



Updating in working memory: A comparison of good and poor comprehenders

Barbara Carretti *, Cesare Cornoldi, Rossana De Beni,
Marta Romanò

Dipartimento di Psicologia Generale, Via Venezia 8, 35131 Padova, Italy

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Abstract

In this research, we examined the relation between reading comprehension and success in a working memory updating task. We tested the hypotheses that poor comprehenders' deficiencies are associated with a specific difficulty in the working memory updating process, particularly in controlling for information that is no longer relevant. In the first experiment, groups of poor and good comprehenders, ages 8–11 years, were administered a working memory updating task. In the second experiment a year later, a subgroup of participants involved in the first experiment was tested with a different updating task. In both experiments, poor comprehenders had less accurate recall performance and made more intrusion errors than did good comprehenders. Moreover, distinguishing intrusion errors on the basis of their permanence in memory, we found that poor comprehenders were more likely to intrude items that were maintained longer in memory than were good comprehenders. This type of error predicted reading comprehension abilities better than did working memory recall. This suggests that the relation between reading comprehension and working memory is mediated by the ability to control for irrelevant information.

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* Corresponding author. Fax: +39 049 827 6600.

E-mail address: barbara.carretti@unipd.it (B. Carretti).

Introduction

Memory updating is the act of modifying the content of memory to accommodate new input (Morris & Jones, 1990). The updating function goes beyond the simple maintenance of task-relevant information by requiring a dynamic manipulation of the content of working memory, and it is broadly considered an executive function (Lehto, 1996; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Morris & Jones, 1990). Furthermore, updating represents the most typical way by which working memory is involved in psychological functioning. In fact, the importance of working memory is related to the temporary maintenance and elaboration of memory contents that are continuously changed to meet the online requests; it is improbable that this change happens in the form of simple substitution of old information with new information. Very often, this change seems to also include an updating of old information based on its comparison with the new information. Despite its importance, the process of updating information in working memory has been studied only rarely, whether directly or in relation to other cognitive processes. Furthermore, until now, no well-established and completely satisfactory procedures for testing updating have been proposed.

In particular, although working memory seems critical in reading comprehension (for a review, see Daneman & Merikle, 1996; Oakhill, Cain, & Bryant, 2003), and this relation is probably mediated by an updating function (Gernsbacher, Varner, & Faust, 1990), only a few studies have directly examined the relation among updating, reading comprehension, and working memory. Furthermore, the results of the studies that have been carried out are not entirely consistent. A study by Palladino, Cornoldi, De Beni, and Pazzaglia (2001) found a relation between reading comprehension and updating in working memory. But from a different perspective, Radvansky and Copeland (2001) showed that measures of working memory, such as the reading span test (Daneman & Carpenter, 1980), operation span test (Turner & Engle, 1989), and spatial span test (Shah & Miyake, 1996), are not good predictors of success in updating situation models during reading comprehension. In the reading comprehension task used by Radvansky and Copeland (2001), each passage mentioned a critical object that was either spatially associated with the protagonist or spatially dissociated from the protagonist. The construction of a coherent mental model was tested by asking participants to solve an anaphor. The results of the study showed that the measures of success in the updating process during the reading comprehension task were weakly related to working memory measures but were strongly related to a general measure of situation model processing (a situation model identification test). Radvansky and Copeland did not exclude the existence of a relation among reading comprehension, updating, and working memory, highlighting that their results could suggest only a lack of relation with a capacity measure of working memory. They hypothesized that some other aspects of working memory related to attentional control and information manipulation could reveal the role of working memory in reading comprehension. This could be the case for a working memory task devoted specifically to examining its updating component.

