The use of attention to maintain information in working memory: a developmental investigation of spontaneous refreshing in school-aged children

Vergauwe, Evie; Besch, Vincent; Latreche, Caren; Langerock, Naomi

This publication URL: https://archive-ouverte.unige.ch/unige:150831
Publication DOI: 10.1111/desc.13104

DRAFT APPROVED FOR PUBLICATION IN DEVELOPMENTAL SCIENCE

Vergauwe, E., Besch, V., Latrèche, C., & Langerock, N. (2021). The use of attention to maintain information in working memory: A developmental investigation of spontaneous refreshing in school-aged children. *Developmental Science*, e13104.

The use of attention to maintain information in working memory: A developmental investigation of spontaneous refreshing in school-aged children

Evie Vergauwe, Vincent Besch, Caren Latrèche, and Naomi Langerock

University of Geneva

Switzerland

Word count: 7’995

Running head: Spontaneous refreshing in children ?

Author Note

This work was supported by the Swiss National Science Foundation [Grant numbers PZ00P1_154911 and PCEFP1_181141 to Evie Vergauwe]. Correspondence should be sent to Evie Vergauwe, Université de Genève, Faculté de Psychologie et des Sciences de l’Education, 40 bd du Pont d’Arve, 1211 Genève 4, Switzerland, Evie.Vergauwe@unige.ch.

Conflict of interest

The authors have no conflict of interest to declare.

Data availability statement

All data will be available on Open Science Framework: https://osf.io/5cqwr/

Acknowledgments

The authors thank Noémie Avisse, Mathilde François, Helin Hazal, and Camille Pestiaux for assisting with data collection.

Research Highlights

- One proposed reason for the expansion of working memory capacity is the emergence of active maintenance mechanisms, such as refreshing, around the age of 7.
- Our results show that simply giving free time in a basic working memory task does not lead to spontaneous refreshing in 9- to 12-year-old children.
- When instructed to do so, children are able to switch their focus of attention away from the last-presented item to refresh another memory item.
- The conventional story of the development of refreshing in working memory needs important modifications to account for the current findings.

Abstract

The capacity of working memory is limited and undergoes important developmental changes during childhood. One proposed reason for the expansion of working memory capacity during childhood is the emergence and increased efficiency of active maintenance mechanisms, such as that of *refreshing*. Refreshing is a proposed mechanism to keep information active in working memory by bringing memory items back into the focus of attention. One prevalent view is that the spontaneous use of refreshing emerges around the age of 7, and becomes more efficient during middle childhood and beyond. Using a novel approach to examine refreshing in children in Experiment 1, we show, against common conceptions, that simply giving free time in a basic working memory task does not lead to spontaneous refreshing in 9 to 12 year old children. Instead, their focus of attention appears to linger on the last-presented memory item, even when ample time for refreshing is provided. Experimentally imposing the use of refreshing in Experiment 2, however, showed that children in this age range are able to switch their focus of attention away from the last-presented item in order to switch to another memory item. Thus, the current study uncovers that children in middle childhood do not always spontaneously switch attention away from the last-presented memory item to refresh the entire list, even though they are able to switch attention away from the last-presented memory item when instructed to do so. The theoretical implications of these findings are discussed.

Keywords: working memory; attention; refreshing; focus of attention; short-term storage

Goal-directed behavior rests on the ability to maintain a small amount of information over brief periods of time, such that information that is no longer present in the immediate environment can still guide behavior. The cognitive system that keeps information temporarily accessible and available is referred to as working memory. Working memory capacity is limited and undergoes important developmental changes during childhood. This development is reflected in an age-related increase in working memory performance, reaching adult-like levels around the age of 15 years, depending on the task (Gathercole, Pickering, Ambridge, & Wearing, 2004). Working memory is involved in early learning, academic achievement, and classroom behavior (e.g., Bull & Scerif, 2001; De Smedt et al., 2009; St Clair-Thompson & Gathercole, 2006). Understanding why working memory performance improves with age has thus both theoretical and practical implications.

One proposed reason for the expansion of working memory capacity during childhood is the emergence of active maintenance mechanisms (e.g., Camos & Barrouillet, 2011; Dempster, 1981; Gathercole & Adams, 1994; Magimairaj & Montgomery, 2012; Shimi & Scerif, 2017). Inspired by the multiple-component model (Baddeley & Hitch, 1974; Baddeley & Logie, 1999), there has been much focus, historically, on the emergence of domain-specific maintenance mechanisms. In particular, a qualitative shift in the spontaneous use of speech-based rehearsal is proposed around the age of 7 years (Flavell, Beach, & Chinsky, 1966; see also Baddeley, Gathercole, & Papagno, 1998), and this abrupt onset of speech-based rehearsal is assumed to contribute to the developmental increase in children's working memory capacity (e.g., Gathercole, 1998; Gathercole & Adams, 1994; Hitch, Woodin, & Baker, 1989).

More recently, several researchers have also proposed the existence of a more domain-general maintenance mechanism in working memory, called *refreshing* (e.g., Barrouillet et al., 2009 ; Higgins & Johnson, 2009; Shimi & Scerif, 2017; Vergauwe & Cowan, 2014). Refreshing refers to an attention-based mechanism for short-term maintenance and, similar to the qualitative shift proposed for speech-based rehearsal, it has been proposed that the spontaneous use of attentional refreshing emerges around the age of 7 years (e.g., Barrouillet et al., 2009; Camos & Barrouillet, 2011). Refreshing is assumed to be similar in many respects to speech-based rehearsal, but is domain-general and not specifically related to speech. Instead, refreshing is proposed to operate by bringing representations into the focus of internal attention (e.g., Barrouillet & Camos, 2012; Cowan, 1995; Higgins & Johnson, 2009; Vergauwe & Cowan, 2014). To maintain a list of items, refreshing operates serially, with the focus of attention cycling from one item to the next, thereby sequentially boosting the list items (e.g., Barrouillet & Camos, 2012; Cowan, 2011; Nee & Jonides, 2013; Vergauwe, 2018; Vergauwe, Camos, & Barrouillet, 2014). The act of refreshing a list item, or “thinking of” a list item, is assumed to result in the list item becoming highly accessible again in working memory and this, in turn, is proposed to protect the information from being forgotten (see Camos et al., 2018, for a recent review). The development of refreshing is assumed to play an important role in working memory improvement during childhood (e.g., Barrouillet et al., 2009; Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Gaillard, Barrouillet, Jarrold, & Camos, 2011; Shimi & Scerif, 2017).

Developmental differences in refreshing

One prevalent view is that young children do not yet engage in attention-based refreshing, and that the spontaneous use of refreshing emerges around the age of 7 years (e.g., Barrouillet et al., 2009; Camos & Barrouillet, 2011). At least three findings support this view. First, in line with the idea that children older than 7 use refreshing to maintain a list of items, it has been shown that their recall performance suffers when an attention-demanding task is to be performed during retention (e.g., Bayliss et al., 2003; Tam, Jarrold, Baddeley, & Sabatos-DeVito, 2010), and that the decrease in recall performance is a direct function of the attentional demands of concurrent processing in children between 8 and 14 years old

(Barrouillet et al., 2009). Second, in support of the idea that active maintenance in children's working memory relies on domain-general attentional resources, it has been shown that children's recall performance for verbal lists (e.g., lists of digits or words) is hindered by concurrent attention-demanding activities, even when these activities are nonverbal (e.g., Anderson, Bucks, Bayliss, & Della Sala, 2011; Mora & Camos, 2015; Portrat, Camos, & Barrouillet, 2009; Tam et al., 2010). And third, in line with the idea that refreshing emerges around the age of 7, a detrimental effect of concurrent attentional demands on memory performance has been shown in 7 year olds, but not in 5 year olds (Barrouillet et al., 2009; Camos & Barrouillet, 2011). Under the assumption that the decrease in recall performance reflects the disruption of refreshing by a concurrent attention-demanding task (see Barrouillet et al., 2009; Hudjetz & Oberauer, 2007; Jarrold, Tam, Baddeley, & Harvey, 2011; Ricker & Cowan, 2010; but see Doherty et al., 2019; Oberauer et al., 2012), this set of findings supports the view that attentional refreshing emerges around the age of 7 years.

In addition to the developmental shift in the spontaneous use of refreshing around the age of 7, a developmental improvement in the efficiency of refreshing has been proposed to occur during middle childhood and beyond. This proposal is based on the observation that the detrimental effect of concurrent attention-demanding processing on recall performance increases gradually between the ages of 8 and 14 years (Barrouillet et al., 2009; Gaillard et al., 2011; see Bayliss et al., 2005, for a similar proposal in children between 6 and 10 years old). Taken together, the picture that arises from the current literature is that refreshing undergoes a qualitative shift around the age of 7 (when refreshing emerges), followed by quantitative changes between the ages of 8 and 14 (when refreshing becomes more efficient).

However, a more detailed look at the available data suggests that the development of refreshing may be more complicated than previously thought. Two sets of observations are particularly relevant here. First, Bertrand and Camos (2015) observed that even much younger children (4- to 6-year old children) can be sensitive to an increase of the attentional demands of concurrent processing in a playful context. Similarly, Tam et al. (2010) observed verbal memory performance to be disrupted by a concurrent attention-demanding non-verbal task in 6 year olds. Thus, attention-based effects, typically associated with refreshing, can be detected before the age of 7. Second, Tam et al. (2010) found that the disruptive effect of concurrent processing on recall performance in 6 year olds was not different from that observed in 8 year olds, indicating that refreshing does not develop much in this age range (see also Anderson et al., 2011; Conlin, Gathercole, & Adams, 2005). This echoes a set of more recent findings in children between 6 and 8-9 years old (Oftinger & Camos, 2016, 2017, 2018), showing that attention-based effects typically associated with refreshing do not consistently increase after the age of 7. Given these inconsistent findings and the potentially important role of refreshing in working memory development, further research on developmental differences in refreshing is needed.

