent-sample t-tests, t(122) = 15.79, p < .01, Cohen’s d = 2.85 for color span, and t(122) = 15.66, p < .01, Cohen’s d = 2.83; in the other tasks, the difference, although significant, was less abrupt: t(124) = 8.16, p < .01, Cohen’s d = 1.46 for word span, t(123) = 5.47, p < .01, Cohen’s d = 0.99 for digit span, t(123) = 5.48, p < .01, Cohen’s d = 0.99 for Corsi span, and t(111) = 8.87, p < .01, Cohen’s d = 1.68, for abstract shape span.

A repeated-measures analysis of variance with age group and type of task as independent variables revealed a significant effect of type of task across age groups, F(4, 808) = 253.70, p < .001, with performance on digit span being the best, followed by word span, followed by Corsi span and than by object and color span, for age groups 1 and 2. An interesting interaction effect appeared when comparing age group 2 and age group 3 on the visual-spatial measures: in this case, if children from age group 2 had worse performance on object and color span than on Corsi span, in age group 3, the situation was reversed, and object and color span were better than Corsi span.

Taking into account the diverse effects of gender across age groups as revealed by Fig 1-3, we decided to analyze separately the impact of this variable.
across age groups. One-way ANOVAs with gender as a between-subject factor were conducted for each span task. Only on the color span task did we find significant differences, with girls outperforming boys within age group 1, $F(1, 41) = 4.4, p < .05$, and age group 2, $F(1, 72) = 7.06, p < .01$. On the object span task, in age group 2, the girls also outperformed the boys [mean 2.53 (SD = .73) vs. 2.28 (SD = .57)], although this difference did not reach significance, $F(1, 74) = 2.65, p = .10$.

It is important to note that the preschool girls actually outperform the boys in the two visual-spatial, but verbally recodable tasks (names of colors and objects). No other significant differences appear in the preschool group among the girls’ and boys’ performance.

In the school-age group, no significant gender differences are present on any of the span tasks.

**Correlations among span tasks**

The following correlation analyses attempt to reflect the interrelations among the simple span tasks within the four age groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td><strong>Age group 1 (n = 47)</strong></td>
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<td></td>
</tr>
<tr>
<td>1. Age</td>
<td>.47**</td>
<td>.46**</td>
<td>.49**</td>
<td>.43**</td>
<td>.33*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Word span</td>
<td></td>
<td>.81**</td>
<td>.34*</td>
<td>.26</td>
<td>.31*</td>
<td></td>
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<tr>
<td>3. Digit span</td>
<td></td>
<td></td>
<td>.61**</td>
<td>.37*</td>
<td>.54**</td>
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<td>4. Corsi span</td>
<td></td>
<td></td>
<td></td>
<td>.36*</td>
<td>.44**</td>
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<tr>
<td>5. Color span</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.36*</td>
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<tr>
<td>6. Object span</td>
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<td>7. Abstract shape span</td>
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<tr>
<td><strong>Age group 2 (n = 79)</strong></td>
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<td></td>
</tr>
<tr>
<td>1. Age</td>
<td>-.04</td>
<td>-.02</td>
<td>.27*</td>
<td>.28*</td>
<td>.37**</td>
<td>.26*</td>
<td></td>
</tr>
<tr>
<td>2. Word span</td>
<td></td>
<td>.73**</td>
<td>.01</td>
<td>.11</td>
<td>.15</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>3. Digit span</td>
<td></td>
<td></td>
<td>.09</td>
<td>.17</td>
<td>.26*</td>
<td>.30</td>
<td></td>
</tr>
<tr>
<td>4. Corsi span</td>
<td></td>
<td></td>
<td></td>
<td>.42**</td>
<td>.27*</td>
<td>.19</td>
<td></td>
</tr>
<tr>
<td>5. Color span</td>
<td></td>
<td></td>
<td></td>
<td>.47**</td>
<td>.58**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Object span</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.47**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Abstract shape span</td>
<td></td>
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</tr>
</tbody>
</table>
While the influence of Age was extremely powerful in the preschool age groups, the correlations being significant between this variable and all the span tasks in age group 1, the associations between age and span performance became non-significant during school age (except a moderate correlation with Corsi span). Performance on the verbal memory span tests, word and digit span remained highly interrelated across age groups, with higher values in preschool children. The same strong interrelations were visible when analyzing the visual-spatial tasks (Corsi, object, color, and abstract shape span). While in school-age children they appeared relatively equally interrelated (with the highest correlations between color and object Span), in preschoolers the associations were more moderate. Moreover, in age group 2, abstract shape span only correlated with the visual tasks, and not with the spatial span.