With this work, we intended to pursue two main objectives: (a) to find clearer evidence of the relation between working memory updating and reading comprehension abilities and (b) to examine the role of the control mechanism used to suppress information. Indeed, after Radvansky and Copeland's (2001) results, we wanted to determine whether there is a relation between reading comprehension and working memory and also whether it is mediated by inhibition. We believe that it may be possible that this mechanism, involved during the execution of a working memory task (Bunting & Conway, 2002; Hasher, Zacks, & May, 1999; May, Hasher, & Kane, 1999), could be the mediator of the relation between reading comprehension and working memory.

Working memory updating and reading comprehension

During comprehension of a text, the reader is continuously required to change the content of memory, that is, to maintain the important information and eliminate the irrelevant information (Gernsbacher et al., 1990). For example, to solve an anaphor, the reader must recover the antecedent of a pronoun (Ehrlich & Rayner, 1983; Garnham & Oakhill, 1992; Just & Carpenter, 1992). Sometimes this process implies the updating of other possible referents of the pronoun, for example, when more than one character or object could be grammatically coherent with the pronoun (Johnson & Seifert, 1998). Information treated in these processes must necessarily be maintained by a temporary memory system. Therefore, given the limits of the working memory capacity, good use of memory involves not only maintaining as much information as possible but also continuously selecting and updating this information.

Several researchers have shown that the process of updating occurs especially when new information is not compatible with past information (Albrecht & O'Brien, 1993; de Vega, 1995). To maintain global coherence, the reader must update previous information with new information. Failure in this process could lead to misinterpreting the content of a text (Blanc & Tapiero, 2001; de Vega, 1995; Johnson & Seifert, 1998).

Palladino and colleagues (2001) argued that it may be possible to draw a parallel between reading comprehension and updating in working memory. They administered a series of updating working memory tasks to groups of adolescents and young adults categorized according to their reading comprehension ability. In the first experiment, they used the procedure adopted by Morris and Jones (1990) in asking participants to recall the last four letters in lists of consonants of varying length. To carry out the task successfully, participants had to change the content of memory by updating old irrelevant items with relevant incoming items. Palladino and colleagues (2001) found that college students with a high reading comprehension ability were better at the task than were students with a low reading ability. However, the difference was also observed when the participants were presented with a limited number of items and updating was not required.

A problem with this experiment was that Morris and Jones's (1990) task does not require a complete updating process because a simple substitution of the material on the basis of a recency criterion is sufficient (Ruiz, Elousa, & Lechuga, in press). On

the contrary, the essence of the updating process lies in the need to dynamically manipulate information in working memory. Modifying Morris and Jones's task, Palladino and colleagues (2001) devised a new updating task in which the updating process relied on a semantic criterion to make the task as similar as possible to the updating process involved in reading comprehension. In fact, participants were presented with lists that included concrete nouns (objects and animals) and were required to select the three smallest items in each list. The results showed that participants with low reading comprehension ability not only had poorer recall but also made more intrusion errors than did good comprehenders, replicating the observation that a poor working memory performance is associated with a higher number of intrusion errors (Carretti, Cornoldi, De Beni, & Palladino, 2004; De Beni & Palladino, 2001; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998). That is, poor comprehenders were more likely to recall items presented on prior trials that should have been excluded from the memory set.

Although Palladino and colleagues' (2001) results did not completely support their predictions, they suggested that certain kinds of items intrude in working memory tasks due to their higher level of activation. Since this study, others have supported their claims using modified versions of the classic listening span test (Carretti et al., 2004; Osaka, Nishizaki, Komori, & Osaka, 2002).

Updating, inhibition, and success in working memory tasks

Studies on the mechanisms that underlie performance in working memory tasks are sometimes controversial. Indeed, Miyake and colleagues (2000) showed that the updating function seems to better explain performance in working memory tasks compared with two other executive functions: inhibition and task shifting. However, in a reanalysis of Miyake and colleagues' data, Bunting and Conway (2002) demonstrated that both inhibition and updating functions could explain working memory performance and that those two executive functions could be considered as different components of a single factor. More recently, Friedman and Miyake (2004), analyzing the inhibition construct in detail, found that the inhibition mechanism, considered as the ability to resist memory intrusion of information that was previously relevant to the task but has since become irrelevant, is linked to working memory performance.