Refreshing in children has predominantly been examined through the disruptive effect of attention-demanding processing on memory performance in dual-task situations, especially in verbal working memory. Recently, in the adult literature, Vergauwe and Langerock (2017) have proposed an alternative approach to examining refreshing, which (1) does not require the presence of a concurrent processing task and thus, allows the use of very basic working memory tasks, and (2) infers the occurrence of refreshing from a specific pattern in response times (see below) and thus, avoids the use of memory accuracy to infer the use of refreshing, while memory performance is the to-be-explained behavior. The current study proposes to use this novel approach to examine developmental differences in refreshing during childhood.

A novel paradigm to assess the occurrence of refreshing

Vergauwe and Langerock (2017) presented short series of letters, followed by a probe letter which needed to be judged present in or absent from the list presented (i.e., item recognition task, see Sternberg, 1966). They manipulated the presentation rate, such that letters were presented at either a fast or a slow rate. The rationale was that, with fast presentation, there is no time for refreshing in between the successive letters. As a result, with fast presentation, the last-presented letter remains in the focus of attention. In this case, because the item in the focus of attention is assumed to be in a privileged state of heightened accessibility (e.g., Basak & Verhaeghen, 2011; McElree, 2006; Nee & Jonides, 2008; Oberauer & Hein, 2012), Vergauwe and Langerock (2017) expected that responses to probes matching the final letter should be speeded, relative to responses to probes matching any of the other to-be-remembered letters (i.e., last-presented RT benefit). With slow presentation, however, there is time to refresh the to-be-remembered letters. As a result, with slow presentation, if refreshing occurs spontaneously, the last-presented letter is replaced in the focus of attention. In this case, the focus of attention is assumed to rotate among the different to-be-remembered letters in working memory, and thus, Vergauwe and Langerock (2017) no longer expected speeded responses to probes matching the final to-be-remembered letter (i.e., abolishment of last-presented RT benefit). Using this paradigm in adults, Vergauwe and Langerock (2017) indeed found a last-presented RT benefit when list items were presented quickly one after another (350ms/letter), indicating that the last-presented item remains in the focus of attention when there is no time for refreshing to occur. However, the last-presented RT benefit disappeared when approximatively three times more time was provided (1000ms/letter), indicating that the last-presented item had been replaced in the focus of attention and thus, that refreshing had occurred spontaneously.

The current study

The current study proposes to use the approach of Vergauwe and Langerock (2017) to examine developmental differences in the spontaneous use of refreshing in children. We used this approach in children for whom, based on the literature, it could be reasonably expected that spontaneous refreshing would occur. Therefore, we tested 9 and 12 year old children. We expected to show spontaneous refreshing at both ages. However, to anticipate, in Experiment 1, we did not detect spontaneous refreshing, neither in the 9-year-olds, nor in the 12-year-olds. Even when the lists were presented much more slowly, we found overwhelming evidence for a last-presented RT benefit, indicating that the focus of attention lingered on the last-presented memory item in both age groups. Initially, we were planning to follow up by testing increasingly younger children, thereby testing whether a qualitative shift could be detected around the age of 7. However, to follow up on the surprising findings in Experiment 1, rather than testing spontaneous refreshing in earlier childhood, we next tested, in Experiment 2, whether children in middle childhood can switch their attention away from the last-presented item towards another memory item when explicitly instructed to do so, using refreshing cues to guide children's attention.

EXPERIMENT 1

Children of 9 and 12 years old were presented with lists of four to-be-remembered letters, and had to judge whether the probe letter corresponded to any of the list items. The rate of list presentation was manipulated, to allow refreshing to come online when more time is available. In the Fast condition, timings were chosen to be somewhat slower than what had been used in adults. Thus, we reasoned that 1 letter every 500ms would be enough time for the child to encode the to-be-remembered letter, but not to switch their attention to another memory item to start refreshing. For both age groups, we expected to find strong evidence for a last-presented RT benefit in the Fast condition, showing that the last-presented item remains in the focus of attention when there is no time for refreshing to occur. In the Slower condition, letters were presented three times more slowly (1 letter every 1500ms), to allow refreshing to occur. For both age groups, we expected to find evidence for the spontaneous occurrence of refreshing, reflected in the abolishment of the last-presented benefit in the Slower condition, with the possibility of a more pronounced disappearance of the benefit in the older children if they are more efficient in refreshing. Because no evidence for refreshing was found when the presentation rate was three times slower, we ran an additional condition in which the presentation rate was further slowed down, resulting in a rate of 1 letter every 2500ms.

Method

Participants and Design. A total of 187 children participated in this experiment. In a first wave of data collection, 126 children participated: 60 children from 5th grade (30 girls; M = 9.13 years old, SD = .39, "9-year-olds" henceforth) and 66 children from 8th grade (30 girls; M = 11.96 years old, SD = .30, "12-year-olds" henceforth). Children were randomly assigned to either the Fast condition (500ms/memory item) or the Slow condition (1500ms/memory item), such that about half of the 9-year-olds (31 out of 60) and about half of the 12-year-olds (32 out of 66) performed the task with fast presentation times, while the remaining children performed the task with slow presentation times (29 9-year-olds, and 34 12-year-olds). After analyzing the data of the first wave, we decided to test an additional group of 61 children for whom we slowed down the presentation rate even more (2500ms/memory item; Much slower condition): 31 children from 5th grade (16 girls; M = 9.34 years old, SD = .39) and 30 children from 8th grade (18 girls; M = 12.10 years old, SD = .33) participated in this second wave of data collection. All children were recruited from Geneva public schools via an opt-in procedure. Prior to testing, we obtained (1) authorization from the Geneva Department of Public Instruction to carry out our study in Geneva public schools, (2) ethical approval from the appropriate Research Ethics Board at the University of Geneva, and (3) written informed consent from the parents/guardians of the children. All children had normal or corrected-to-normal vision.

Materials and Procedure. The task was presented on a laptop and was administered using E-prime software (Psychology Software Tools). Children sat at a comfortable distance from the screen. They were asked to watch carefully and memorize series of four letters presented sequentially, chosen randomly without replacement from a set of 18 consonants (all except W, Y, and Z). At the end of each trial, a probe letter was shown for which the children had to indicate whether it corresponded to one of the four to-be-remembered letters presented in the current trial.

Like in Vergauwe and Langerock (2017), to-be-remembered letters were presented in 4 boxes on screen (see Figure 1). These boxes were presented in two rows of two boxes, one row presented in the upper part of the screen and another row in the lower part of the screen. The size of each box was about 4.5cm wide X 3.5cm high and each box had a thin, black border line. Each letter was presented in the center of one of these boxes, in upper case (see Panel B of Figure 1), approximately 2cm wide X 2.5cm high. The presentation time of the letters differed between the three experimental conditions of the experiment: one letter every 500ms in the Fast condition, one letter every 1500ms in the Slow condition, and one letter every 2500ms in the Much slower condition.

Each series began with the presentation of a fixation cross centrally displayed. After 500ms, the four boxes appeared, with the first to-be-remembered letter shown in the upper-left box. Next, the first to-be-remembered letter disappeared while the second to-be-remembered letter was presented in the upper-right box. This continued for the third letter shown in the lower-left box and the fourth letter in the lower-right box. This clock-wise sequence of presentation was the same across all trials, and for all participants. The fixation cross and four boxes remained on screen until probe presentation. In the Fast condition, each to-be-remembered letter was displayed for 400ms, followed by a screen leaving only the fixation cross and the four empty boxes on screen for 100ms (i.e., 1 letter every 500ms). In the Slow condition, we multiplied the presentation durations times of the Fast condition by 3, and thus, each to-be-remembered letter was displayed for 1200ms, followed by a screen with the fixation cross and the boxes on screen for 300ms (i.e., 1 letter every 1500ms). Finally, in the Much slower condition, we multiplied the presentation durations times of the Fast condition by 5, and thus, each to-be-remembered letter was displayed for 2000ms, followed by a screen with the fixation cross and the boxes on screen for 500ms (i.e., 1 letter every 2500ms). After the last fixation/empty boxes screen, each of the boxes was filled with a mask for 50ms. The mask was composed of a superposition of 3 letters (*A*, *I* and *O*) presented in Courier New font in uppercase, in the center of each of the four boxes, approximately 1.2cm wide X 1.2cm high. The mask was followed by the presentation of the probe, in the middle of the screen in an invisible box of 2cm wide x 3cm high. This probe consisted of a cursive letter in lower case and could correspond to (1) the last-presented letter (i.e., the fourth to-be-remembered letter; "last-presented probe" henceforth), (2) any of the to-be-remembered letters but the last-presented letter (i.e., the first, second or third to-be-remembered letter; "not-last-presented probe" henceforth), (3) a new letter (i.e., a letter that was not presented on the current trial; "new probe" henceforth). Note that the mask and different case for memory items and probes were used to disallow straightforward perceptual matching between the last-presented memory item and the probe (see also McElree & Dosher, 1989; Nee & Jonides, 2008; Vergauwe et al., 2018). Probe letters were sampled such that last-presented probes, not-last-presented probes, and new probes were equally often presented (i.e., 1/3 of the trials for each; serial positions 1, 2, and 3 had equal probability of being randomly selected as not-last-presented probe, each serial position appearing 6 or 7 times as probe), and remained on screen until a response was made or until 5000ms had elapsed. All stimuli were presented in black on a white background.