As for between-modalities interrelations, within the preschool group these associations were weak: while digit span was associated with Corsi and object span in age group 1, in age group 2 the associations between verbal and visual-spatial tasks were very weak. The picture changed in school-age children: the associations between verbal and visual-spatial tasks were all strong (moderate only in the case of abstract shape span).

### Error analysis

In order for an answer to be considered “wrong” during the span trials, three types of errors could appear: omission (one or more elements less than the list presented by the examiner), commission (an extra-list element was presented), and order reversal (the elements were correct, but the order in which they were presented was not). Figure 4 presents the configurations of these error types and total errors across age groups.

### Table

<table>
<thead>
<tr>
<th>Task</th>
<th>Age group 3 (n = 50)</th>
<th>Age group 4 (n = 47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.00</td>
<td>0.12</td>
</tr>
<tr>
<td>Word span</td>
<td>-0.70** -0.48** -0.59** -0.63** -0.45**</td>
<td>-0.63** -0.58** -0.54** -0.37* -0.31*</td>
</tr>
<tr>
<td>Digit span</td>
<td>-0.51** -0.64** -0.63** -0.49**</td>
<td>-0.58** -0.75** -0.45** -0.47**</td>
</tr>
<tr>
<td>Corsi span</td>
<td>-0.64** -0.60** -0.48**</td>
<td>-0.74** -0.62** -0.54**</td>
</tr>
<tr>
<td>Color span</td>
<td>-0.81** -0.60**</td>
<td>-0.65**</td>
</tr>
<tr>
<td>Object span</td>
<td>-0.65**</td>
<td>-0.60**</td>
</tr>
<tr>
<td>Abstract shape span</td>
<td>-0.10</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

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It is obvious that there was a steep decrease in the total number of errors between preschool and school-aged children. We investigated the significance of these differences using one-way ANOVAs with age group as between-group factor. There was a significant main effect of age group, $F(1, 217) = 129.56$, $p < .001$. However, post-hoc Tukey tests revealed that this decrease was significant between consecutive age groups (1 and 2, 2 and 3, 2 and 4), but again not between age groups 3 and 4.

![Figure 4](image)

**Figure 4**

Error (omission, commission, order reversal, total) across age groups

Looking at specific types of errors, and at the effect of age group, in the case of omission errors, the picture was identical to the one of total errors. In the analysis of commission and order reversal errors, the difference between age groups 1 and 2 was no longer significant. Comparing the proportion of types of errors between preschoolers and school-age children, it appears that, in both age groups, the commission errors are the most frequent [paired sample t-tests within each group confirm this trend, both when comparing commission errors to omission errors in preschoolers, $t(121) = 7.41$, $p < .01$, and school-age children, $t(94) = 12$, $p < .01$; and when comparing commission errors to order reversal errors in preschoolers, $t(121) = 9.66$, $p < .01$, and in school-age children, $t(94) = 12.73$, $p < .01$]. It means that both groups, (but particularly older children) rather suffer from interference effects (commission errors are almost always confined to other elements that were previously presented).
PRESCHOOLERS’ METAMEMORY JUDGMENTS