It has been suggested that a poor performance in working memory tasks is associated with an increased number of intrusion errors and that the probability of intrusions of irrelevant items is a function of the degree of item activation; the more items are activated, the more they are likely to be erroneously included in the set of items to be recalled (De Beni et al., 1998; Oberauer, 2001; Osaka et al., 2002). This seems particularly true for some categories of participants, including poor comprehenders (Carretti et al., 2004; De Beni & Palladino, 2001; De Beni et al., 1998), poor problem solvers (Passolunghi, Cornoldi, & De Liberto, 1999), participants with low working memory capacity (Carretti et al., 2004; Conway & Engle, 1994; Kane & Engle, 2000; Osaka et al., 2002; Rosen & Engle, 1998), and older people (Dywan & Murphy, 1996; Palladino & De Beni, 1999).

These and other previously collected data suggest that inhibition mechanisms play an important role in explaining working memory performance. On the basis of these considerations, it is possible to predict that this mechanism could have an important role in the relation between working memory and reading comprehension.

Analyzing this hypothesis in more detail, [Palladino and colleagues \(2001\)](#) distinguished intrusions according to the probable degree of associated activation: (a) intrusions of relevant items that can be immediately excluded from the pool of items to be remembered because they do not satisfy the maintenance criterion (here we call this kind of error an “immediate intrusion” because it concerns an item that is to be forgotten immediately) and (b) intrusions of relevant items that must be excluded later from the set of items to be recalled because they are temporarily consistent with the updating criterion (we call this kind of error a “delayed intrusion”). The rationale for this distinction was that items that participants maintain in working memory for some time (delayed intrusion) should gain a higher level of activation than should items excluded immediately. Thus, they tested the possibility that words activated for a longer period of time were more difficult to exclude than were words immediately eliminated from memory and that this would occur more in the case of poor comprehenders than in the case of good comprehenders due to the poor comprehenders’ problem in controlling irrelevant information in working memory. Unfortunately, the results of Palladino and colleagues did not support this prediction. This contrasts with the assumption that working memory performance is associated with the control of irrelevant information and that control is particularly difficult with highly activated information ([Carretti et al., 2004](#)). [Palladino and colleagues \(2001\)](#) attributed the lack of results in this direction to the fact that the numbers of items belonging to the two categories of intrusion were not the same. However, intrusion errors might also be a simple by-product of a memory failure and could be based on a random selection of irrelevant items. It follows that the relation between reading comprehension and working memory should critically concern the recall performance without a positive significant contribution of a specific ability in the control of irrelevant information.

Another problem arising from [Palladino and colleagues’ \(2001\)](#) experiment concerns the updating criterion because they asked participants to compare the physical sizes of objects and animals. Although participants in both groups were able to complete the tasks correctly, some comparisons could be influenced by the participants’ past experiences. For example, in the case of object comparisons, one participant could consider a television to be bigger than a suitcase because he or she is used to watching a 20-in. television and normally travels just with hand luggage, whereas another participant with a different set of experiences could consider a suitcase to be larger than a television.

To remedy the problems arising from [Palladino and colleagues’ \(2001\)](#) study, the current study used new updating tasks with familiar pictures rather than words and a set of instructions that children could process more easily. We devised a task involving spatial material (columns of pictures) that required items to be selected on the basis of a straightforward criterion: the position of the pictures in the columns (the highest or lowest) in Experiment 1 and the position of the items in word lists (the last three presented critical items) in Experiment 2. Finally, in contrast to the preceding