The children were instructed to decide whether the probe corresponded to any of the to-be-remembered letters presented in the current trial. This judgment was made by pressing the green button on the keyboard when the probe corresponded to any of the to-be-remembered letters (green sticker on the letter L) and pressing the red button on the keyboard when the probe did not correspond to any of the to-be-remembered letters (red sticker on the letter A). The overall keyboard was hidden by a paper cover leaving only the red and green buttons visible, to avoid key presses on irrelevant keys. Children were to judge the probe as fast as possible without making errors and initiated the next series by pressing the space bar.

A training phase preceded the experimental trials, to familiarize the children with the task, see Supplementary materials 1 for a detailed description. The children were asked to continue responding as they had been doing during training, and to keep their index fingers on the response keys to be able to respond as quickly as possible in the experimental trials. They performed 60 experimental trials (20 trials with a last-presented probe, 20 trials with a not-last-presented probe, and 20 trials with a new probe, randomly intermixed). Every 10 trials, an additional star was shown on screen so the child could follow their progress in the experiment (i.e., one star after 10 trials, two stars after 20 trials, and so on).

Performance-based exclusions. Following adult studies using the last-presented benefit to examine spontaneous refreshing, we planned to discard the data of participants whose average accuracy across the different probe types fell below 55% (see Vergauwe & Langerock, 2017). One child did not reach this criterion (a 9-year-old in the Much slower condition). Thus, the data of 186 children were included in the analyses reported below.[1]

Results

General performance. As expected, participants had high rates of correct responses across all probe types, and accuracy was better for the older children (84% vs. 89% in the Fast condition, 88% vs. 91% in the Slow condition, and 87% vs. 92% in the Much slower condition, for the 9-year-olds vs. the 12-year-olds, respectively)[2], see Table 1.

Analysis of Wave 1 participants' RT: Fast vs. Slow presentation. Only RTs of correct responses to the probes were included in the following analyses. As can be seen in

Figure 2, a clear last-presented benefit was apparent in both age groups and at both presentation rates. We ran a Bayesian analysis of variance (BANOVA; Rouder, Morey, Speckman, & Province, 2012) on correct RTs with Age group (9-year-old vs. 12-year-old), Presentation rate (Fast vs. Slow) as between-subject variables and Probe type (last-presented vs. not-last-presented) as independent within-subjects variable. The BayesFactor package for the R statistical analysis language was used with the default settings. Using these three variables, models were specified for each combination of main effects and interactions and the BANOVA computed the Bayes factors for each of these models. We used these Bayes factors to identify the best model (i.e., the model that yielded the highest Bayes factor). The best model was shown to only include a main effect of Age group, a main effect of Probe type, and an interaction between Age group and Probe type. The evidence for including the interaction between Age group and Probe type was very weak, $BF_{10} = 1.30$. The main effects can be seen in Figure 2; RTs were faster for older children, and RTs were faster for last-presented probes than for not-last-presented probes. Importantly, the best model was about 4 times better than a model that also included a main effect of presentation rate and about 15 times better than a model that also included the main effect of presentation rate as well as an interaction between presentation rate and Probe type. Finally, the best model was more than 50 times better than the full model including a triple interaction between Age group, Presentation rate, and Probe type. Thus, the last-presented benefit was not affected by presentation rate, and there were no developmental differences in this pattern.

To assess and quantify the evidence for a last-presented benefit more directly, we ran separate one-sided Bayesian t-tests for each experimental group, testing whether RTs to last-presented probes were faster than RTs to not-last-presented probes. T-tests were run using JASP (2019), with default settings. Doing so showed overwhelming evidence for a last-presented benefit in each group, see Table 2.

Analysis including Wave 2 participants' RT as well : Fast vs. Slow vs. Much slower presentation. As can be seen in Figure 2, a clear last-presented benefit was still apparent in the Much slower condition, for both age groups. We ran the aforementioned BANOVA on RTs, this time also including the data of the participants of Wave 2. Thus, in this BANOVA, Presentation rate had 3 levels (Fast vs. Slow vs. Much slower), rather than 2. The best model again included a main effect of Age group, a main effect of Probe type, and an interaction between Age group and Probe type. The evidence for including an interaction between Age group and Probe type was modest to strong (BF_{10} = 7.38); as can be seen in Figure 2, the last-presented benefit was larger in 9-year-olds than in 12-year-olds[3]. This time, the best model also included a main effect of Presentation rate (BF_{10} = 483.08); overall, responses were slower in the Much slower condition. Importantly, however, the best model did not include an interaction between Presentation rate and Probe type; including this interaction made the model about 14 times worse. Moreover, the best model was about 150 times better the full model, which also includes the triple interaction between Age group, Presentation rate, and Probe type. Thus, the last-presented benefit was not affected by presentation rate, and there were no developmental differences in this pattern. A more detailed break-down of the RTs can be found in Supplementary materials 2.

To assess the evidence for a last-presented benefit more directly in the two Much slower presentation rate groups, we ran two additional one-sided Bayesian t-tests for both experimental groups, testing whether RTs to last-presented probes were faster than RTs to not-last-presented probes. Doing so showed overwhelming evidence for a last-presented benefit in both groups with Much slower presentation rates, see Table 2.

Discussion

Experiment 1 used a novel approach to study refreshing in children, in which patterns of response times are used to assess the spontaneous occurrence of refreshing during list presentation. Against our expectations, we observed overwhelming evidence for speeded responses to the last-presented memory item, at all presentation rates, and for both age groups, suggesting that no spontaneous refreshing occurred. Exploratory analyses on a more individual level corroborate this conclusion; the proportion of children displaying a last-presented RT benefit does not decrease consistently with the increase of the rate of presentation rate (Supplementary materials 2), and thus, there is no evidence that more children spontaneously use refreshing when more time is available during list presentation. Overall, our results strongly suggest that 9 and 12 year old children's attention lingers on the last-presented memory item in a simple working memory task, even when ample time for refreshing is provided.

The observation that children in our study did not switch their attention away from the last-presented item to refresh the entire list during list presentation contrasts sharply with previous observations in adults in the same task situation (see Vergauwe & Langerock, 2017). The absence of spontaneous refreshing in a very basic working memory task, in 9 to 12 year old children, i.e., in a population for which it is typically assumed that refreshing is well in place, raises questions about the generality of refreshing as a strategy to maintain information in working memory, as well as about the role of refreshing in working memory development. Moreover, the absence of spontaneous refreshing in Experiment 1 raised the question of whether children in this age range *can* switch their attention away from the last-presented item towards another memory item when explicitly instructed to do so. To test this, we used refreshing cues between list and probe presentation, to guide 10-11 year old children's attention in Experiment 2.

EXPERIMENT 2

Experiment 2 aimed at testing whether children can switch their attention away from the last-presented item towards another memory item, when instructed to do so. Therefore, in Experiment 2, we used a similar task as in Experiment 1, and added refreshing cues to guide the children's attention from one memory item to the next (see Shimi et al., 2014, and Shimi & Scerif, 2017, for the use of attentional cues during maintenance to guide children's attention). Children were instructed to think of the cued list items sequentially, before the probe appears (see Vergauwe and Langerock, 2017, for a study using this approach in adults). We reasoned that, if 10-11 year old children can switch their attention away from the last-presented item, then, in sharp contrast to what was observed in Experiment 1, we should no longer observe a last-presented RT benefit in Experiment 2. Moreover, if 10-11 year old children can efficiently switch their attention towards another memory item, then we should observe speeded responses to the item that was cued to be refreshed. That is, if children can switch their attention efficiently from one letter to the next, then the just-refreshed item should be in the focus of attention when refreshing cues are presented. As a result, the just-refreshed item should be in a privileged state of accessibility, leading to speeded responses to probes matching that just-refreshed memory item, relative to probes matching any other memory item.

Method

Participants. A total of 39 children (25 girls) from 7th grade (M = 10.93 years old, SD = .40) took part in this experiment. All children were recruited from Geneva public schools using the same recruitment procedure as in Experiment 1. Prior to testing, we obtained (1) authorization from the Geneva Department of Public Instruction to carry out our study in Geneva public schools, (2) ethical approval from the appropriate Research Ethics Board at the University of Geneva, and (3) written informed consent from the parents/guardians of the children. All children had normal or corrected-to-normal vision.

Materials and Procedure. Like in Experiment 1, the task was presented to the children on a laptop and was administered using E-prime software. The same materials and procedure were used as in Experiment 1, except for the modifications described below. A moderate presentation rate was chosen. Each to-be-remembered letter was displayed for

750ms, followed by a screen showing the fixation cross and the empty boxes for 250ms (i.e., 1 letter every 1000ms).[4] Like in Experiment 1, after the last fixation/empty boxes screen, each of the boxes filled was filled with a mask for 50ms (same mask as in Experiment 1).