Aside from a purely quantitative measure of the child’s memory span on verbal and visual tasks, completed by the analysis of different types of errors, we considered that the child himself/herself might represent an important source of information regarding the type of strategies that are employed in encoding the visual material (the interview was only conducted with preschool children). The essential question of this research is related to the emergence of verbal recoding of visual material. Traditionally, children were thought to be able to use primitive verbal recoding strategies paralleling the visual coding only after the age of 6 years (Conrad, 1971; Brown, 1977); up to that point, they were supposed to rely solely on the “pictorial”, stimulus-bound representations of the visual stimuli. This conclusion was derived indirectly from studies contrasting verbal interference (e.g. names of animals) to visual interference (e.g. visually similar animals) in recall tasks. No verbal interference effects were found for 3-5 year old children, unlike the case for the 5-11 year old sample.

The results from our direct investigation of the children’s reported strategies would suggest strong interindividual differences in both the amount of information offered by the children about their own mental strategies, and in their specific content. A comprehensive analysis of the preschool children’s interviews was performed on a subsample from Age group 2 (60 children, mean age 72 months, SD = 6.68, 31 girls, 29 boys) for which we had videotaped the tasks, since the non-verbal behavior during task solving was considered essential for uncovering the underlying strategies. First of all, children evaluated the “games” as being easy; very few (2 children) considered them hard, and this appraisal also correlated with very poor performance on the tasks.

Children reported having used either a verbal recoding strategy (the reports were either spontaneous, or prompted by the examiner), or a non-verbal recall strategy (just looking at the pictures), a third possibility being either no reply, or an “I don’t know how” answer (see the Appendix for examples of such statements from several children younger than 7 years). Interestingly, children reported more spontaneously (without additional prompting from the examiner) the use of strategies in the case of abstract shape span than in the case of color or object span (32% for abstract shape span, versus 6% for color span, and 22% for object span); this could be interpreted as children somehow acknowledging the need for more “intense” elaboration in order to recall the images from the abstract shape span.

Figure 5 represents the percentages of these responses across the entire sample. Clearly, as it appears in the figures, children spoke more easily about mentally “verbalizing” during color and object span tasks, rather than during abstract shape span. The most interesting responses came in the few cases that reported verbal strategies in the abstract shape span. Although some children appeared to verbalize only post-hoc (had difficulties thinking about a possible verbal label, but tried to find one), others had “prepared” very interesting verbal labels (broken moon, ship, penguin etc.). A 74-months-old boy and a 73-months-
old girl chose a set of verbal labels from the beginning of the task, and verbalized when presented with the items on each trial, and when retrieving them from the others (the verbal labels remained constant throughout the task). A 63 months old girl presented an interesting “generalization” phenomenon: she spontaneously utilized a good strategy of naming the colors in order to remember them in the color span task, but on the subsequent abstract shape task, on every presentation of items, she repeated the color: “the first one is green, the second green, than green, and green”, although without any use for the abstract shape task.

Girls reported more verbal strategies on the object span, and especially on the color span, where the gender-related discrepancy in verbal strategies was very large. This is correlated with the actual better performance seen in preschool girls on these two tasks. In the “don’t know category” we also included several children who denied their concomitant thoughts as if it would be a bad thing to do while performing the task (it is probable that many children, irrespective of gender might have interpreted the question as something like: "have you been doing something else – thinking – instead of concentrating on the task”, because some denied with great emphasis and said that they thought “nothing” while solving it).

Children under the age of 6 had difficulties in verbalizing their mental processes; few of them managed to provide coherent accounts of their memory processes. However, many of them, verbalized spontaneously (especially in the case of color span) during the task (when presented with the items, and/or while retrieving them), as a memory aid. Some children verbalized both the name of the color, and the order (e.g. the first one was red, the second one was blue), although this did not necessarily correlate with better recall. Table 3 summarizes the percentages of strategy use across age and gender groups.

