Journal of Educational and Developmental Psychology; Vol. 6, No. 1; 2016
ISSN 1927-0526 E-ISSN 1927-0534
Published by Canadian Center of Science and Education

Maintenance Mechanisms in Children's Verbal Working Memory

Anne-Laure Oftinger[1] & Valérie Camos[1]

[1] Université de Fribourg, Fribourg, Switzerland

Correspondence: Valérie Camos, Université de Fribourg, département de psychologie, Fribourg, Switzerland. Tel: 41-026-300-7675. E-mail: valerie.camos@unifr.ch

Received: September 30, 2015 Accepted: November 4, 2015 Online Published: December 21, 2015

doi:10.5539/jedp.v6n1p16 URL: http://dx.doi.org/10.5539/jedp.v6n1p16

Abstract

Previous research in adults has indicated two maintenance mechanisms of verbal information in working memory, i.e., articulatory rehearsal and attentional refreshing. However, only three studies have examined their joint contribution to children's verbal working memory. The present study aimed at extending this line of research by investigating the developmental changes occurring from 6 to 9 years old. In two experiments using complex span tasks, children of three different age groups maintained letters or words while performing a concurrent task. The opportunity for attentional refreshing was manipulated by varying the attentional demand of the concurrent task. Moreover, this task was performed either silently by pressing keys or aloud, the latter inducing a concurrent articulation. As expected, recall performance increased strongly with age. More interestingly, concurrent articulation had a detrimental effect on recall even in 6-year-old children. Similarly, introducing a concurrent attention-demanding task impaired recall performance at all ages. Finally, the effect of the availability of rehearsal and of attentional refreshing never interacted at any age. This suggested an independence of the two mechanisms in the maintenance of verbal information in children's working memory. Implications for the development of rehearsal use and for the role of attention in working memory are discussed.

Keywords: working memory, rehearsal, refreshing, development, attention

1. Introduction

Working memory is a system dedicated to the maintenance and the processing of information. Past research has shown that two maintenance mechanisms are involved in the maintenance of verbal information in working memory: articulatory rehearsal and attentional refreshing (Camos et al., 2009). The former was extensively described in Baddeley's multi-component model as the use of inner speech to repeat the to-be-remembered items (e.g., Baddeley, 1986), whereas the latter is an attention-based mechanism at the heart of the time-based resource-sharing model (e.g., Barrouillet, Bernardin, & Camos, 2004). Recent studies have further indicated that these two mechanisms are independent in young adults, having an additive effect on recall performance (Camos et al., 2009; Hudjetz & Oberauer, 2007). Thus, the present study investigated the implication of these two mechanisms in children's maintenance of verbal information by examining the age-related changes that may occur around 7 years of age. This is an especially important age range to examine as several studies have suggested that articulatory rehearsal as well as attentional refreshing emerge at 7 (Barrouillet et al., 2009; Camos & Barrouillet, 2011; Gathercole & Adams, 1993; Gathercole, Adams, & Hitch, 1994).

In adults, neural and behavioral evidence have highlighted the distinction between an attention-based mechanism of refreshing and a more specialized system dedicated to the maintenance of verbal information, articulatory rehearsal. Neuropsychological studies established the dissociation of two complementary brain systems underlying verbal working memory in adults (Johnson et al., 2005). Moreover, behavioral studies confirmed this distinction. First, Hudjetz and Oberauer (2007) showed that another mechanism maintains memory traces even when articulatory rehearsal was impeded in a reading span task. In this study, segments of sentences appeared successively on screen at a slow or fast pace. Recall performance was reduced during a fast compared to a slow pace, even when a continuous reading condition impaired rehearsal. This finding suggested that another mechanism permits the maintenance of verbal information. Secondly, Camos et al. (2009) showed that rehearsal and refreshing are both responsible for the maintenance of verbal information, and they can operate independently and jointly in adults. In a series of experiments using complex span tasks, adults had to remember letters while performing concurrent task. During this concurrent task, the availability of the two maintenance mechanisms was manipulated. To impede inner speech and thus the rehearsal of memory items, an overt concurrent articulation was induced by asking participants to perform the concurrent task aloud instead of silently. The availability of attentional refreshing was varied by presenting participants with a more or less attention-demanding concurrent task. For example, participants were asked to either solve or read arithmetic operations. Because solving operations needs more attention than simply reading them, attention should be less available for refreshing in the former than in the latter condition. As predicted by the authors, the manipulation of one mechanism while the other was impeded led to reduced recall performance, which strengthens the idea that two distinct mechanisms are involved in adults' verbal maintenance. Moreover, when the availability of both mechanisms was orthogonally manipulated, results showed an additive effect of the experimental manipulations on recall performance, which supports the independence of the two mechanisms. To summarize, two maintenance mechanisms are involved in the maintenance of verbal information in adults' working memory (see Camos & Barrouillet, 2014, for review). They are distinct and independent processes, and because of this independence, they can be jointly used to maintain verbal information. Moreover, adults can chose to favor the use of one or the other process, for example under specific instructions or depending on some task characteristics (Camos, Mora, & Oberauer, 2011). Finally, each mechanism is sensitive to different constraints. On the one hand, because attentional refreshing is more attentional-demanding than articulatory rehearsal, the former is highly sensitive to the availability of attention and its variation. On the other hand, because articulatory rehearsal relies on processes involved in language production, it is impeded by any concurrent articulation.

Contrary to the extensive exploration in adults, few studies examined the joint implication of rehearsal and refreshing in verbal working memory in children. Indeed, most studies in this field chose to focus on one or the other mechanism. As a consequence, considerable evidence has suggested that children start using rehearsal from age 7 onwards. At 7 years old, the emergence of lip movements and of significant correlation between speech rate and memory span indicate the use of subvocal rehearsal (e.g., Flavell, Beach, & Chinsky, 1966; Gathercole & Adams, 1993; Gathercole et al., 1994). Moreover, recall performance is sensitive to the phonological similarity of visually presented memoranda in children older than 7, whereas visual similarity affects recall in younger children (e.g., Gathercole et al., 1994; Hitch et al., 1991). However, recent findings have questioned this qualitative change showing that children younger than 7 could use rehearsal (Al-Namlah et al., 2006; Henry et al., 2012; Jarrold & Tam, 2011; Tam et al., 2010). Because children younger and older than 7 were involved in the present study, this allowed a further examination of this question, i.e., if such a qualitative change appears or not at 7.