In contrast to Experiment 1, the mask was not immediately followed by the presentation of the probe. Instead, there was a delay before the presentation of the probe. Like in Vergauwe and Langerock (2017), the duration of the delay could be 1, 2, 3, 4 or 5 seconds and each duration was used equally often (12 times per Delay condition). During this delay, the boxes of the four to-be-remembered letters were presented on screen with the central fixation cross and the boxes were highlighted at a rate of one box per second, in the order of presentation (i.e., first the box where the first to-be-remembered letter was presented, followed by the box where the second to-be-remembered letter was presented, and so on) during the entire delay. Thus, for example, in the 3-sec delay of the Instructed-refreshing delay condition, first the upper-left box was highlighted for 1 sec, followed by the upper-right box for 1 sec, followed by the lower-left box for 1 sec, see Figure 3. Highlighting existed in the borderline of a box becoming thicker and red. Participants were instructed to think about the letter that was presented in that box when a box was highlighted (see Souza, Rerko, & Oberauer, 2015; Vergauwe, 2018; and Vergauwe & Langerock, 2017; for similar instructions). After the delay, the probe was presented. Like in Experiment 1, this probe consisted of a cursive letter in lower case, and like in Vergauwe and Langerock (2017), the probe corresponded in 1/3 of the trials to the just-refreshed letter, in 1/3 of the trials to any of the other to-be-remembered letters (on half of these trials, the last-presented letter was used, in the remaining half any of the to-be-remembered letters but the last-presented letter was used), and in 1/3 of the trial to a random new letter for that series. The probe remained on screen until a response was made or until 5000ms had elapsed. Response modalities were the same as in Experiment 1. Children were to judge the probe as fast as possible without making errors and initiated the next series by pressing the space bar.

A training phase preceded the experimental trials. The training phase was very similar to the one used in Experiment 1, except that the child was first trained on the memory task without refreshing cues before being trained in the memory task with refreshing cues (including an explanation, a visualization of a trial, trials at own pace, and trials at same pace as in experimental trials). Feedback was given as described in Experiment 1. Thereafter, the experimental trials started and it was explained that, from that point on, no more feedback would be given. The children were asked to respond to the experimental trials as they had been doing during the last part of the training and then performed the 60 experimental trials (20 trials with a just-refreshed probe, 20 trials with a not-just-refreshed probe, and 20 trials with a new probe, randomly intermixed). Like in Experiment 1, every 10 trials, an additional star was shown on screen so they could follow their progress.

Performance-based exclusions. Like in Experiment 1, and following adult studies, we planned to discard the data of participants whose average accuracy across the different probe types fell below 55% (see Vergauwe & Langerock, 2017). One child did not reach this criterion. Next, like Vergauwe & Langerock (2017), we verified participants' precise compliance with the refreshing instructions. Because it is important that participants judged whether the probe matches any of the memory items, rather than judging whether the probe matches the just-refreshed memory item, we planned to exclude the data of participants who scored below 55% on target-present probes that did not match the just-refreshed memory item. No participants had to be excluded due to this criterion and thus, the data of 38 children were included in the analyses reported below.

Results and Discussion

General performance. The children had high rates of correct responses to the probes, with mean overall accuracy of 90% (90% for just-refreshed probes, 93% for new probes, and 86% for not-just-refreshed probes, regardless of whether not-just-refreshed probes matched the last-presented-letter or another list item).

Analysis of last-presented benefit in RT. To test the evidence for or against a last-presented benefit when refreshing is instructed, we compared correct RTs to probes matching the last-presented item to correct RTs to target-present probes that did not match the last-presented item. Like in Vergauwe & Langerock (2017), target-present probes matching the just-refreshed item were excluded from this analysis. Like in Experiment 1, a one-sided Bayesian *t*-test was run in JASP with default settings. As can be seen in Figure 4, when cues were used to instruct the use of refreshing, strong evidence is found against a last-presented benefit (BF_{01} = 12.69). This shows that, under refreshing instructions, the focus of attention can be switched away, and thus no longer lingers on the last-presented item.

Analysis of just-refreshed benefit in RT. Our study also allowed us to assess the evidence in the data for a just-refreshed benefit. Therefore, we compared correct RTs to probes matching the just-refreshed item to correct RTs to target-present probes that did not match the just-refreshed item. A one-sided Bayesian *t*-test was run in JASP with the default settings. This showed that, even though descriptively RTs were slightly shorter for just-refreshed items than for not-just-refreshed probes (25 ms faster; 1187 vs. 1212 ms), there was no evidence in the data for a just-refreshed benefit, with an inconclusive Bayes factor of 1.97 against the described difference in RT.

The abolishment of the last-presented benefit under instructed refreshing shows that children are able, upon a cue, to switch their focus of attention away from the last-presented item. The fact that, overall, this was not accompanied by a just-refreshed benefit suggests that children may be less efficient in focus switching, relative to adults for whom a just-refreshed benefit was observed by Vergauwe and Langerock (2017). The results of additional, exploratory analyses show some evidence for a just-refreshed benefit when children needed to switch to the first item of the list, which is consistent with the idea that instructed refreshing resulted in replacing the last-presented item by another list item in the focus of attention, at least for the first list item (see Supplementary materials 3).

GENERAL DISCUSSION

The current study used a novel approach to examine refreshing in school-aged children. Using response times to infer the spontaneous use of refreshing, we observed, in sharp contrast with previous observations in young adults (Vergauwe & Langerock, 2017), that simply giving more free time in a simple working memory task does not lead to the spontaneous use of refreshing in 9 to 12 year old children (Experiment 1). Indeed, our results indicate that 9 to 12 year olds do not spontaneously switch attention away from the last-presented memory item to refresh the entire list, even when there is ample time. Importantly, our results further show that children in this age range *can* switch their focus of attention away from the last-presented item, when instructed to do so[5]. They further suggest that the ability to switch the focus of attention flexibly from one memory item to another, to refresh memory items sequentially, may not be optimally efficient yet. These findings have important theoretical implications concerning (1) children's spontaneous use of refreshing, (2) childhood development of refreshing and its role in working memory development, and (3) the relation between attention and working memory in children, addressed in turn, below.

Children's spontaneous use of refreshing to maintain information in working memory

The current results suggest strongly that the spontaneous use of refreshing is not as general in children as previously assumed. Indeed, whereas previous studies found evidence for spontaneous refreshing in school-aged children (e.g., Barrouillet et al., 2009; Gaillard et al., 2011; Portrat et al., 2009), we found evidence against spontaneous refreshing in 9- to 12-year old children. There are, however, at least two important differences between the previously published studies and the current study.

The first difference is concerned with the specific task situation in which refreshing is examined. Indeed, specific consideration of the precise task requirements is necessary when interpreting performance across different paradigms (Macken, Taylor, & Jones, 2015). Whereas previous studies have used quite complex tasks, our study used a fairly simple task. In previous studies, children were required to reproduce the entire memory list and to carry out an attention-demanding processing task during list presentation. In our task, children were required to judge a memory probe, and there was no concurrent processing task. It is possible that the spontaneous use of refreshing in children depends on specific task requirements, such that they spontaneously refresh in more complex tasks, but not in more basic tasks. In adults, too, boundary conditions have been observed to spontaneous refreshing (e.g., Vergauwe et al., 2016; Vergauwe, Langerock, & Cowan, 2018). The task characteristics determining whether or not refreshing is spontaneously used in 9- to 12-year olds appear to be different, however, than those in young adults. Indeed, using the same task as in the current study, Vergauwe and Langerock (2017) did observe spontaneous refreshing in undergraduate students. Assuming that task characteristics matter for spontaneous refreshing in children implies that refreshing is less general than previously thought. Uncovering the boundary conditions of spontaneous refreshing in children will then be important to understand in which circumstances an account in terms of time-based forgetting and refreshing is viable to explain the limited capacity of working memory in children, and the improvement of working memory capacity during childhood.

The second difference between studies is concerned with the index used to assess the spontaneous occurrence of refreshing. Whereas previous studies have used patterns in recall accuracy to infer whether concurrent attention-demanding processing has disrupted working memory maintenance or not, our study used patterns in response times to infer whether the last-presented memory item is still in the focus of attention or not. One could argue that the accuracy index assesses a broad implementation of refreshing, by which the disruption of any attention-demanding activity towards maintenance can be taken as evidence for refreshing, whereas our response time index assesses a specific implementation of refreshing, that of serial refreshing. In that case, it could be hypothesized that, in children, refreshing is occurring during list presentation (resulting in disruptive effects of attention-demanding activities as measured via the accuracy index), but refreshing operates on the last-presented item, rather than on the entire list (resulting in a continued last-presented benefit as measured via the response times index). In contrast, in adults, refreshing operates on the entire list, resulting in the observation of disruptive effects of attention-demanding activities together with the abolishment of the last-presented benefit. This would, however, require a drastic change in the basic, and commonly-accepted, assumptions about the operation and content of refreshing. Moreover, it would imply that, from childhood to young adulthood, what changes with age is the specific working memory content on which the focus of attention operates to support maintenance. This would imply a drastic change in the conventional view on the development of refreshing.

The development of refreshing and its role in working memory development

As described in the introduction, the conventional view on the development of refreshing is one whereby its spontaneous use emerges around the age of 7, followed by an increase in its efficiency in middle childhood and beyond (e.g., Barrouillet et al., 2009). Our results appear to contradict this conventional story in at least two ways: (1) in contrast with the idea that refreshing is used spontaneously from the age of 7 onwards, we found evidence against spontaneous refreshing in 9- and 12-year-olds, and (2) in contrast with the idea that refreshing undergoes quantitative increases in middle childhood, no developmental differences were observed between 9- and 12-year-olds when it comes to refreshing.