![Figure 5](image_of_diagram)

*Figure 5*

Reported strategies (percentages) in the visual-spatial tasks. First (to the left) is Color Span, than Object Span, and finally Abstract Shape Span.
Table 3  
Percentages of Reported Strategies on the Visual-Spatial Tasks

<table>
<thead>
<tr>
<th>Gender</th>
<th>Color Span</th>
<th>Object span</th>
<th>Abstract Shape Span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VB Non-VB</td>
<td>NR VB Non-VB</td>
<td>VB Non-VB NR VB</td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70 13.3 16.7 56.7 20</td>
<td>23.3 20 66.7 13.3</td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>20.7 65.5 13.8 50 25</td>
<td>25 20.7 65.5 13.8</td>
<td></td>
</tr>
</tbody>
</table>

Note. VB = verbal, Non-VB = non-verbal, NR = no response.

Finally, we were also interested to see whether the presence of reported verbal strategies would be related to better span performance. Only in the case of abstract shape span did we find a significant strong effect of strategy: $F(2, 55) = 5.60, p < .001$; post-hoc tests revealed that children with a verbal recoding strategy had better performance than children with a non-verbal recoding strategy.

GENERAL DISCUSSION

The ability to retain information for short intervals has been inextricably linked to a wide range of cognitive phenomena, including language, consciousness, and cognitive control (Baddeley, 2007). Memory span tasks have been widely used in the investigation of this construct in adults and children alike. The development of (mostly verbal) memory span is well-documented throughout childhood; however, the source of this systematic improvement remains a mystery. Summarizing the “critical” sources of working memory variation in typically developing children, Towse and Hitch (2007) mention the rate at which information can be processed, the child’s ability to perform dual tasks, the timing of these processes, and the parameters that describe specific memory subsystems at different ages.

The target variables investigated in this study consisted in accuracy and metamemory measures extracted from the preschool and school-aged children’s results on the span tasks and from the metamemory interview. With regard to accuracy, we were interested in the influence of age (in a cross-sectional and longitudinal design with an emphasis on preschool age), gender, and stimulus modality (verbal vs. visual-spatial; visual vs. spatial; visual and verbally recodable vs. visual and non-verbally recodable). Visuospatial short-term memory has received less attention and is less well understood than phonological WM (Leijenhorst, Crone, & Van der Molen, 2007), so our analysis of span accuracy has focused more on this domain.

Our hypotheses have been mainly confirmed by the results of this investigation. In terms of processing accuracy, we expected an increase across the four age groups in span performance on all the memory tasks (Alloway, Gathercole, Willis, & Adams, 2004; Alloway, Gathercole, & Pickering, 2006). The
findings confirm the increase in all span measures from the preschool years towards early school age. As revealed by the cross-sectional perspective, there is a much steeper increase in visual, but verbally recodable tasks (color and object span), a transition that takes place from the late preschool years to early school age, and is also confirmed by the metamemory results (see the discussion bellow).

Second, we looked closer at relationships between same-modality tasks (within the verbal and the visual-spatial domain). Within the verbal domain, digit span performance was better than word span, and both were better than non-word span, confirming previous findings in the preschool literature (Alloway, Gathercole, & Pickering, 2006; Gathercole & Adams, 1993; Gathercole, Pickering, Ambridge, & Wearing, 2004).

Within the visual-spatial domain, which represented the focus of our accuracy analysis, there were several findings worth mentioning. First, it has been proven (using abstract visual stimuli), that age-related changes in (abstract) object STM present a slower trajectory than in spatial STM (Hitch, 1990; Leijenhorst, Crone, & Van der Molen, 2007). The present study reveals that this slower developmental pace for object memory is present even when using familiar, verbally recodable stimuli (colors of objects) in preschoolers. The situation was reversed when considering early school years; at that point, the use of verbal recoding and the visual familiarity of stimuli lead to a better performance on the visual, verbally recodable tasks, than on the spatial task. However, abstract shape span (pure visual recall) was poorer than location memory across age groups, this confirming findings of a slower developmental pace for object memory that were