studies on updating that concerned mainly adults, the current study focused on children's performance, distinguishing them for their reading ability. The study of updating processes in children could be important from a theoretical and practical point of view. From a theoretical point of view, it is likely that the relation between working memory and reading comprehension is more critical in children than in adults because the latter can rely to a larger extent on general knowledge; thus, the analysis of the children's performance could provide clearer results on the nature of the mechanisms underlying this relation. In addition, because reading comprehension difficulties are particularly critical during the first years of school and may affect the overall school trajectory, selecting children on the basis of the criteria adopted for a diagnosis of learning disability (Swanson & Siegel, 2001) could also suggest practices for planning educational trainings. We hypothesized that reading-disabled children would have a poorer updating performance. Furthermore, we hypothesized that items maintained in memory longer (delayed intrusion) would be more likely to intrude in recall than would items immediately eliminated (immediate intrusion) and that this difficulty would be related to reading ability.

In Experiment 1, we compared groups of poor and good comprehenders attending primary school. In Experiment 2 a year later, we tested a subgroup of participants from Experiment 1 in a different updating task to analyze the generality of the results of Experiment 1. Because several studies have established the contribution of working memory to reading comprehension (Daneman & Hannon, 2001; Daneman & Merikle, 1996; Oakhill et al., 2003), an experiment using individuals with specific reading comprehension difficulties may clarify the relation between reading comprehension and underlying working memory processes (Cornoldi & Oakhill, 1996; Swanson & Ashbaker, 2000). A problem with this kind of research is that working memory tasks require some form of linguistic processing. Poor comprehenders could have a lower working memory performance due to their lower efficiency in the verbal domain (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000) and not due to a specific working memory difficulty. Consequently, we used a visually based task that relies, to a lesser extent, on verbal abilities.

The current research also offered the possibility of examining other characteristics of the updating task. Bellezza (1982) defined updating as a nonlearning process, suggesting that the updating process would not imply the learning of processed information. Over five experiments using mnemonic devices, he demonstrated that when associative interference was maximized, only a limited disruption of updating resulted. He ascribed the key factors that prevent interference during the updating process to temporal and contextual cues. Taking Bellezza's results into account, we expected proactive interference to be lower than in other working memory tasks. However, this conclusion contrasts with the assumption that proactive interference in working memory tasks can be produced by lists already presented and recalled (Friedman & Miyake, 2004; May et al., 1999). To further understand the role of proactive interference in the updating process, in both experiments we computed the number of intrusion errors due to previous lists and compared the performance in the first block of trials (concerning the first half of lists) with the performance in the second block of trials.

Experiment 1

Method

Participants

A total of 109 poor readers (50 girls and 59 boys), ages 8–11 years, and 109 good readers matched for grade, gender, and type of school participated in the experiment. The two groups were selected on the basis of the general criteria proposed by Cornoldi, De Beni, and Pazzaglia (1996). The two groups were matched for scores in the spatial subscale of the Primary Mental Ability (PMA) intelligence test (Thurstone & Thurstone, 1963), in a reading–decoding task measured with the “word search” subtask of the PRCR-2 test (Cornoldi, Miato, Molin, & Poli, 1992), and a questionnaire filled out by the teacher that investigated the comorbidity for attention deficit/hyperactivity disorder (ADHD). On all three measures, the children in both groups obtained scores above the 30th percentile. The two groups differed in a standardized reading comprehension test appropriated for their age, the MT test (Cornoldi & Colpo, 1998). Poor readers obtained scores below the 25th percentile, and good readers obtained scores above the 75th percentile. Table 1 reports the mean scores obtained by the two groups in the selection tasks. Participants were selected from an original sample of 629 children.

Materials

The updating task consisted of eight columns of pictures and eight corresponding lists of nouns. Columns of pictures consisted of 15 pictures, 9 × 9 cm, taken from a pool of 54 highly familiar and nameable pictures prepared for very young children devised by teaching staff of “La Scuola” in 1970 (for an example of a column and list, see Fig. 1). Each list of words included nine concrete nouns,¹ all of which were displayed in the column of pictures. To maintain the structure of the updating task used by Palladino and colleagues (2001), the list also included six filler items. These items had the function of increasing the overall amount of material that had to be processed during the updating operations, thereby offering a better simulation of what happens during complex everyday processes, including reading comprehension. However, to make this totally irrelevant material perfectly distinguishable from the critical material, filler items were abstract nouns selected for their high degree of familiarity to children (e.g., *truth*, *anger*, *lie*) and obviously not associated with any picture.