It appears that the conventional story needs important modifications to account for the current findings, in one or more of the following ways: (1) abandon the idea of a qualitative shift in refreshing with its emergence around the age of 7, to account for the fact that no refreshing was observed in 9- to 12-year olds in the current study (see Jarrold & Citroen, 2013; Jarrold & Hall, 2013; Morey, Mareva, Lelonkiewicz, & Chevalier, 2017, for a similar argument against a qualitative shift for domain-specific maintenance mechanisms), (2) abandon the idea that spontaneous refreshing is a central, and generally-used maintenance mechanism, to account for the fact that no refreshing was observed in children in our simple working memory task, and/or (3) modify the idea that developmental differences in refreshing are best described in terms of its emergence and its efficiency, to allow for the possibility that developmental differences can be described in terms of changes in the content of refreshing. Any of these modifications of the conventional story may have strong implications for the role of refreshing in the development of working memory capacity in children.

One alternative view could be to view the development of refreshing as embedded within the more general development of cognitive control, whereby children broadly develop from a more passive to a more active stance, i.e., from a reactive to a proactive mode (e.g., Chevalier, James, Wiebe, Nelson, & Espy, 2014). A similar argument has been made by Morey and colleagues (2017) related to the use of gaze-based rehearsal. In a reactive mode, children stay close to what happens in the moment, merely reacting to events and thus, they would keep their attention focused on the last-presented memory item. In a proactive mode, however, children anticipate the next events of the task and thus, they would switch their attention away from the last-presented item to refresh the entire list in preparation of the upcoming test. An important developmental change may then be the increase in the spontaneous tendency to proactively use refreshing, and perhaps, with age, a decreasing need for external cues encouraging the use of refreshing (see Munakata, Snyder, & Chatham, 2012, for a similar argument). The idea that the operation and content of refreshing may change with age during childhood, from focused on the last-presented item to the entire list, could easily be integrated in such view.

Finally, it is worth noting that alternative accounts of the effect of attentional demands on recall have been proposed in the adult literature, such as the use of free time to remove distractors (Oberauer et al., 2012). Removal may not be needed in the current paradigm because no distractors are presented between the memory items. This could explain why school-aged children typically show a disruptive effect of concurrent processing on recall, whereas we observed that their attention lingered on the last-presented memory item. Additional assumptions would then be needed to explain why Vergauwe and Langerock (2017) observed that adults' attention did not linger on the last-presented item in working memory in the same paradigm.

The relation between attention and working memory in children

One way in which the relationship between attention and working memory has been examined is through the effect of retro-cues on short-term memory performance. A small number of items is shown, and during retention, a cue is displayed, indicating which memory item should be attended and is most likely to be tested (e.g. Giffrin & Nobre, 2003). Both in adults (see Souza & Oberauer, 2016, for recent review) and in children between 7 and 11 years old (Shimi et al., 2014; Shimi & Scerif, 2017), it has been shown that retro-cues enhance memory performance, demonstrating a beneficial effect of attentional focusing in working memory. This indicates that 7-11 year olds are able to focus on one memory item out of a set within working memory and that their performance can benefit from this. The results of our Experiment 1, however, indicate that children do not spontaneously make use of this ability to refresh the content of working memory. Why is that? We see at least two possibilities.

It is possible that children can focus their attention on one particular item within working memory, but that they have difficulties switching from one item to the next, an ability that is required to engage in serial refreshing (see Loaiza & Souza, 2018, for a similar proposal in older adults). The fact that we found, in Experiment 2, that children can switch away from the last-presented item, when a cue instructs them do so, but are not efficient in switching towards another item, is consistent with the idea that children's sequential focus switching may not be fully optimal yet. This may then explain why we did not observe spontaneous refreshing in Experiment 1. Alternatively, it is possible that children can efficiently use their focus of attention within working memory, but that they do not always opt to do so (see also Shimi & Scerif, 2017, for the strategic use of refreshing in children). In line with this idea, it has recently been shown that children between 7 and 10 years old can use their attention to prioritize an item within working memory, but that they only do so in a task situation designed to optimally motivate children (Atkinson, Waterman, & Allen, 2019; Berry, Waterman, Baddeley, Hitch, & Allen, 2018). This raises the possibility that the use of attentional mechanisms in working memory is strategic in children. The current study cannot distinguish between these two possibilities.

One could argue that the observation of children's attention, but not adults' attention, lingering on the last-presented item may be counterintuitive in the light of common views of children being more prone to distractibility (e.g., Elliott, 2002; Wetzel, Widmann, Berti, & Schröger, 2006). Very similar observations exist, however, in the field of perceptual attention, whereby adults spontaneously switched their attention away from a cued location in a goal-directed way (resulting in inhibition-of-return for the cued location), whereas children continued to focus their attention on the cued location (resulting in the absence of inhibition-of-return for the cued location; MacPherson, Klein, & Moore, 2003). Only when a second location was cued did children disengage their attention from the first-cued location. This pattern in perception is highly similar to what we have observed here in working memory: children did not spontaneously switch away from the last-presented memory item, unless a cue instructed them to do so.

CONCLUSION

To conclude, the current study uncovered that children between 9 and 12 years old do not spontaneously switch attention away from the last-presented memory item to refresh the entire list in a situation in which young adults do, even though they are able to do so when instructed. This pattern contrasts sharply with previous studies on refreshing in children and puts important constraints on models of working memory and working memory development, by requiring critical modifications to one or more of the following basic and common assumptions about (1) the generality of spontaneous refreshing as a mechanism critically important for working memory capacity in children, (2) the operation and content of refreshing in children, and/or (3) the development of refreshing.

References

Atkinson, A. L., Waterman, A. H., & Allen, R. J. (2019). Can children prioritize more valuable information in working memory? An exploration into the effects of motivation and memory load. *Developmental psychology*, *55*(5), 967–980.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, 105(1), 158-173.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. *The psychology of learning and motivation*, *8*, 47-89.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple component model. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 28-61). New York: Cambridge University Press.

Barrouillet, P., & Camos, V. (2012). As time goes by: Temporal constraints in working memory. *Current Directions in Psychological Science, 21*, 413-419.

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*, 477-490.

Basak, C. & Verhaeghen, P. (2011). Three layers of working memory: Focus-switch costs and retrieval dynamics as revealed by the N-count task. *Journal of Cognitive Psychology, 23*, 204-219.

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General*, *132*(1), 71.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M., & Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology*, *41*(4), 579.

Berry, E. D., Waterman, A. H., Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2018). The limits of visual working memory in children: Exploring prioritization and recency effects with sequential presentation. *Developmental Psychology, 54*(2), 240.

Bertrand, R., & Camos, V. (2015). The role of attention in preschoolers' working memory. *Cognitive Development, 33*, 14-27.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273-293.

Camos, V., & Barrouillet, P. (2011). Developmental change in working memory strategies: From passive maintenance to active refreshing. *Developmental Psychology, 47*(3), 898.

Camos, V., Johnson, M. R., Loaiza, V. M., Portrat, S., Souza, A. S., & Vergauwe, E. (2018). What is attentional refreshing in working memory?. *Annals of the New York Academy of Sciences, 1424*(1), 19-32.

Chevalier, N., James, T. D., Wiebe, S. A., Nelson, J. M., & Espy, K. A. (2014). Contribution of reactive and proactive control to children's working memory performance: Insight from item recall durations in response sequence planning. *Developmental Psychology, 50*(7), 1999.

Conlin, J. A., Gathercole, S. E., & Adams, J. W. (2005). Children's working memory: Investigating performance limitations in complex span tasks. *Journal of Experimental Child Psychology, 90*(4), 303-317.

Cowan, N. (1995). *Attention and memory: An integrated framework*. New York: Oxford University Press.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. *Neuropsychologia, 49*, 1401-1406.

De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology*, *103*(2), 186-201.

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin, 89*(1), 63.

Doherty, J. M., Belletier, C., Rhodes, S., Jaroslawska, A., Barrouillet, P., Camos, V., Cowan, N., Naveh-Benjamin, M., & Logie, R. H. (2019). Dual-task costs in working memory: An adversarial collaboration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 45*(9), 1529-1551.

Elliott, E. M. (2002). The irrelevant-speech effect and children: Theoretical implications of developmental change. *Memory and Cognition, 30,* 478–487.

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

Gaillard, V., Barrouillet, P., Jarrold, C., & Camos, V. (2009). Developmental differences in working memory: Where do they come from*? Journal of Experimental Child Psychology*, *110,* 469-479.

Gathercole, S. E. (1998). The development of memory. *The Journal of Child Psychology and Psychiatry*, *39*(1), 3-27.

Gathercole, S. E., & Adams, A. M. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language, 33*(5), 672.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40*(2), 177.

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience, 15*(8), 1176-1194.

Higgins, J.A., & Johnson, M.K. (2009). The consequence of refreshing for access to nonselected items in young and older adults. *Memory & Cognition, 37*, 164-174.

Hitch, G. J., Woodin, M. E., & Baker, S. (1989). Visual and phonological components of working memory in children. *Memory & Cognition*, *17*(2), 175-185.

Jarrold, C., & Citroën, R. (2013). Reevaluating key evidence for the development of rehearsal: phonological similarity effects in children are subject to proportional scaling artifacts. *Developmental Psychology*, *49*(5), 837.

Jarrold, C., & Hall, D. (2013). The development of rehearsal in verbal short-term memory. *Child Development Perspectives*, *7*(3), 182-186.

Jarrold, C., Tam, H., Baddeley, A. D., & Harvey, C. E. (2011). How does processing affect storage in working memory tasks? Evidence for both domain-general and domain-specific effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(3), 688.

JASP Team (2019). JASP (Version 0.10.0.0) [Computer software].

Lendínez, C., Pelegrina, S., & Lechuga, M. T. (2015). Age differences in working memory updating: the role of interference, focus switching and substituting information. *Acta psychologica*, *157*, 106-113.