mentioned before (Leijenhorst, Crone, & Van der Molen, 2007). However, there was an increase from the preschool years to the early school years in Corsi performance as well; these results contradict Hasher and Zacks' (1979) proposal that, in contrast to color, spatial location would not show developmental improvement because it is remembered automatically, and confirm previous findings of developments in spatial serial recall with age (Walker, Hitch, Doyle, & Porter, 1994). As an explanation for the developmental improvement, these authors suggest that although 5-year-olds are as capable as 7-year-olds at creating and immediately accessing an “object file” (in the terms used by Kahneman & Treisman, 1984), they are less able to access information about the visual features of objects whose files are no longer current.

Interestingly, these verbally recodable tasks are also the only ones on which a gender effect is notable: during the preschool years, as reflected also by our direct metamemory interviews, girls present better performance than boys on these tasks, suggesting earlier use of verbal recoding. Gender differences in STM performance have not been extensively studied in young children. A recent study by Steenari, Vuontela, Carlson, Koivisto, Fjällberg, and Aronen (2003) has revealed that on a WM task, boys had shorter reaction times, were less accurate, and made more multiple responses than girls; these gender differences were most prominent in the group of 6-8 year olds. However, these results are not directly comparable to ours, since the WM tasks involved significantly more executive demands. A closer comparison can be made with the extensive study investigating gender differences in 14 memory tasks across the 5-19 years interval by Lowe, Mayfiels, & Raynolds (2003). The authors found gender effects only on two tasks: girls had better performance than boys on Object recall (very similar to the task that we used), and on word span. Males scored higher on the Memory for Location and Abstract Visual Memory subtests, the key spatial memory tasks on the battery. Compared to our results, it appears that neither the pure verbal, nor the pure spatial advantage is present in our 3-10 years sample; instead, preschool girls have better performance on the visual, but verbally recodable tasks very early on, suggesting an earlier use of such verbal strategies. In early school years, the gender differences in performance on these tasks are no longer present.

We expected higher associations among tasks from the same modality (verbal vs. non-verbal), corresponding to the subslave systems in the Baddeley and Hitch (1974) model, versus different modality tasks. The essential distinction between the unitary (Jones et al., 1996) and multicomponent WM models (Baddeley & Hitch, 1974) relates to whether serial STM is served by a unique representational system, or by separate verbal and visual-spatial systems. There is convincing developmental data to argue for both the unitary position (Chuah & Maybery, 1999), and for the tripartite WM model –with dual storage – during childhood (mostly data from early school age, Gathercole & Pickering, 2000; Tillman, Nyberg, & Bohlin, 2007; but see Alloway, Gathercole, Willis, & Adams, 2004, and Alloway, Gathercole, & Pickering, 2006, for preschool evidence). The view that spatial and verbal short-term memory systems are independent has been
challenged. Specifically, Jones, Farrand, Stuart, & Morris (1995) have argued that the mental representations of verbal and spatial information in serial short-term memory are functionally equivalent. The key component that led to this unitary model is that of “changing state,” in which a stream of information is shifting, as opposed to being repetitive. Another “unitary” account of WM in children was proposed by Chuah and Maybery (1999), for 6- to 12 year-olds, in an investigation of possible mechanisms accounting for the development of verbal and spatial STM.

This idea, already suggested from the pattern of correlations (the high correlation between digit span and Corsi span was the only relevant cross-modality association in preschoolers), was supported by a confirmatory analysis (Alloway et al., 2006) which clearly favored the distinctiveness of these two domains in preschoolers, but to a lesser degree in school-age. It was somehow surprising to note that this trend towards distinctiveness of the verbal and the visual-spatial domains was very obvious in preschool children, more so than in school-age children. In school-age children, both unitary and dual models provided a better fit to the aggregate span data, and the choice of one over the other is less clear-cut than in the case of preschoolers.