¹ Because item familiarity may affect a child’s memory (Nation, Marshall, & Snowling, 2003), the words used in the experiments were analyzed for familiarity. The concrete nouns included in the lists ranged in familiarity from 46.0 to 70.7; the closer the frequency index to 100, the higher the degree of familiarity (Marconi, Ott, Pesenti, Ratti, & Tavella, 1993). An exception was the noun *plum*, which was not present in the frequencies dictionary. The lists used in Experiments 1 and 2 did not differ in their mean frequencies.

Table 1

Means and standard deviations obtained by each group in the selection tasks in Experiment 1 ($N = 218$)

	Good comprehenders	95% CI	Poor comprehenders	95% CI
Reading comprehension	11.25 (1.05)	11.05–11.45	7.15 (1.43)	6.87–7.42
Reading decoding skill	19.31 (2.99)	18.74–19.88	19.00 (2.92)	18.45–19.55
Spatial reasoning PMA	16.29 (3.54)	15.62–16.97	15.40 (2.97)	14.84–15.97

Note. Standard deviations are in parentheses.

Participants listened to the list of words while looking at the column of pictures to detect the relevant information. The task required participants to recall the highest (or lowest) pictures in the column that were named in the word list. In each list, of nine concrete words, there were three items to be recalled (correct recall), three items that did not satisfy the criterion of the task and that could be excluded immediately (immediate intrusion), and three items that could be considered important but that had to be excluded later because they no longer were relevant (delayed intrusion).

When the request was to find the “lowest” items, the items to be recalled were located between positions 9 and 14. In the “highest” condition, items were located between positions 2 and 7. However, children were not informed about the range of positions within which the target items were going to appear, so they had to pay attention to all positions.

Procedure

Children were tested in small groups of four participants. At the beginning of the experimental session, they were required to name each picture to verify that all of the words were easily distinguishable.

The experimental session began with the researcher displaying the column of pictures. The experimenter then started reading the word list aloud (at a rate of 1 word/2s) while pointing, for concrete nouns, to the related pictures. The task involved recalling the three words depicted in the column that appeared in either the highest or lowest positions (the updating criterion was specified at the beginning of each trial). Half of the trials (four) had to be carried out following the highest criterion, and the remaining trials (four) had to be carried out following the lowest criterion (the criterion was balanced between subjects). Therefore, in the case of the lowest position criterion, items in the highest position could be immediately forgotten, whereas items close to the bottom part of the column had to be maintained for some time. For example, in the case of the column in Fig. 1, if the criterion was “recall the lowest three items,” the words *start*, *umbrella*, and *car* could be forgotten immediately, whereas the words *pen*, *tree*, and *elephant* had to be considered as relevant for a prolonged period of time. When a filler abstract noun was presented, the experimenter said “not in the column.”

A recalled word was considered to be a correct response if it respected the list order, not the column order. So, *sock*, *wheel*, and *mushroom* could be scored as correct. Ordered recall was preferred with respect to free recall, not only to be consistent with the typical measures of working memory, and particularly of updating, but also






	squirrel		
	star		
	egg		
	umbrella	Experiment 1	Experiment 2
	bulb	<i>Tree</i>	<i>Tree</i>
		Honesty	<u>Sock (I)</u>
		<i>Pen</i>	<i>Car</i>
	car	Sock	<u>Pen (I)</u>
		Shyness	<i>Star</i>
		<u>Car</u>	Umbrella
	lemon	Wheel	<u>Lemon (I)</u>
		Feeling	Elephant
	tree	<u>Star</u>	Mushroom
		Hate	
		<u>Umbrella</u>	
	elephant	<i>Elephant</i>	
		Character	
		Mushroom	
	pen	Laziness	
	wheel		
	mushroom		
	broom		
	sock		
	ball		

Fig. 1. Examples of a column of pictures and lists presented in Experiments 1 and 2, respectively. Bold words are items to be remembered (correct recall). Italic words are items to be forgotten successively (delayed intrusions). Underlined words are items to be forgotten immediately (immediate intrusions).

to make it impossible for children to use the simple strategy of focusing only on the column.