Concerning attentional refreshing, fewer studies have examined it in children (Barrouillet et al., 2009; Camos & Barrouillet, 2011; Gaillard, Barrouillet, Jarrold, & Camos, 2011). Recent research has shown that the use of refreshing also begins at around 7 years of age and increases until 14 years, reaching then a similar level of use and efficiency as in adulthood (Barrouillet et al., 2009). In a complex span task in which children read series of digits while maintaining letters, these authors showed that the beneficial effect on recall of having few digits to read in a fixed interval was stronger in older children. Thus, older children take more advantage of the increasing availability of attention when fewer digits have to be read. This improvement in refreshing efficiency is a major determinant of the developmental increase in working memory capacity observed in childhood (Gaillard et al., 2011). Conversely, recall performance does not depend on the attentional demand of the concurrent task in children younger than 7, but on the duration of the concurrent task, i.e., the retention interval (Camos & Barrouillet, 2011). This suggests that children younger than 7 do not use an attention-based mechanism of maintenance.

Despite the fact that both refreshing and rehearsal may emerge at similar age, only three studies have examined the joint implication of these two maintenance mechanisms in children's working memory (Magimairaj & Montgomery, 2012; Mora & Camos, 2015; Tam et al., 2010). Magimairaj and Montgomery (2012) showed that two factors, verbal storage and general attentional control, contributed to independent and unique variance in 7- to 11-year-old children's verbal working memory. This suggests that domain-general attention and verbal storage mechanisms independently constrain children's verbal working memory. However, these authors did not investigate the age-related evolution of these mechanisms. Mora and Camos (2015) also did not examine developmental changes, as they studied only 8-year-old children. Nevertheless, they observed that these children could use these two maintenance mechanisms, and that impeding one of the two reduced recall performance in complex span task. Moreover, the experimental manipulation of the availability of the two mechanisms did not interact, as previously observed in adults. This suggests that the two maintenance mechanisms are independent in 8-year-old children as they are in adults. Finally, only one study examined the age-related changes in rehearsal and refreshing comparing 6- and 8-year-old children (Tam et al., 2010). In two experiments, primarily using Brown-Peterson paradigm, Tam et al. (2010) varied the opportunities for memory maintenance by manipulating the type of tasks introduced between the presentation of the memoranda and their recall. The concurrent task was either a verbal task, which impeded rehearsal, or a non-verbal task to hinder refreshing but to allow rehearsal. In addition, the memoranda were either phonologically similar or dissimilar words. When compared to an unfilled delay condition, introducing a non-verbal task similarly reduced 6- and 8-year-old children's recall. Based on this finding and contrary to Barrouillet et al. (2009; Camos & Barrouillet, 2011), the authors proposed little development in the use of refreshing between these two ages. Moreover, both types of concurrent task reduced recall, the verbal task resulting in a greater reduction than the non-verbal task. The detrimental effect of the verbal task was stronger in 8- than in 6-year-old children. Contradicting previous studies on the emergence of rehearsal, the authors suggested that young children aged 6 use rehearsal, although to a lesser extent than the 8-year-old children. In line with this suggestion, the phonological similarity effect, which is often conceived as an index of the use of rehearsal, affected recall in both 6- and 8-year-old children, and the effect disappeared under verbal concurrent task. Finally, the authors suggested that the stronger effect of the verbal concurrent task suggests that such a task impairs both rehearsal and refreshing, whereas the non-verbal task only impeded the use of refreshing.

Given that only one study thus far has examined the age-related changes of the two mechanisms in children's working memory, the aim of the present study was to extend this examination. Consequently, in line with Tam et al. (2010), we contrasted different age groups around the age of 7 to investigate the developmental changes in the use of these two mechanisms in children's verbal working memory. Our two experiments included 6-year-old and 7-year-old children, as well as another group of older children (9- and 8-year olds in Experiments 1 and 2, respectively) for whom there is no doubt that they can use rehearsal and refreshing. As in Mora and Camos (2015), the experiments employed a fully crossed design by orthogonally manipulating the opportunity to use articulatory rehearsal and attentional refreshing within the same complex span task. Contrary to Tam et al.'s (2010) procedure, this design allowed the assessment of the distinct effect of each mechanism and to examine the potential interactions between the two mechanisms. Thus, in the two experiments, children performed four different complex span tasks that differed in the availability of rehearsal and refreshing. In the first experiment, we varied the concurrent attentional demand: the low-demanding task was a color-discrimination task in which children had to judge if the presented pictures were in black-and-white or in color, and the high-demanding task was a categorization task, in which children judged if the pictures represented an animal or not. In the second experiment, we induced a stronger manipulation of attentional demand as in Tam et al. (2010) who compared a condition with a concurrent task to a condition without any concurrent task (i.e., an unfilled delay condition). However, the two conditions in Tam et al. (2010) did not only differ on the existence of a concurrent attentional demand during the maintenance, but on other aspects. For example, the introduction of a concurrent task requires the maintenance of an additional task-set, and the programming and performance of motor responses. As a consequence, the reduction in recall performance observed by Tam et al. (2010) may be due to the difference in these other aspects and not in refreshing *per se*. Barrouillet et al. (2009; Exp. 3) executed a similar comparison between filled and unfilled conditions with the same criticism. Thus, Experiment 2 compared two conditions that both involved a concurrent task, but this concurrent task was attentionally-demanding only in one of the two conditions. In the other low-demand condition, the concurrent task did not induce a concurrent attentional demand, and thus it should not affect recall although it required maintaining its own task-set and performing motor responses. Barrouillet et al. (2007) have shown that the simple reaction time task is such a task. In a complex span task, these authors observed that increasing the number of stimuli for which participants had to press a key did not affect recall performance. The serial reaction time task has also the advantage of being simple to explain and perform by young children. Thus, Experiment 2 contrasted the serial reaction time task to the color-discrimination task used in the first experiment. In both experiments, children had to perform the concurrent task either silently by pressing keys or aloud by pressing key while saying the response aloud. To induce a concurrent task, Mora and Camos (2015) asked children to perform a supplementary articulation in addition to the concurrent task (i.e., repeating "oui" at the pace of beeps). We changed this because it was already difficult for 8-year-old children, and the present study involved younger children. The great advantage of this design was that children were presented with the same memoranda and the same distracting pictures, and variation in the availability of refreshing or rehearsal only relied on changes in the instructions. Consequently, the risk that differences in performance across conditions arise from interference between memoranda and distractors was minimized.