Loaiza, V. M., & Souza, A. S. (2018). Is refreshing in working memory impaired in older age? Evidence from the retro-cue paradigm. *Annals of the New York Academy of Sciences, 1424*(1), 175-189.

Macken, B., Taylor, J., & Jones, D. (2015). Limitless capacity: A dynamic object-oriented approach to short-term memory. *Frontiers in Psychology, 6*, 293.

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.

Magimairaj, B. M., & Montgomery, J. W. (2013). Examining the relative contribution of memory updating, attention focus switching, and sustained attention to children's verbal working memory span. *Child Development Research*, 2013.

McElree, B. (2006). Accessing recent events. In B. H. Ross (Ed.), *The psychology of learning and motivation, Vol. 46*. San Diego: Academic Press.

MacPherson, A. C., Klein, R. M., & Moore, C. (2003). Inhibition of return in children and adolescents. *Journal of Experimental Child Psychology, 85*(4), 337-351.

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.

Morey, C. C., Mareva, S., Lelonkiewicz, J. R., & Chevalier, N. (2018). Gaze-based rehearsal in children under 7: a developmental investigation of eye movements during a serial spatial memory task. *Developmental Science, 21*(3), e12559.

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current directions in psychological science, 21*(2), 71-77.

Nee, D. E., & Jonides, J. (2013). Trisecting representational states in short-term memory. *Frontiers in Human Neuroscience, 7*, 796.

Nee, D. E., & Jonides, J. (2008) Neural correlates of access to short-term memory. *Proceedings of the National Academy of Sciences*, *15*, 14228-14233.

Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science, 21*, 164–169.

Oberauer, K., Lewandowsky, S., Farrell, S., Jarrold, C., & Greaves, M. (2012). Modeling working memory: An interference model of complex span. *Psychonomic Bulletin & Review, 19*(5), 779-819.

Oftinger, A. L., & Camos, V. (2016). Maintenance mechanisms in children’s verbal working memory. *Journal of Educational and Developmental Psychology, 6*(1), 16-28.

Oftinger, A. L., & Camos, V. (2017). Phonological similarity effect in children’s working memory: Do maintenance mechanisms matter. *Journal of Child Psychology*, *1*(1), 5-11.

Oftinger, A. L., & Camos, V. (2018). Developmental improvement in strategies to maintain verbal information in working memory. *International Journal of Behavioral Development*, *42*(2), 182-191.

Portrat, S., Camos, V., & Barrouillet, P. (2009). Working memory in children: A time-constrained functioning similar to adults. *Journal of Experimental Child Psychology, 102*(3), 368-374.

Ricker, T. J., & Cowan, N. (2010). Loss of visual working memory within seconds: The combined use of refreshable and non-refreshable features. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(6), 1355.

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology*, *56*(5), 356-374.

Shimi, A., Nobre, A. C., Astle, D., & Scerif, G. (2014). Orienting attention within visual short-term memory: Development and mechanisms. *Child development, 85*(2), 578-592.

Shimi, A., & Scerif, G. (2017). Towards an integrative model of visual short-term memory maintenance: Evidence from the effects of attentional control, load, decay, and their interactions in childhood. *Cognition, 169*, 61-83.

Souza, A. S., & Oberauer, K. (2016). In search of the focus of attention in working memory: 13 years of the retro-cue effect. *Attention, Perception, & Psychophysics*, *78*(7), 1839-1860.

Souza, A. S., Rerko, L., & Oberauer, K. (2015). Refreshing memory traces: Thinking of an item improves retrieval from visual working memory. *Annals of The New York Academy of Sciences*, *1339*, 20-31.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly journal of experimental psychology, 59*(4), 745-759.

Sternberg, S. (1966). High speed scanning in human memory. *Science, 153*, 652–654.

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.

Vergauwe, E. (2018). Comparing different instructed-refreshing schedules: evidence for cumulative, forward-order refreshing of verbal lists?. *Annals of the New York Academy of Sciences, 1424*(1), 102-114.

Vergauwe, E., Camos, V., & Barrouillet, P. (2014). The effect of storage on processing: How is information maintained in working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 1072-1095.

Vergauwe, E., & Cowan, N. (2014). A common Short-Term Memory retrieval rate may describe many cognitive procedures. *Frontiers in Human Neuroscience, 8*:126.

Vergauwe, E., Hardman, K., Rouder, J., Roemer, E., McAllaster, S., & Cowan, N. (2016). Searching for serial refreshing in working memory: Using response times to track the content of the focus of attention over time. *Psychonomic Bulletin and Review, 23,* 1818-1824.

Vergauwe, E., & Langerock, N. (2017). Attentional refreshing of information in working memory: Increased immediate accessibility of just-refreshed representations. *Journal of Memory and Language, 96,* 23-35.

Vergauwe, E., Langerock, N., & Cowan, N. (2018). Evidence for spontaneous serial refreshing in verbal working memory?. *Psychonomic bulletin & review, 25*(2), 674-680.

Verhaeghen, P. and Basak, C. 2005. Ageing and switching of the focus of attention in working memory: Results from a modified N-Back task. *Quarterly Journal of Experimental Psychology, 58*A, 134–154.

Wetzel, N., Widmann, A., Berti, S., & Schröger, E. (2006). The development of involuntary and voluntary attention from childhood to adulthood: a combined behavioral and event-related potential study. *Clinical Neurophysiology, 117*(10), 2191-2203.

Tables

Table 1

Mean accuracies (percentage correct responses) and standard deviations (in parentheses) for probes matching the last-presented item, probes matching other list items, and new probes, for each presentation rate (Fast, Slow, Much slower) and for each Age group (9-year-olds and 12-year-olds).

	Presentation rate								
	Fast			**Slow**			**Much slower**		
Probe type	*Last-presented*	*Not-last-presented*	*New*	*Last-presented*	*Not-last-presented*	*New*	*Last-presented*	*Not-last-presented*	*New*
9-year-olds	90 (11)	71 (20)	89 (9)	95 (6)	79 (16)	90 (11)	92 (10)	79 (15)	91 (8)
12-year-olds	94 (7)	82 (13)	92 (6)	95 (5)	86 (12)	92 (7)	95 (8)	89 (11)	93 (6)

Table 2

Evidence in the data for the last-presented benefit in Experiment 1, for each experimental group resulting from the design Age (9-year-olds vs. 12-year olds) x Presentation rate (Fast, Slow, or Much slower). Bayes factors are from paired, one-sided t-tests testing the last-presented benefit (i.e., faster responses for last-presented item, compared to not-last-presented probes).

	Presentation rate		
	Fast	Slow	Much slower
9-year-olds	329’070	1’876	$1.41x10^{6}$
12-year-olds	586’060	$1.46x10^{6}$	6’619

Figure captions

Figure 1

Panel A: Schematic representation of a trial in Experiment 1, together with the duration (in milliseconds, ms) of different events on each trial, as a function of Presentation rate (fast, slow, or much slower). Panel B: Upper case and lower case (cursive) letters used in Experiments 1 and 2.

Figure 2

Mean response times in ms for probes matching the last-presented item (grey bars) vs. probes matching other list items (white bars) for each presentation rate (Fast, Slow, Much slower, on X-axis) and for each Age group (9-year-olds in upper panel, 12-year-olds in lower panel) in Experiment 1. Error bars show standard errors of the mean.

Figure 3

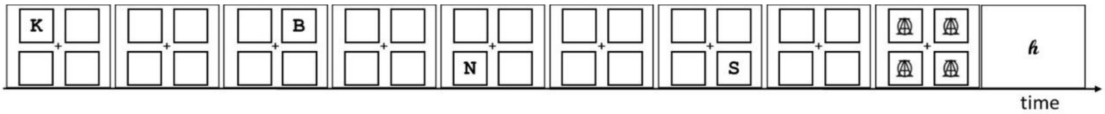
Schematic representation of a trial in Experiment 2, here shown with three refreshing cues.

Figure 4

Mean response times in ms for probes matching the last-presented item (grey bars) vs. probes matching other list items (white bars) in Experiment 2. Error bars show standard errors of the mean.

Figures

A



Condition

Fast	400 ms	100 ms	400 ms	100 ms	400 ms	100 ms	400 ms	100 ms	50 ms	Until response or 5000 ms
Slow (x3)	1200 ms	300 ms	1200 ms	300 ms	1200 ms	300 ms	1200 ms	300 ms	50 ms	Until response or 5000 ms
Much slower (x5)	2000 ms	500 ms	2000 ms	500 ms	2000 ms	500 ms	2000 ms	500 ms	50 ms	Until response or 5000 ms

B

Figure 1. Panel A: Schematic representation of a trial in Experiment 1, together with the duration (in milliseconds, ms) of different events on each trial, as a function of Presentation rate (fast, slow, or much slower). Panel B: Upper case and lower case (cursive) letters used in Experiments 1 and 2.