Recall was written. The test was preceded by a warmup session with two lists of words, and the warmup session could be repeated in case of a misunderstanding of the task. Before starting the actual trial, the experimenter commented on the performance of the children, giving some feedback on their performance.

Results

All children were able to complete the task. We computed the number of correctly recalled words, the number of intrusion errors, and the number of omissions. Responses were considered correct only if they were given in the order of presentation. To understand the characteristics of a poor performance in an updating task, we made a distinction within the category of intrusion errors from the current list; we calculated the numbers of immediate intrusions and delayed intrusions. No errors due to the recall of filler items were observed. However, there were some errors due to interference of visual material not included in the list of words, inventions, and order errors. These errors were rare, so we collapsed the data (we called this index “other errors”). Regarding errors, we also computed intrusion errors due to the recall of items from preceding lists.

The means and standard deviations obtained by poor and good comprehenders are reported in Table 2.

Correct recall

For the statistical analysis, each main performance index was split into two scores: one score for the first block of four trials and another score for the second block of the last four trials. A 2×2 mixed analysis of variance (ANOVA) design (Group \times Block of Trials) on correctly recalled words revealed a significant main

Table 2
Mean numbers and standard deviations of items recalled by poor and good comprehenders in Experiment 1

	Good comprehenders	95% CI	Poor comprehenders	95% CI
Correct recall ^a	20.62 (1.74)	29.29–29.95	15.67 (3.76)	14.95–16.38
Percentage of correct recall	85.93 (7.26)	83.63–88.24	65.29 (15.67)	62.99–67.60
Delayed intrusions ^b	1.86 (1.04)	1.66–2.06	5.92 (2.78)	5.39–6.45
Immediate intrusions ^c	0.10 (0.30)	0.04–0.15	0.28 (0.82)	0.13–0.44
Other errors	0.26 (0.46)	0.17–0.34	0.35 (0.63)	0.23–0.47
Intrusions from previous lists	0.12 (0.33)	0.057–0.18	0.18 (0.44)	0.09–0.27
Omissions	0.88 (1.14)	0.66–1.09	1.44 (1.92)	1.08–1.80

Note. Standard deviations are in parentheses. Values describe the summed number of items recalled in the eight lists.

^a Correct recall = items to be remembered.

^b Delayed intrusions = intrusions from items to be forgotten successively.

^c Immediate intrusions = intrusions from items to be forgotten immediately.

effects of group, $F(1,216) = 155.7$, $p < .001$, $\eta^2 = .419$ (for means and percentages, see Table 2), and block of trials, $F(1,216) = 21.96$, $p < .001$, $\eta^2 = .092$. The block of trials effect was due to the fact that the children's performance improved during the trials rather than being disturbed by proactive interference.

Errors

As can be seen in Table 2, the rates of intrusion errors from the preceding lists, other kinds of errors (intrusions from visual material, inventions, and order errors), and omissions were very low. So, it was impossible to compare performances between groups. This was also the case for immediate intrusion errors.

Among error measures, the most frequent seemed to be what we called delayed intrusions (i.e., intrusions of words–pictures that were relevant for a certain amount of time during the execution of the task). The 2×2 mixed ANOVA design, with group (good comprehenders vs. poor comprehenders) as a between factor and block of trials as a within variable, showed a main effect of group, $F(1,216) = 203.4$, $p < .001$, $\eta^2 = .485$, with poor comprehenders making this kind of error more often than good comprehenders, and a main effect of block of trials, $F(1,216) = 21.63$, $p < .001$, $\eta^2 = .091$, as both groups made more intrusion errors in the first block than in the second block. No interaction was observed.