It was predicted that increasing the attentional demand of the concurrent task should reduce the availability of attention, and thus the use of refreshing, thereby leading to reduced recall performance. Because refreshing emerges at 7, this should occur in older children and not in 6-year-old children. However, Tam et al. (2010) suggested that even 6-year-old children use refreshing, which does not further develop between 6 and 8. Given the aforementioned possibility that the difference observed by Tam et al. (2010) could rely on other factors, the current study introduced a better control condition in order to clarify this issue and shed light on the controversy about the development of refreshing between 6 and 8. Similarly, the introduction of a concurrent articulation should reduce recall by impeding rehearsal. A debate recently rose about the existence of a qualitative change in the use of rehearsal. According to the idea that the use of rehearsal appears at 7, the concurrent articulation should reduce recall in children aged 7 and older. Alternatively, such an effect could be observed in younger children, providing support to the more recent studies which question the qualitative change hypothesis (Al-Namlah et al., 2006; Henry et al., 2012; Jarrold & Tam, 2011; Tam et al., 2010). Finally, the present design would allow for examining the potential interaction between refreshing and rehearsal across three age groups. The only study that examined this question in children reported a lack of interaction in 8-year-old children (Mora & Camos, 2015). But the use of articulatory rehearsal may require attention in younger children. The present study extends this examination to a larger age range, searching for some age-related changes in the utilization of refreshing and rehearsal.

2. Experience 1

The first experiment used a similar complex span task as in Mora and Camos (2015) but with some changes. Contrary to Tam et al. (2010) and Mora and Camos (2015) in which the memoranda were words, consonants were used as memoranda to reduce any impact of long-term memory knowledge, which could differ between younger and older children. Preliminarily, it was verified that all participants knew (i.e., recognized and named) the consonants. Each letter was followed by two pictures, and according to the experimental condition, the availability of articulatory rehearsal and of attentional refreshing was reduced by introducing a concurrent articulation and by increasing the concurrent attentional demand, respectively. To vary the concurrent attentional demand, two different tasks were performed on the pictures, either a color-discrimination or a categorization tasks. For the color-discrimination task, children had to determine if the pictures were in black-and-white or in color. For the categorization task, they had to determine if the pictures represented an animal or not. The categorization task should induce a stronger attentional demand than the color-discrimination task, thereby reducing the relative opportunity for attentional refreshing and yielding poorer recall than the color-discrimination task. According to Camos and Barrouillet's (2011), this negative effect of increased attentional demand should be observed in children older than 7 who could use attentional refreshing, and not in younger children. Alternatively, if younger children use refreshing as proposed by Tam et al. (2010), such a reduction of recall should appear at each age. Moreover, to induce a concurrent articulation, half of the children had to say their responses aloud while pressing keys to respond. The introduction of a concurrent articulation should impede the use of articulatory rehearsal, and should therefore result in reduced recall performance in children old enough to use this mechanism. Although rehearsal is thought to emerge at 7, recent evidence has suggested that younger children (aged 6) could already use rehearsal. Experiment 1 involved children aged between 6 and 9, therefore allowing an assessment of the age at which a concurrent articulation impedes recall of verbal information.

2.1 Method

2.1.1 Participants

One-hundred-and-eighty children from primary schools participated in the experiment: 65 kindergarteners (33 boys, mean age = 6 years 5 months, *SD* = 5 months), 59 first graders (21 boys, mean age = 7 years 5 months, *SD* = 5 months), and 56 third graders (32 boys, mean age = 9 years 7 months, *SD* = 7 months). There were all French native speakers, and none of children had difficulties with perceiving colors. Children's caretakers provided written informed consent.

2.1.2 Materials

Two lists of 18 series of one to six consonants were created, with three series of each length. All consonants in the alphabet were used, except W because it is trisyllabic in French, and they occurred equally in the lists. Series of acronyms, repetitions, and alphabetic-ordered strings were avoided. Pictures of animals and non-animals (e.g., door, book, hand) were selected from Snodgrass and Vanderwart (1980). For each category, 35 pictures with the most frequent name were used based on two measures of objective word frequency (i.e., in Brulex and Frantext ;

New, Pallier, Ferrand, & Matos, 2001). It was also verified that the names were acquired before 74.5 months (Chalard, Bonin, Meot, Boyer, & Fayol, 2003). Pictures were presented in two versions: in black-and-white and in color. In each length of the complex span task, the same proportion of black-and-white and color pictures, as well as of animals and non-animals, were presented.

2.1.3 Procedure

Children were tested individually in a quiet room. Each child performed two complex span tasks differing on the type of concurrent task (categorization or color-discrimination) but with the same type of responses (key press alone or with aloud response). A different list of consonant series was associated to each complex span task, the association between lists and complex span task being counterbalanced across participants. In a trial, children were asked to remember the consonants and to perform a concurrent task on pictures (Figure 1).

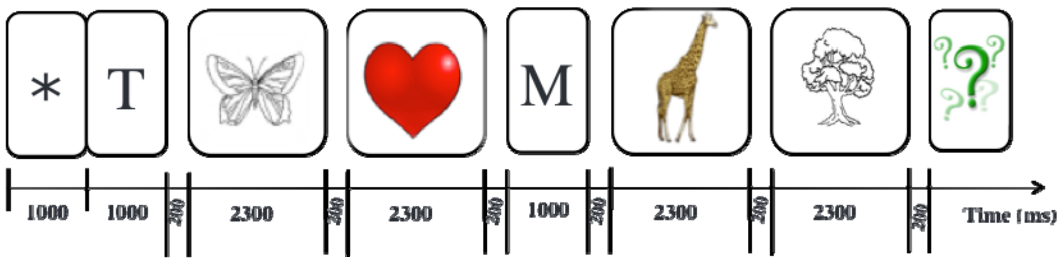

Figure 1. Illustration of a length-2 trial in the complex span task used in Experiment 1

Each trial began by a first screen indicating the number of letters to be remembered (e.g., “2 letters”), which was read by the experimenter. Then, an asterisk appeared centered on screen during 1000 ms, followed by a letter for 1000 ms. After a delay of 200 ms, two pictures were presented in an invisible 10 x 10 cm square in the center of the screen for 2300 ms each with a 200-ms Inter Stimulus Interval (ISI). Then, the second letter appeared and so on until the end of trial when a question mark appeared. This question mark prompted the aloud recall of the letters in their order of presentation. Before each complex span task, a training phase included one trial with 1 letter to be remembered and no concurrent task, one trial with 2 pictures and no letter to maintain, and then 2 complex span task trials for length 1 and for length 2.