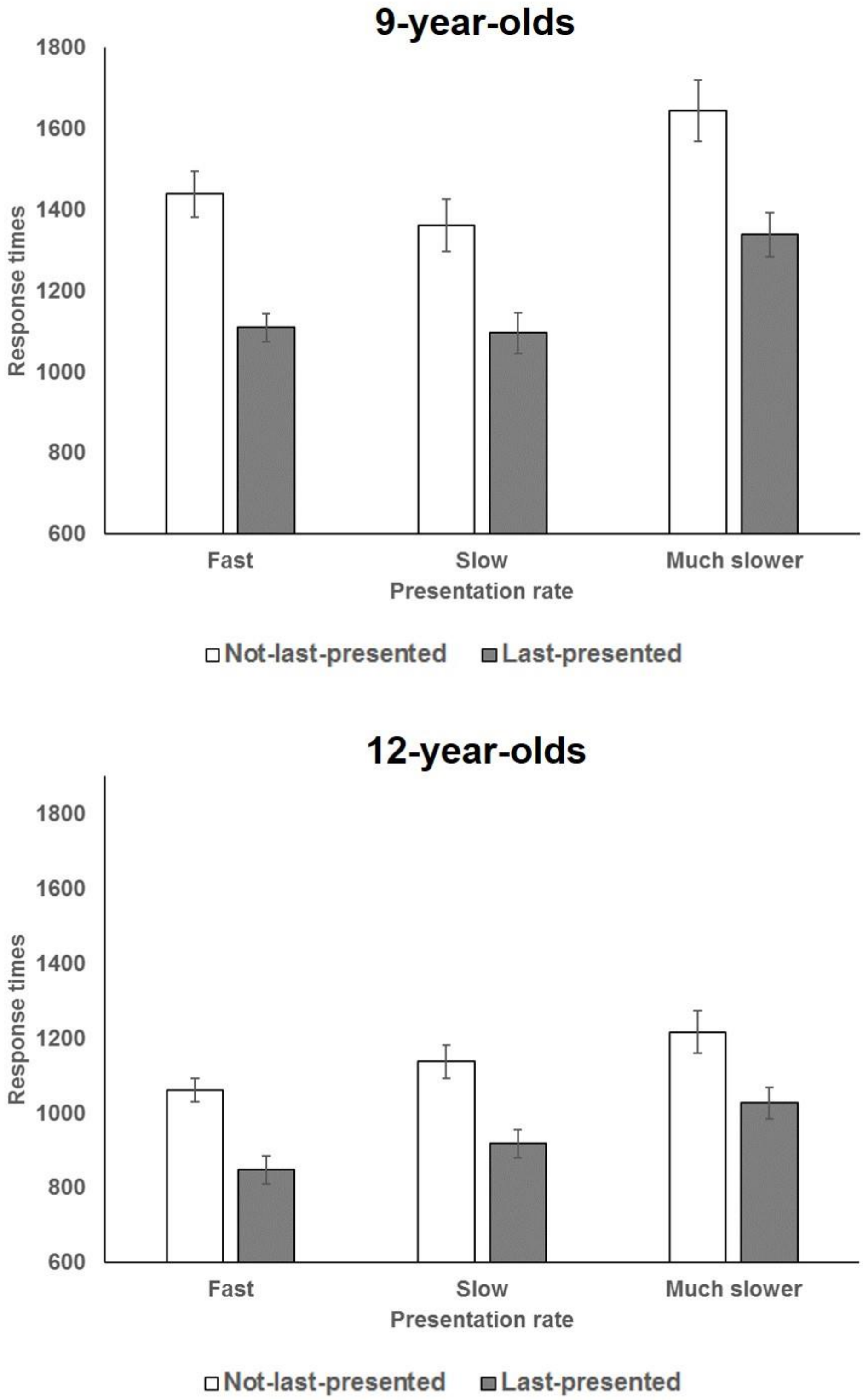


Figure 2. Mean response times in ms for probes matching the last-presented item (grey bars) vs. probes matching other list items (white bars) for each presentation rate (Fast, Slow, Much slower, on X-axis) and for each Age group (9-year-olds in upper panel, 12-year-olds in lower panel) in Experiment 1. Error bars show standard errors of the mean.

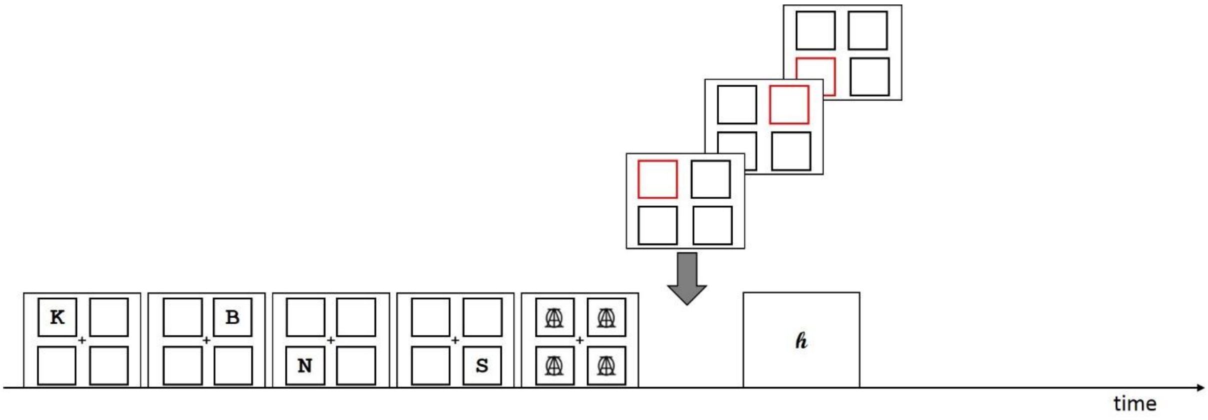


Figure 3. Schematic representation of a trial in Experiment 2, here shown with three refreshing cues.

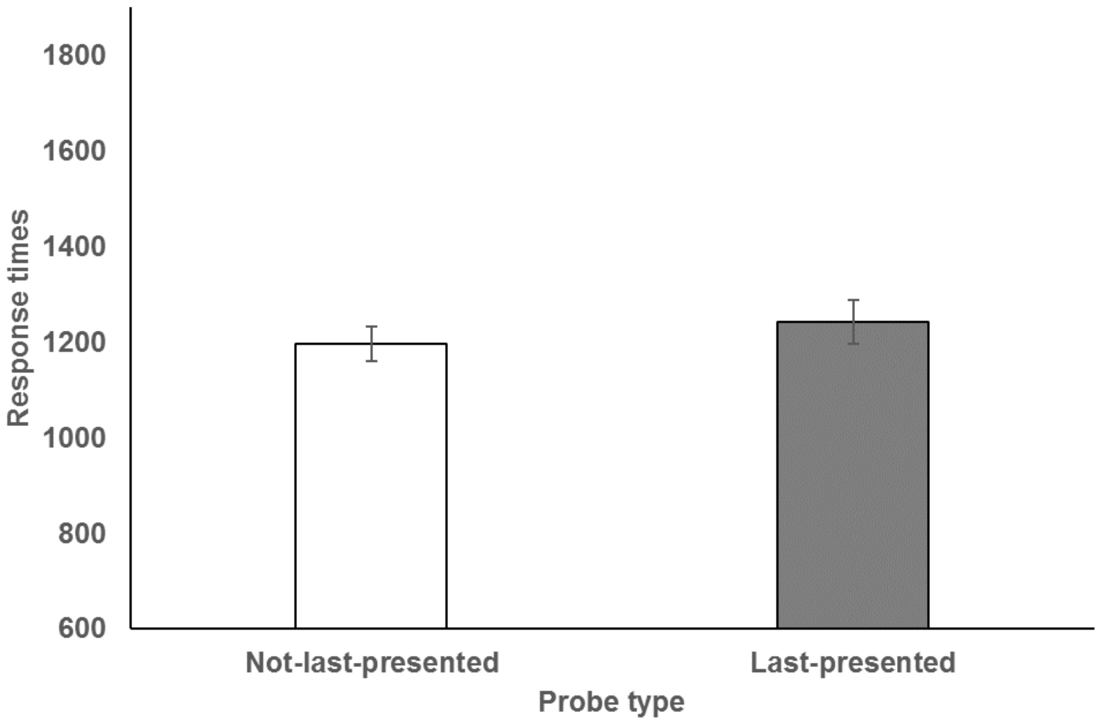


Figure 4. Mean response times in ms for probes matching the last-presented item (grey bars) vs. probes matching other list items (white bars) in Experiment 2. Error bars show standard errors of the mean.

Footnotes

Footnote 1. To check the robustness of our results, we have re-run our analyses applying a stricter performance-based exclusion criterion by which accuracy needed to reach 55% for each of the different probe types. Applying this criterion to our data set, the data of 12 additional children needed to be discarded (for the 9-year-olds: 5 in the Fast condition, 2 in the Slow condition, and 2 in the Much slower condition; for the 12-year-olds: 1 in the Fast condition, 1 in the Slow condition, and 1 in the Much slower condition). Doing so did not change the pattern of results, strong evidence for a last-presented benefit was found in all six groups defined by Age (9-year-olds vs. 12-year-olds) x Presentation rate (Fast, Slow, or Much slower).

Footnote 2. A Bayesian ANOVA on the accuracy scores of all participants in Experiment 1 with Age group (9-year-old vs. 12-year-old) and Presentation rate (Fast, Slow, Much slower) as between-subject variables and Probe type (Last-presented, Not-last-presented, New) as within-subjects variable showed that the best model only included a main effect of Age group, a main effect of Probe type, and an interaction between Age group and Probe type. As can be seen in Table 1, and in line with what we had observed for the response times, the difference between last-presented and not-last presented probes was larger in 9-year-olds than in 12-year olds.