Regression analyses

To directly assess the hypothesis that inhibition is the crucial mechanism in the relation between working memory and reading comprehension, after scoring reading comprehension as the dummy variable, we ran a logistic regression analysis, with reading comprehension as the dependent variable and the measures of correct recall and delayed intrusions as independent variables, using a stepwise selection method. Results of the analysis showed that the number of delayed intrusions was the best predictor of reading comprehension because it entered at the first step (the approximated pseudo- R^2 of Cox and Snell was .619). Correct recall measure entered at the second step with a modest increase of approximated pseudo- R^2 (the value at the second step was .646).

The role of inhibition was further examined by partialing out intrusion error measures from the relation between working memory capacity and reading comprehension and, alternatively, by partialing out working memory capacity from the relation between inhibition (intrusion errors) and reading comprehension. If the inhibitory mechanism plays a substantial role, the association between working memory and reading comprehension should become weaker when removing its effect. To summarize, the two hierarchical regression analyses either had correct recall as a criterion, delayed intrusions as a predictor in the first step, and reading comprehension in the second step (Model A) or had delayed intrusions as a criterion, correct recall as a predictor in the first step, and reading comprehension in the second step (Model B). In Model A, reading comprehension did not show a significant increase of R^2 (from .765 to .768), $B = .074$, showing that when partialing out the effect due to delayed

intrusions, the correlation between working memory capacity and reading comprehension was not significant. However, in Model B, the change of R^2 was significant (from .765 to .794) with $B = -.224$. That is, when removing the effect of working memory capacity, the correlation between reading comprehension and intrusion errors was still significant.

Discussion

Group comparisons showed an impairment for poor comprehenders in carrying out the updating task. Indeed, they recalled significantly fewer correct words and made significantly more intrusion errors than did good comprehenders. This result offers evidence in favor of the hypothesis that updating in working memory and updating in reading comprehension are related. The evidence was collected with a visually cued task, thereby relying on knowledge and language to a lesser extent than the task used previously by Palladino and colleagues (2001). Children were quite able to maintain the correct sequence of items; inversions were infrequent. These findings suggest that children clearly understood task requirements and were able to process temporal information.

Concerning memory errors, we computed intrusions of words–pictures learned in previous lists, intrusions of words–pictures temporarily coherent with the updating criterion during the execution of the task, and intrusions of words–pictures evidently not relevant to the updating criterion. Delayed intrusion errors were most common. Furthermore, poor comprehenders made more delayed intrusions than did good comprehenders, suggesting that poor comprehenders had difficulty in controlling information that was no longer relevant. It is worth noting that children could not simply rely on the positions of pictures in the column to recall the correct words; indeed, the positions of immediate intrusions in the column were not notably farther from the extremes than were the positions of the items requiring successive exclusion (delayed intrusions).

Moreover, several important points arose from the results obtained in the regression analyses. First, from the logistic regression analysis, we were able to demonstrate that the best predictor for reading comprehension was the measure of delayed intrusions. Second, the results of the hierarchical regression specified the role of the intrusion errors measure, assigning it a prominent role in the relation between reading comprehension and working memory. Indeed, we found that if the effect of inhibition is removed, the correlation between working memory capacity measure and reading comprehension completely disappears, whereas this is not the case in the reversed model.

Finally, the performance of both groups improved, and the number of errors due to pictures belonging to preceding lists continuously remained very low. This could be due to the fact that either proactive interference did not affect the level of recall in the updating task or the effect was compensated for by a practice effect as children progressively developed strategies to carry out the task. Another possible explanation for the absence of proactive interference is that the number of trials was not sufficient to produce interference.