Two different tasks were performed on pictures either a color-discrimination or a categorization tasks. For the color-discrimination task, children had to determine if the pictures were either in black-and-white or in color by pressing a right or left key on the keyboard, respectively. To help children, black-and-white and colored stickers were stuck on corresponding keys. For the categorization task, they had to determine if the pictures represented an animal or not by pressing a left or right key, respectively. To help children, stickers with a cat or with a crossed-out cat were stuck below the corresponding keys. Response times and percentages of correct responses were recorded during these two concurrent tasks.

Half of the children started with 18 trials involving the color-discrimination task, and then the 18 trials with the categorization task; the other half did the reverse order. Moreover, to induce a concurrent articulation, half of the children in each age group had to say aloud their response (“color” and “no-color” in the color-discrimination task, and “animal” and “no-animal” in the categorization task) while pressing keys to respond.

The aloud recall of the consonants was written down by the experimenter, who systematically asked children the position of each recalled item afterwards in case of omissions. The task was terminated when the child failed all trials of the same length, or when all trials had been presented. Each correctly recalled series counted as one third; the total number of thirds was added up to provide a span score (cf. Barrouillet et al., 2004). For example, the correct recall of all the series of one, two, and three letters, of two series of four letters and one series of five letters resulted in a span of (3+3+3+2+1) x 1/3 = 4

2.2 Results and Discussions

Data from 15 children were discarded: 9 kindergarteners, 5 first graders and 1 third grader had less than 50% of correct responses in the concurrent task. Moreover, data from children who were not able to recall a single item in one of the experimental conditions were discarded from the analysis. The remaining 48 kindergarteners, 52 first graders and 53 third graders had a mean rate of correct responses of 86% (*SD* = 11).

An analysis of variance (ANOVA) was performed on the percentage of correct responses in the concurrent task with age (6, 7 and 9 years), type of responses (keyed vs. aloud), and concurrent task (categorization vs. color-discrimination), with age and responses as between-subject factors and concurrent task as within-subject factor. Although percentage of correct responses was already high at 6 (82%, *SD* = 12), it was significantly greater in older children, with 86% (*SD* = 10) at 7 and 92% (*SD* = 7) at 9, $F(2, 147) = 23.12$, $p < .0001$, $\eta_p^2 = .24$; all differences between two age groups being significant, *ps* < .05 with Bonferroni correction except between 6 and 7, $p = .08$. A difference emerged according to the type of responses, with higher accuracy when children produced an aloud response with the key-press (90%, *SD* = 9) than when only pressing keys (85%, *SD* = 11), $F(1, 147) = 20.89$, $p < .0001$, $\eta_p^2 = .12$. As expected, the categorization task (*M* = 86%, *SD* = 11) induced a lower percentage of correct responses than the color-discrimination task (*M* = 88%, *SD* = 10), $F(1, 147) = 8.01$, $p < .01$, $\eta_p^2 = .05$. No interaction was significant, *Fs* < 1.

A similar ANOVA was performed on the response times for correct responses in the concurrent task. As observed for accuracy, older children outperformed the younger. Nine-year-old children (1246 ms, *SD* = 178) were faster than 7-year olds (1311 ms, *SD* = 161) and 6-year olds (1346 ms, *SD* = 165), $F(2, 147) = 5.44$, $p < .01$, $\eta_p^2 = .07$. However, pairwise comparisons with Bonferroni adjustments indicated that the only significant difference emerged between 6 and 9 ($p < .01$); the remaining differences were not significant (*ps* > .09). As expected, children were significantly slower in categorization (1343 ms, *SD* = 174) than in color-discrimination (1256 ms, *SD* = 171) tasks, $F(1, 147) = 60.40$, $p < .0001$, $\eta_p^2 = .29$. The type of responses did not affect the response times (aloud: 1300 ms, *SD* = 172 vs. keyed: 1300, *SD* = 173), $F < 1$. No interaction was significant, *ps* > .10. These preliminary analyses showed that children in the three age groups did their best to perform the concurrent task, reaching a higher level of accuracy. Moreover, as expected, the categorization task led to poorer performance with a lower accuracy and longer response times than the color-discrimination task.

Finally, an ANOVA was performed on the mean spans with the same design as the previous ANOVAs. As often reported in literature, recall performance significantly increased with age, with 1.19 (*SD* = .71) at 6, 1.80 (*SD* = 1.05) at 7 and 2.97 (*SD* = 1.27) at 9, $F(2, 147) = 60.99$, $p < .0001$, $\eta_p^2 = .45$, with all differences between each age group being significant, *p*s < .0001 with Bonferroni correction (Figure 2). The type of response also had a significant effect on recall, with poorer recall when response was aloud (*M* = 1.44, *SD* = 0.88) than silent (*M* = 2.53, *SD* = 1.35), $F(1, 147) = 65.49$, $p < .0001$, $\eta_p^2 = .31$. As we predicted, recall performance was reduced during the categorization task (*M* = 1.92, *SD* = 1.26) than the color-discrimination task (*M* = 2.12, *SD* = 1.29), $F(1, 147) = 9.95$, $p < .01$, $\eta_p^2 = .06$. Moreover, as observed in adults, the type of responses and the type of concurrent task did not interact, $F(1, 147) = 2.09$, $p = .15$, $p\mathrm{BIC}(H0|D) = .81$(Note 1). Finally, whereas the manipulation of the concurrent task did not interact with age, $F(2, 147) = 1.40$, $p = .25$, $p\mathrm{BIC}(H0|D) = .98$, the type of response interacted with age, $F(2, 147) = 6.30$, $p < .01$, $\eta_p^2 = .08$. The difference between silent and aloud responses was larger in older children (i.e., 0.40 at 6, 1.24 at 7 and 1.48 at 9), but significant in all age groups, $F(1, 46) = 5.10$, $p < .03$, $\eta_p^2 = .10$ at 6, $F(1, 50) = 33.38$, $p < .0001$, $\eta_p^2 = .40$ at 7, and $F(1, 51) = 32.52$, $p < .0001$, $\eta_p^2 = .39$ at 9. The 3-way interaction was not significant, $F < 1$, $p\mathrm{BIC}(H0|D) = .99$.

Besides an expected increase of recall performance with age, this first experiment revealed the main effect of introducing a concurrent articulation and of increasing the attentional demand of the concurrent task. Before discussing these findings, we will present a second experiment.