The detailed examination of error patterns under various memory span task conditions has proved useful in comparing different models of adult verbal STM (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1999), although this connection has been rarely investigation in developmental studies, the focus being solely on overall performance levels (see McCormack, Brown, Vousden, & Henson, 2000; and Pickering, Gathercole, & Peaker, 1998, for exceptions). There are three divisions of recall errors; two of these categories can be thought of as item errors (McCormack et al., 2000): an intrusion error (we termed it “commission error”) occurs when an item from outside the original presentation set is given as a response, and an omission error occurs when no response is given for a particular serial position. An order or movement error (we named it “order reversal”) occurs when a list item is recalled in an incorrect serial position.

In a comparative cross-sectional analysis of letter, digit and block (Corsi) recall, Pickering, Gathercole, and Peaker (1998) compared 5 and 8 year olds’ performances and error types. They found that the error patterns were similar in the tasks requiring recall of letters and of blocks, although order errors predominated in the block but not the letter recall task for the older children. “These results appear to reflect the application of common processes specialized for the extraction of serial order information from the phonological and visuospatial components of short-term memory” (p. 1128). In an investigation of a different span task (serial letter recall), McCormack et al. (2000) have found developmental differences in the patterns of errors of 7-year-olds as compared to 9-year-olds, 11-year-olds, and adults. They found an overall decrease in total errors, with a decrease in the proportion of commission errors, and a marginally significant increase in order reversal errors.
In the investigated samples from the present study, the pattern of errors was indeed relatively similar across age groups, with a decrease with age, but a remaining preeminence of commission errors. Of course, if the task would be allowed to continue despite all types of errors for a fixed number of trials, omission errors could be more visible at higher levels; at this level the children appear to be more influenced by the interference effects of similar items rather than not correctly distinguish the correct number of items and their sequence.

The traditional conception was that relative to older children and adults, preschoolers do not use verbal strategies effectively in learning, memory, or other cognitive tasks, although they are not unskilled in the use of language (Brown, 1977; Flavell, 1970; Reese, 1962; Vygotsky, 1962), and that they rely primarily on visual representation in cognition (Bruner et al., 1966). Conrad (1962) showed that children 3-5 years of age were not affected by auditory similarity in memorizing the names of animal pictures, an effect visible for the 5-11 years old group (which would suggest they used a verbal coding strategy). Brown (1977a) also showed that in preschool children (mean age 61.5 months) high visual similarity had a deleterious effect in recall accuracy regardless of the verbal codability of the stimuli; but Brown (1977b) showed that if the children were probed verbally for their responses, there was a strong detrimental effect of phonetic similarity; this was taken as a proof of “coding flexibility” in preschool age.

The memory performance picture was completed with the additional information from the short metamemory interview that followed each task. Preschool children were required to produce memory judgments to reflect their thinking and answer the question: “How did you remember the colors/pictures?”; if no answer was provided by the child, a second prompter was introduced: “What were you telling yourself when you tried to remember them?” Although this reflective request might appear too challenging, several children (from the older preschool group) were able to provide us with some interesting proofs (see the Appendix for example of such statements) suggesting the presence of both spontaneous rehearsal and verbal coding of visual stimuli (e.g. many children declared about the color span task that they “said to themselves repeatedly” the names of the colors in order to remember them). Examples of metamemory reports of verbal recoding of abstract stimuli have been found in children as young as 6-7 years, in the recent study of Leijenhorst, Crone, & Van der Molen, 2007, confirming the results of our interviews. Similar to their results, we found that children who used idiosyncratic verbal recoding strategies on the abstract patterns span task also had a significantly better memory performance than those children who relied only on the pictorial representation of the stimuli.