Footnote 3. The observation of a larger last-presented RT benefit in 9-year-olds than in 12-year-olds may suggest that the younger children are less efficient in focus switching, i.e., the process by which the focus of attention selects and accesses another item in working memory. If younger children are less efficient in switching their focus of attention from the last-presented item to another working memory item at test, this would result in a larger last-presented RT benefit (for similar findings, see Lendinez, Pelegrina, & Lechuga, 2015, comparing focus switch costs in 8-11 year olds vs. adolescents and adults, and Magimairaj & Montgomery, 2013, studying focus switch costs in children from 7 to 11 years old). However, even though the last-presented benefit was considerably larger in the 9-year-olds than in the 12-year-olds when comparing the absolute differences in RT (i.e., responses to last-presented probes were 301 ms faster than to not-last-presented probes in the 9-year-olds, and only 208 ms faster in the 12-year-olds), this difference disappears largely when comparing relative differences in RT (i.e., responses to last-presented probes were 20% faster than to not-last-presented probes in the 9-year-olds, and 18% faster in the 12-year-olds). Thus, no important age differences in the size of the last-presented RT benefit are observed once more general age-related differences in processing speed are taken into account (see Verhaeghen & Basak, 2005, for a similar observation when comparing focus switching between young and older adults).

Footnote 4. Compared to the presentation rates used in Experiment 1 (1 letter every 500ms, every 1500ms, or every 2500ms, for the fast, slow, and much slower conditions, respectively), the presentation rate used in Experiment 2 (1 letter every 1000ms) could be classified as a moderate rate.

Footnote 5. This conclusion is based on the fact that evidence for refreshing was only found in Experiment 2, in which we used refreshing cues and instructions. However, one could argue that the difference between Experiment 1 and Experiment 2 is not only one in terms of refreshing cues and instructions, but also in terms of time available to refresh. Indeed, in Experiment 2, there was more opportunity for spontaneous refreshing than in Experiment 1, because the time during which refreshing cues were presented could have been used for spontaneous refreshing. It is worth noting, however, that our findings do indicate that the children were following our instructions, displaying a just-refreshed benefit, at least for the first memory item. Moreover, directly comparing the Much slower trials of Experiment 1 and the 1-cue trials of Experiment 2 indicates that the difference in the occurrence of refreshing cannot be entirely due to differences in time available for refreshing. Indeed, there was a clear last-presented benefit when memory was probed 2550ms after the onset of the presentation of the last memory item in the Much slower condition of Experiment 1, whereas the last-presented benefit had already disappeared after 1 cue in Experiment 2, i.e., when memory was probed only 2050ms after the onset of the presentation of the last memory item (BF_{01} = 13.70).

Supplementary materials 1

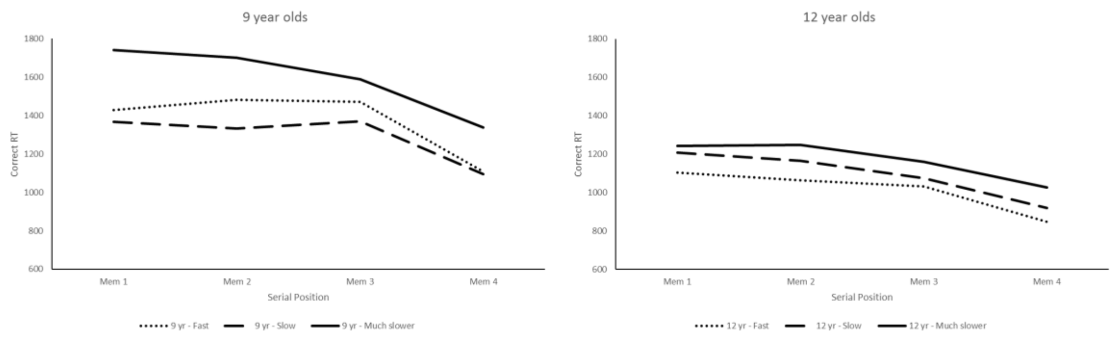
Detailed description of training phase used in Experiment 1

The training phase comprised 4 steps: (1) First, the experimenter verified that the child was able to recognize each of the letters used in the experiment, both in the uppercase and cursive fonts used for to-be-remembered letters and probes on experimental trials. To do so, all letters were shown on screen one by one, first in uppercase and then in cursive, and the experimenter verified that the child could name each letter correctly. This was the case for all children. (2) Next, the trial procedure was explained and shown to the child, with the presentation of an entire trial. This visualisation of a trial was self-paced by the experimenter, to allow adapting the pace for each child individually. At the end of the visualisation trial, the experimenter asked the child to respond to the probe by pressing the appropriate keys, and feedback was given (on screen and orally) concerning the accuracy of the child's response (correct or incorrect). Next, the screen showed the probe next to the four letters to be memorized for that trial and the experimenter explains why the child's response was correct or incorrect. (3) After the visualisation trial, the child performed four practice trials at the rhythm of the experimental trials (one to-be-remembered letter every 500ms, every 1500ms, or every 2500ms, for the Fast, Slow, and Much slower conditions, respectively). Feedback was shown on the accuracy (correct vs. incorrect), and the additional feedback-screen showed the probe next to the four memorized letters after each of the four practice trials. When needed, the experimenter commented orally on the given response. Finally, (4) after these four trials, 10 more practice trials followed for which the child still received feedback on their response, but the additional feedback-screen was no longer shown. Thereafter, the experimental trials started and it was explained that, from that point on, no more feedback would be given.

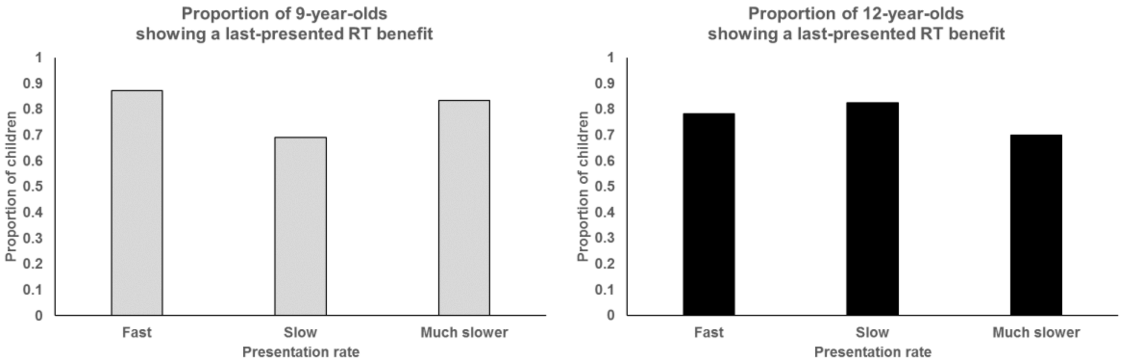
Supplementary materials 2

Exploratory analyses of Experiment 1

Two sets of additional, exploratory analyses were run. First, to provide a more detailed break-down of the RT results, we have plotted correct RTs in the six experimental groups as a function of the Target-present Probe Type (probe matching Memory item 1, memory item 2, memory item 3, or memory item 4). As can be seen in the Figures below, the shape of the serial position curve did not vary substantially across the experimental groups. Overall, all groups showed a benefit for the last-presented memory item and none of the groups showed a benefit for any other memory item (e.g., no primacy effect in any of the groups).



Second, we explored the possibility that there may be some evidence for spontaneous refreshing at the more individual level. Therefore, we calculated the proportion of children showing a last-presented benefit per age group. Using different criteria to determine the presence of a last-presented benefit at the individual level (i.e., last-presented benefit is coded as present for a given child, if their mean correct $RT_{last\text{-}presented}$ is minimum 20, 50, or 100ms faster, respectively, than their mean correct $RT_{not\text{-}last\text{-}presented}$), we found that the proportion of children showing a last-presented benefit was slightly smaller in the older group when using the 20-ms or the 100-ms criterion (.89 vs. .91, for the 20-ms criterion; .77 vs. .80, for the 100-ms criterion), and slightly larger in the older group when using the 50-ms criterion (.88 vs. .87). Next, and more importantly, we explored whether these proportions consistently varied with Presentation rate in either age group. We reasoned that a monotonic decrease in this proportion with the increase of presentation rate could be interpreted as an indication of more children using spontaneous refreshing when there is more free time. No such consistent pattern was found for any of the criterions, as can be seen in the Figure below (using the proportions of the most conservative criterion, i.e., 100ms).



Supplementary materials 3

Exploratory analyses of Experiment 2

The findings of Vergauwe and Langerock (2017) showed that the just-refreshed benefit was largest in adults when one needed to switch attention to the first list item (i.e., after one or fives refreshing cues). As explained in Vergauwe and Langerock (2017), one possible explanation for this observation is that it may be easier to think about memory item 1 when instructed to, than to think about any other item of the list. Under that assumption, one could expect to see a just-refreshed benefit more clearly when one needs to switch attention to the first list item in children as well. To explore this possibility, we followed up on our planned analyses by examining the just-refreshed benefit only in correct RTs collected for probes that were presented after a refreshing cue that referred to the first list item (i.e., mean RT for just-refreshed probes was calculated per participant by taking the average value across mean RT for just-refreshed probes after 1 cue and mean RT for just-refreshed probes after 5 cues). Descriptively, this showed a larger RT difference (81 ms), and a one-sided Bayesian *t*-test using only correct RTs collected for probes that were presented after a refreshing cue referring to the first list item showed some modest evidence for a just-refreshed benefit (BF_{10} = 3.62). When mean RT for just-refreshed probes was calculated in an unweighted fashion, the RT difference was still quite large (65 ms), but the BF_{10} for a just-refreshed benefit dropped to 2.03. Overall, this is not very strong evidence, but it is consistent with the idea that instructed refreshing resulted in replacing the last-presented item by another list item in the focus of attention, at least for the first list item.