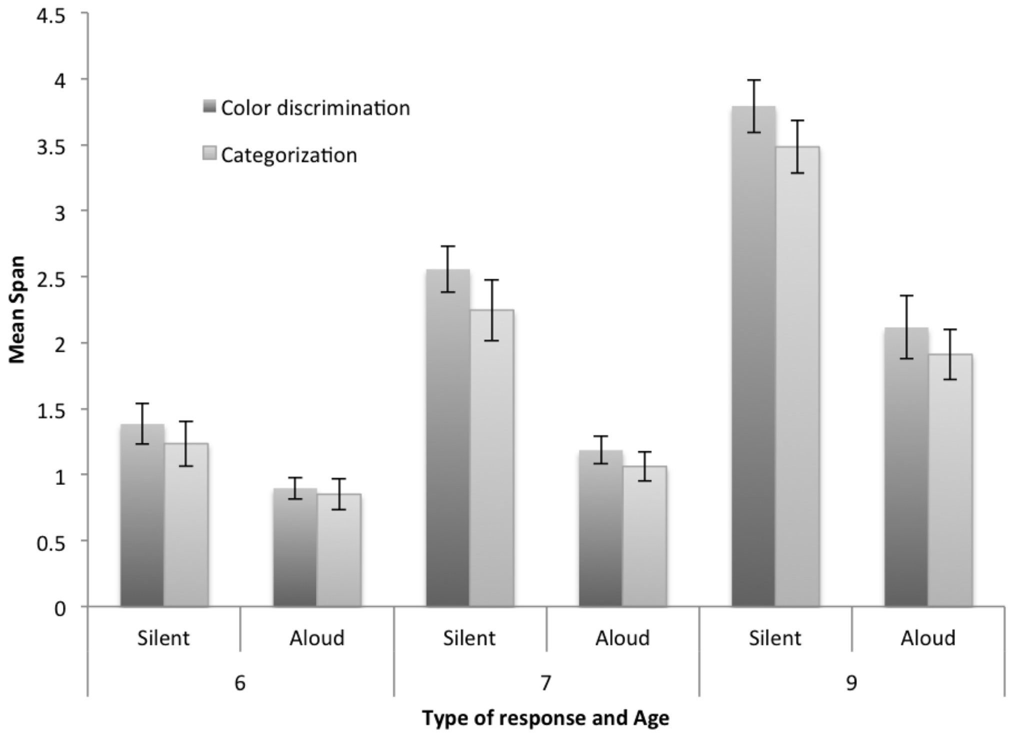

Figure 2. Mean spans according to the concurrent tasks (color-discrimination vs. categorization), the type of responses (keyed vs. oral) and the age. Y bars represented standard errors

3. Experience 2

For sake of replication, Experiment 2 reexamined the implication of refreshing and rehearsal in children's verbal working memory by introducing three changes. First, we implemented a stronger manipulation of the concurrent attentional demand, and compared the effect of the same color-discrimination task used in Experiment 1 to the effect of a simple reaction time task, which does not rely on attentional resources (Barrouillet et al., 2007). In the latter task, children had to press a key or to say "animal" while pressing a key as fast as possible when an animal appeared on screen (all pictures depicted animals). Second, because the use of visually presented consonants as memoranda in Experiment 1 cannot fully assure that these items were verbally encoded and maintained, memoranda in Experiment 2 were auditorily-presented words through headphones to ensure verbal encoding of memoranda and also to avoid bias in encoding due to difference in reading ability. Finally, the procedure was also changed because children found Experiment 1 very long and had difficulties remaining attentive until the end. Thus, instead of an increasing length procedure with a stop rule, children in Experiment 2 were presented with four series of four words in each condition. As a result, all children performed the same number of trials in each condition whatever their age. Moreover, to avoid a ceiling effect in older children with such length, the older group was younger (8 years) than in Experiment 1.

3.1 Method

3.1.1 Participants

A total of 247 children from primary schools participated in the experiment: 86 kindergarteners (42 boys, mean age = 6 years 1 month, *SD* = 7 months), 87 first graders (34 boys, mean age = 7 years 3 months, *SD* = 6 months), and 74 second graders (42 boys, mean age = 8 years 2 months, *SD* = 5 months). There were all French native speakers, and none of children had difficulties with perceiving colors. None of them participated in Experiment 1. The children's caretakers provided written informed consent.

3.1.2 Materials and Procedure

The materials and procedure were similar to Experiment 1, with the following exceptions. Children were presented with four series of four words to be remembered in each complex span task. Each word was randomly selected from a set of 48 monosyllabic singular French nouns. These nouns were highly frequent words according to the French database Manulex-Inframanu 35 (Peereman, Lété, & Sprenger-Charolles, 2007) with an age of acquisition below 60 months. All series were recorded by a female voice and auditorily presented through headphones for 1000 ms. The two pictures following each word were the animal pictures used in Experiment 1 with two versions (black-and-white and color). Each picture was presented during 1800 ms with a 200-ms ISI. In each trial, the same proportion of color and black-and-white pictures appeared.

The color-discrimination task used in Experiment 1 was compared to a simple reaction time task. During the latter task, children had to press a key in the middle of keyboard (and to say “animal” in the aloud response condition) as soon as an animal appeared. A sticker with a cat was stuck on this key to help children. For training, children saw 8 pictures at the beginning of each complex span task to which they practiced the color-discrimination or simple reaction time task. If the percentage of correct responses was lower than 75%, they had to repeat this training one time. All participants performed two complex span tasks, starting either with the color-discrimination task or the simple reaction time task, and the order was counterbalanced across participants. As in Experiment 1, the concurrent articulation (aloud responses vs. silent keyed responses) was manipulated between-subjects.

To ensure that children assigned to the different experimental groups did not differ in their basic short-term memory capacity, all children performed, prior to any other tasks, a simple span task in which they had to memorize four lists of four words. Each word was presented during 1000 ms. Immediately after the presentation of the last word, children recalled the words out loud in the order of their presentation. Recall performance was scored as the percentage of words recalled in their correct position.

3.2 Results and Discussion

As in Experiment 1, data from children who achieved less than 50% of correct responses on the concurrent task or who had 0% or 100% recall in one of the experimental conditions were discarded from the analysis. The remaining 54 kindergarteners, 68 first graders and 64 second graders had a mean rate of correct responses of 90% (*SD* = 10).