In several developmental and neuropsychological investigations, especially when compared to WM, STM has been explicitly considered a passive, non-executive storage mechanism (Hughes, Leboyer, & Bouvard, 1997; Walley & Donaldson, 2005; Robbins, Weinberger, Taylor, & Morris, 1996, etc.). Although children are not thought to spontaneously rehearse the information until the age of 6 or 7 years, our metamemory interviews have revealed that many children...
reported having used rehearsal even earlier than this age. An important contribution of the articulatory loop model advanced by Baddeley and collaborators, suggesting that information “fades away” from the (auditory) memory trace unless rehearsed in about 2 seconds (revised by Hulme et al., 1999 to a 3.6 seconds interval), is to actually set a superior limit to the “automaticity” of processing during STM tasks. Above this limit (which is actually lower in children), different strategies come into place to ensure continuation of performance beyond the simple reflection of stimulus trace. These strategies differ from simple rehearsal, to chunking, verbal recoding in the case of visual material, sorting, etc. Of course, this does not always lead to better performance, as “utilization deficiencies” can appear (Miller, 1990), in which a new strategy initially impairs performance until it becomes automatized (as reflected by the increase in inter-word pauses of older children at T1). Some children even misuse these strategies (e.g. the child that kept verbally recoding the color even when abstract shapes were to be remembered). All these argue in favor of a dynamic interplay between executive and non-executive processing in solving STM tasks.

ACKNOWLEDGEMENTS
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APPENDIX
Sample of responses from various children (translation of exact quotations) to the questions:
“How did you memorize these pictures?”, or
“What were you saying to yourself when you were trying to remember these pictures?”

<table>
<thead>
<tr>
<th>Color &amp; Object span</th>
<th>Abstract shape span</th>
</tr>
</thead>
<tbody>
<tr>
<td>• “I thought about it... what color it was” (O. M., female, 82 months).</td>
<td>• “I thought about the shapes... I said to myself: car, brown, pole, broken moon, box, walls, y, a ship, a blouse” (A.D., female, 73 months).</td>
</tr>
<tr>
<td>• While picking up the colors in the right order: “yellow, blue, red…” (A.D., female, 73 months).</td>
<td>• “I didn’t say anything to myself, I just looked at them!” (P.D., female, 73 months; A.R., male, 72 months).</td>
</tr>
<tr>
<td>• “I looked carefully and I repeated: red, blue, brown” (P.A., 77 months)</td>
<td>• “I looked at them, and I remembered them... I just looked at them” (B. M., male, 80 months)</td>
</tr>
<tr>
<td>• “I saw a book and an apple and I kept repeating book and apple” (O. M., female, 82 months).</td>
<td>• “Star, flower... this I didn’t call anything, ... this was a star ... nothing” (G.A., female, 63 months).</td>
</tr>
<tr>
<td>• While picking up the cards in the right order: “car, chair, book…” (A.D., female, 73 months; M.D., female 64 months).</td>
<td>• “Square, star, rectangle...moon” (M.I., female, 80 months).</td>
</tr>
<tr>
<td>• “I just thought about it” (C.F., male, 72 months).</td>
<td>• Verbalizes whenever presented with the items: “A mask, a toy, a letter, a bed, a chair, a vegetable, a TV-set”, the verbal labels remain constant across trials (R. R., male, 74 months). The same concomitant verbalization appears in the other tasks (color and object span).</td>
</tr>
<tr>
<td>• “I looked and I said: a circle, color brown” (R. R., male, 74 months).</td>
<td>• “This looked like a penguin” (L.A., male, 74 months).</td>
</tr>
<tr>
<td>• “I looked how they were: here and here ...” (pointing to several parts of the picture; M.C., male, 71 months).</td>
<td>• “The first one is green, the second one green, and the third one also green, and than green and green” – accompanies the presentation of all items (M.D., female, 63 months)</td>
</tr>
<tr>
<td>• “First you put brown, than red” (M.D., female, 64 months).</td>
<td></td>
</tr>
<tr>
<td>• “Well...I just remembered their shapes” (H.P., 87 months).</td>
<td></td>
</tr>
<tr>
<td>• “I remembered the colors” (S. A., female, 61 months)</td>
<td></td>
</tr>
</tbody>
</table>