An ANOVA was performed on the percentage of correct recall in the simple span task with age (6, 7 and 8 years) and type of response (keyed vs. aloud) as between-subject factors. Percentage of correct recall increased significantly with age, $F(2, 180) = 4.42$, $p < .02$, $\eta_p^2 = .05$, with 67% at 6, 72% at 7 and 79% at 8. Pairwise comparisons with Bonferroni correction indicated that recall difference between 6 and 8 was significant ($p = .01$) and all other differences were not significant, *ps* > .21. No other effect was significant, *Fs* < 1. This ensured us that children assigned to the keyed and aloud response groups did not differ in their short-term memory capacity.

As in Experiment 1, we analyzed the concurrent task performance before analyzing recall performance. An ANOVA was performed on the percentage of correct responses with age (6, 7 and 8 years), type of response (keyed vs. aloud), and concurrent task (simple reaction time vs. color-discrimination), with age and type of response as between-subject factors, and concurrent task as within-subject factor. As in Experiment 1, the percentage of correct responses was already high at 6 (87%, *SD* = 11), and significantly increased with age, with 91% (*SD* = 9) at 7 and 93% (*SD* = 8) at 8, $F(2, 180) = 10.81$, $p < .0001$, $\eta_p^2 = .11$. Pairwise comparisons with Bonferroni adjustments indicated that all differences between age groups were significant, *ps* < .01, except between 7 and 8, $p = .37$. Children achieved a better percentage of correct responses when they responded aloud while pressing keys (93%, *SD* = 9) than when only pressing keys (88%, *SD* = 10), $F(1, 180) = 25.75$, $p < .0001$, $\eta_p^2 = .13$. As expected, the color-discrimination task (87%, *SD* = 11) induced a lower percentage of correct responses than the simple reaction time task (94%, *SD* = 8), $F(1, 180) = 74.82$, $p < .0001$, $\eta_p^2 = .29$. The interaction between task and type of responses failed to reach significance, $F(1, 180) = 3.64$, $p = .06$, $\eta_p^2 = .02$, with a stronger difference between silent and aloud condition in color-discrimination task than simple reaction time task. No other interactions were significant, *Fs* < .1.

A similar ANOVA was performed on response times for correct responses. Older children were faster to respond with 842 ms (*SD* = 140) at 8, 871 ms (*SD* = 162) at 7 and 935 ms (*SD* = 167) at 6, $F(2, 180) = 6.96$, $p < .0001$, $\eta_p^2 = .07$. Pairwise comparisons with Bonferroni adjustments indicated that all differences between age groups were significant, *p*s < .04, except between 7 and 8, $p = .72$. As expected, children were significantly slower during the color-discrimination (1051 ms, *SD* = 150) than the simple reaction time (707 ms, *SD* = 170) tasks, $F(1, 180) = 892.46$, $p < .0001$, $\eta_p^2 = .83$. The type of responses did not affect response times, $F < 1$, but the interaction between task and type of responses was significant, $F(1, 180) = 5.03$, $p < .03$, $\eta_p^2 = .03$. Indeed, the difference between color-discrimination task and simple reaction time task was larger in aloud than in silent response conditions. No other interactions were significant, *ps* > .22. To summarize these analyses in concurrent tasks, children in each age group paid enough attention to the concurrent task and achieved a high level of performance. Moreover, the color-discrimination task led to lower accuracy and longer response times than the simple reaction time task.

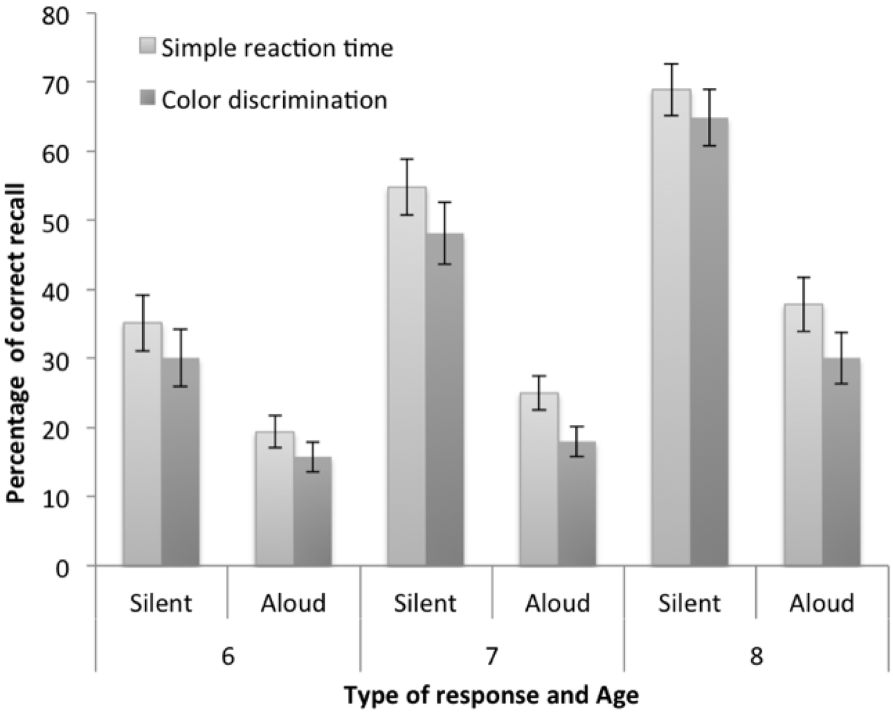

Figure 3. Percentage of correct recall according to the type of tasks (simple reaction time vs. color discrimination), the type of responses (keyed vs. oral) and the age. Error bars represent standard errors

Finally, an ANOVA was performed on the percentage of correct recall with the same design as the previous ANOVAs. As in Experiment 1, the three main effects were significant (Figure 3). Recall performance significantly increased with age, with 34% (*SD* = 19) at 6, 41% (*SD* = 23) at 7 and 48% (*SD* = 25) at 8, $F(2, 180) = 9.95$, $p < .0001$, $\eta_p^2 = .10$; all differences between two age groups being significant, *ps* < .05 with Bonferroni correction, except between 6 and 7, $p = .14$. The type of response had a huge detrimental effect on recall with poorer recall when response was aloud (29%, *SD* = 16) than silent (53%, *SD* = 22), $F(1, 180) = 96.65$, $p < .0001$, $\eta_p^2 = .35$. Recall performance was also reduced when increasing the concurrent attentional demand, as the color-discrimination task (38%, *SD* = 24) yielded lower recall performance than simple reaction time task (44%, *SD* = 22), $F(1, 180) = 21.07$, $p < .0001$, $\eta_p^2 = .11$. Finally, the type of response and the effect of the concurrent task did not interact with age, *Fs* < 1, both *p*BIC(H0|D) = .99, and the interaction between type of response and concurrent task, as well as the 3-way interaction were not significant, *Fs* < 1, *p*BIC(H0|D) = .92 and *p*BIC(H0|D) = .99, respectively. Although several changes were introduced from Experiment 1, the main findings previously observed were replicated. We discussed in turn these three main findings in the General Discussion.

4. General Discussion

The aim of the present study was to examine the contribution of articulatory rehearsal and attentional refreshing in children's verbal working memory. Contrasting with the large amount of studies exploring the implication of these mechanisms in adults, only two studies investigated it in children (Mora & Camos, 2015; Tam et al., 2010).

Besides the differences in the experimental design, a very congruent pattern of findings emerged from the two reported experiments.

First, the introduction of a concurrent articulation in the two experiments led to a reduction of recall performance whatever the age of our participants. In line with Baddeley's (1986) model of working memory, we introduced a concurrent articulation to impede articulatory rehearsal because they use similar language production processes. It should be noted that accuracy was higher when children gave aloud responses to the concurrent tasks than only pressing keys. Although this was not expected, it is well-known that labeling helps children even in more difficult tasks when, for example, they have to switch between two tasks (e.g., Karbach & Kray, 2007). However for our current proposal, this suggests that the reduced recall performance under aloud responses could not result from a higher attentional demand of this type of response, which induced a dual response, i.e., speaking out the responses while pressing keys. It should also be noted that, contrary to Tam et al. (2010) in which verbal concurrent task could impede both rehearsal and refreshing, our design allowed a clear distinction between the effects of impediment one or the other mechanism, and thus provided a cleaner assessment of the impact of a concurrent articulation on children's recall performance. Although we used different memoranda that could elicit a more or less verbal encoding of information (i.e., visually-presented consonants in Experiment 1, or auditory-presented words in Experiment 2), even the younger children aged 6 recalled less information when they performed a concurrent articulation. This finding is congruent with recent studies showing that children younger than 7 could use rehearsal (e.g., Henry et al., 2012; Tam et al., 2010). These studies question the existence of a qualitative change in maintenance mechanisms. This conception suggests that children before 7 use a visual encoding and maintenance of information while children after 7 favor a verbal processing of memoranda (e.g., Gathercole et al., 1994). In the present study, introducing a concurrent articulation by asking children to respond aloud reduced recall performance at any age.

Our second set of findings documented the role of attention in children's working memory. Varying the availability of attention by presenting different attention-demanding tasks affected recall performance in children from 6 years of age onwards. In line with Tam et al. (2010), children as young as 6 would thus be able to use refreshing. This conclusion is also supported by the absence of interaction between the effect of manipulating concurrent attentional demand and age in both experiments. In a similar vein, Bertrand and Camos (2015) have shown that recall performance in children aged 4 to 6 is also reduced by increasing concurrent attentional demand. Using a game-like task, which asked to do some grocery shopping, children were less able to pick the correct fruits when the path to the shop was made difficult (stepping on plastic pads instead of walking straight to the shop). The authors proposed that controlling the walk captures children's attention, which cannot consequently be dedicated to the maintenance of the to-be-collected fruits. Contrary to previous claim (e.g., Barrouillet et al., 2009), young children could use attention for maintenance purpose.

Finally, the present study was the first to examine through a fully crossed design the interactions between refreshing and rehearsal through different ages. In two experiments, we observed no interaction between the availability of language processes and attention, which did not interact with age in the age range studied here (i.e., from 6 to 9). Although their manipulation of the concurrent articulation was different, the present result replicated what Mora and Camos (2015) found in 8-year-old children who maintained words while performing a location judgment task. This suggests that two systems, a language-based system and an attentional system, have independent effect in the maintenance of verbal information in children, as it was evidenced in adults (cf. Camos & Barrouillet, 2014, for a review). Moreover, Tam et al. (2010) reported that a verbal concurrent task, which impedes the two systems, had a stronger detrimental effect on recall than a non-verbal task that blocks the attentional system only. This fact is perfectly congruent with the existence of two independent systems that could have joint effect on children's working memory.

To conclude, previous works provided evidence that the maintenance of verbal information in working memory relies on two independent mechanisms in adults. The present study showed that same structure with two independent mechanisms is in charge of maintaining verbal information in children's working memory from 6 years of age. As in many countries, children are enrolled in primary schools and formal teaching around 6 or 7 years, it would be interesting to question the role of each of these mechanisms in learning. More specifically, maintenance through refreshing would favor the long-term retention of information whereas rehearsal would only be beneficial to short-term maintenance. While some evidence was gathered in adults (e.g., Camos & Portrat, 2015), studies in children are still missing.

Acknowledgements

The authors thank the Direction de l' Instruction Publique for their help in this study as well as the staff of the schools from Attalens, Bulle-Morlon, Courtepin, Estavayer-le-lac, Porrentruy and Romont, and Dr. Vanessa Loaiza for her careful reading of the manuscript.

References

Al-Namlah, A. S., Fernyhough, C., & Meins, E. (2006). Sociocultural influences on the development of verbal mediation: Private speech and phonological recoding in Saudi Arabian and British samples. *Developmental psychology*, *42*(1), 117. http://dx.doi.org/10.1037/0012-1649.42.1.117

Baddeley, A. D. (1986). *Working Memory*. Oxford: Oxford University Press.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General*, *133*(1), 83-100. http://dx.doi.org/10.1037/0096-3445.133.1.83

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(3), 570-585. http://dx.doi.org/10.1037/0278-7393.33.3.570

Barrouillet, P., & Camos, V. (2015). *Working memory: Loss and reconstruction*. Hove, UK: Psychology Press.

Barrouillet, P., Gavens, N., Vergauwe, E., Gaillard, V., & Camos, V. (2009). Working memory span development: A time-based resource-sharing model account. *Developmental Psychology*, *45*(2), 477-490. http://dx.doi.org/10.1037/a0014615

Bertrand, R., & Camos, V. (2015). The role of attention in preschoolers' working memory. *Cognitive Development*, *33*, 14-27. http://dx.doi.org/10.1016/j.cogdev.2014.10.002

Camos, V. (2015). Storing verbal information in working memory. *Current Directions in Psychological Science*, *24*, 440-445. http://dx.doi.org/10.1177/0963721415606630

Camos, V., & Barrouillet, P. (2011). Developmental Change in Working Memory Strategies: From Passive Maintenance to Active Refreshing. *Developmental Psychology*, *47*(3), 898-904. http://dx.doi.org/10.1037/a0023193

Camos, V., & Barrouillet, P. (2014). Attentional and non-attentional systems in the maintenance of verbal information in working memory: The executive and phonological loops. *Frontiers in Human Neuroscience*, *8*, 900. http://dx.doi.org/10.3389/fnhum.2014.00900

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. *Journal of Memory and Language*, *61*(3), 457-469. http://dx.doi.org/10.1016/j.jml.2009.06.002

Camos, V., Mora, G., & Oberauer, K. (2011). Adaptive choice between articulatory rehearsal and attentional refreshing in verbal working memory. *Memory & Cognition*, *39*(2), 231-244. http://dx.doi.org/10.3758/s13421-010-0011-x

Camos, V., & Portrat, S. (2015). The impact of cognitive load on delayed recall. *Psychonomic Bulletin and Review*, *22*, 1029-1034. http://dx.doi.org/10.3758/s13423-014-0772-5

Chalard, M., Bonin, P., Meot, A., Boyer, B., & Fayol, M. (2003). Objective age-of-acquisition (AoA) norms for a set of 230 object names in French: Relationships with psycholinguistic variables, the English data from Morrison et al. (1997), and naming latencies. *European Journal of Cognitive Psychology*, *15*(2), 209-245. http://dx.doi.org/10.1080/09541440244000076

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. http://dx.doi.org/10.2307/1126804

Gaillard, V., Barrouillet, P., Jarrold, C., & Camos, V. (2011). Developmental differences in working memory: Where do they come from? *Journal of Experimental Child Psychology*, *110*, 469-479. http://dx.doi.org/10.1016/j.jecp.2011.05.004

Gathercole, S. E., & Adams, A. (1993). Phonological working memory in very young children. *Developmental Psychology*, *20*, 770-778. http://dx.doi.org/10.1037/0012-1649.29.4.770

Gathercole, S. E., Adams, A., & Hitch, G. J. (1994). Do young children rehearse? An individual-differences analysis. *Memory & Cognition*, *22*, 201-207. http://dx.doi.org/10.3758/BF03208891

Henry, L. A., Messer, D., Luger-Klein, S., & Crane, L. (2012). Phonological, visual, and semantic coding strategies and children's short-term picture memory span. *Quarterly Journal of Experimental Psychology*, *65*(10), 2033-2053. http://dx.doi.org/10.1080/17470218.2012.672997

Hitch, G. J., Halliday, M. S., Schaafstal, A. M., & Heffernon, T. M. (1991). Speech, inner speech, and the development of short term memory: The effect of picture labelling on recall. *Journal of Experimental Child Psychology*, *51*(2), 220-234. http://dx.doi.org/10.1016/0022-0965(91)90033-O

Hudjetz, A., & Oberauer, K. (2007). The effects of processing time and processing rate on forgetting in working memory: Testing four models of the complex span paradigm. *Memory & Cognition*, *35*(7), 1675-1684. http://dx.doi.org/10.3758/BF03193501

Jarrold, C., & Tam, H. (2011). Rehearsal and the development of working memory. In P. Barrouillet, & V. Gaillard (Eds.), *Cognitive development and working memory: A dialogue between neo-Piagetian theories and cognitive approaches* (pp. 177-199). Hove, UK: Psychology Press.

Johnson, M. K., Raye, C. L., Mitchell, K. J., Greene, E. J., Cunningham, W. A., & Sanislow, C. A. (2005). Using fMRI to investigate a component process of reflection: Prefrontal correlates of refreshing a just-activated representation. *Cognitive Affective & Behavioral Neuroscience*, *5*(3), 339-361. http://dx.doi.org/10.3758/CABN.5.3.339

Karbach, J., & Kray, J. (2007). Developmental Changes In Switching Between Mental Task Sets: The Influence Of Verbal Labeling In Childhood. *Journal of Cognition and Development*, *8*(2), 205-236.

Magimairaj, B. M., & Montgomery, J. W. (2012). Children's verbal working memory: Relative importance of storage, general processing speed, and domain-general controlled attention. *Acta Psychologica*, *140*(3), 196-207. http://dx.doi.org/10.1016/j.actpsy.2012.05.004

Masson, M. E. J. (2011). A tutorial on a practical Bayesian alternative to null-hypothesis significance testing. *Behavioral Research Methods*, *43*, 679-690. http://dx.doi.org/10.3758/s13428-010-0049-5

Mora, G., & Camos, V. (2015). Dissociating Rehearsal and Refreshing in the Maintenance of Verbal Information in 8-Year-Old Children. *Frontiers in Psychology*, *6*, 11. http://dx.doi.org/10.3389/fpsyg.2015.00011

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). A lexical database for contemporary french on internet: Lexique. *L' Année Psychologique*, *101*(3), 447-462. http://dx.doi.org/10.3406/psy.2001.1341

Peereman, R., Lété, B., & Sprenger-Charolles, L. (2007). Manulex-Infra: Distributional characteristics of grapheme-phoneme mappings, infra-lexical and lexical units in child-directed written material. *Behavioral Resources Methods*, *39*, 579-589. http://dx.doi.org/10.3758/BF03193029

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, 174-215. http://dx.doi.org/10.1037/0278-7393.6.2.174

Tam, H., Jarrold, C., Baddeley, A. D., & Sabatos-DeVito, M. (2010). The development of memory maintenance: Children's use of phonological rehearsal and attentional refreshment in working memory tasks. *Journal of Experimental Child Psychology*, *107*(3), 306-324. http://dx.doi.org/10.1016/j.jecp.2010.05.006

Trapp, S., Mueller, K., Lepsien, J., Krämer, B., & Gruber, O. (2014). Different neural capacity limitations for articulatory and non-articulatory maintenance of verbal information. *Experimental Brain Research*, *232*(2), 619-628. http://dx.doi.org/10.1007/s00221-013-3770-3

Trost, S., & Gruber, O. (2012). Evidence for a double dissociation of articulatory rehearsal and non-articulatory maintenance of phonological information in human verbal working memory. *Neuropsychobiology*, *65*(3), 133-140. http://dx.doi.org/10.1159/000332335

Note

Note 1. Because p-values do not provide evidence in favor of the null hypothesis, we computed the Bayesian Information Criteria (BIC) for the non-significant effects. A probability above .75 is conceived as positive evidence that the null hypothesis is true (Masson, 2011).