We decided to run a second experiment to examine the generality and permanence of the effect because some children reported that during memorization they paid more attention to the figures in the part of the column closer to the required pole (highest or lowest). In fact, sometimes while carrying out the task it was necessary to force children to avoid focusing their attention on only the relevant part of the column (i.e., the highest or lowest part). In the second experiment, we changed the procedure to prevent this strategy. Lists of different lengths were presented, and children were asked to remember the three last pictures on the basis of their order in the word list, not on the basis of their positions in the column. Because children did not know the length of the list, they had to continuously update the group of target items. The modifications made to the task allowed us to manipulate the number of items to be excluded (from one to four). This modified task was administered to children from Experiment 1 who could be tested again. This second experiment took place during the subsequent academic year, and some participants had moved to different schools where they could not be contacted. Testing the same children also offered the possibility of examining the generality and stability of the poor performance in the working memory updating task observed in the group of poor comprehenders in Experiment 1.

Experiment 2

Method

Participants

A group of 30 poor comprehenders (16 boys and 14 girls) and a group of 30 good comprehenders (18 boys and 12 girls), ages 9 or 10 years, who had been part of the sample in Experiment 1 took part in the second experiment.² The subgroup of children could not be tested again for reading skills and spatial reasoning, but on the basis of the teachers' reports, the group of poor comprehenders appeared to have maintained their comprehension difficulties (on the persistence of specific reading difficulties, see Cornoldi et al., 1996).

Materials

In this experiment, 12 columns of 15 figures were prepared in the same way as in the first experiment, as were 24 lists of concrete nouns associated with the pictures in the columns, two lists for each column (Fig. 1). Lists included either one, two, three, or four items to be ignored (immediate intrusions) and either one, two, three, or four

² During the selection phase of Experiment 1, good comprehenders had obtained the following scores: reading comprehension, $M = 10.47$, $SD = 0.68$; reading decoding skill, $M = 16.97$, $SD = 2.33$; and spatial reasoning, $M = 13.50$, $SD = 2.85$. Poor comprehenders' scores were as follows: reading comprehension, $M = 6.57$, $SD = 1.63$; reading decoding skill, $M = 16.50$, $SD = 1.98$; and spatial reasoning, $M = 13.70$, $SD = 3.18$.

items to be excluded later (delayed intrusions) as well as three final items to be remembered (correct recall). Thus, in this version of the updating task, the length of the list varied from 5 to 11 items. The task of the participants was to recall the last three items of each list of words. Target items were the last three in half of the lists, whereas in the other half they were mixed with the items to be ignored. The items to be ignored appeared before the items to be recalled in 12 lists. In the other 12 lists, items to be ignored were presented mixed with items to be recalled. This was done so that children could not use the cue of the absence of items to be ignored to conclude that they were near the end of the list. The category of items to be ignored made it possible to eliminate the abstract fillers, which could have caused confusion in Experiment 1.

Procedure

The procedure was approximately the same as for the first experiment. Children were again tested in groups of four. At the beginning of the experimental session, they were required to name each picture to verify that all of the words were easily distinguishable.

The experimental session began with the researcher displaying the column of pictures. The experimenter then started reading the word list aloud (at a rate of 1 word/2 s) while pointing to each related picture. When a to-be-ignored noun was presented, the experimenter simply said “to be ignored.” The task involved recalling the three last words in each list.

Recall was considered correct if it respected the list order, not the column order. Thus, *umbrella*, *elephant*, and *mushroom* could be scored as correct responses (Fig. 1). Recall was written. The test was preceded by a warmup session with two lists of words, and the warmup session could be repeated in case of a misunderstanding of the task. Before starting the actual trial, the experimenter commented on the performance of the children, giving some feedback on their performance.

Trials were divided into two blocks comparable in list length and organization. The status of the words across the lists (to be recalled, to be ignored, and to be updated later) was controlled to avoid a word appearing in the same position throughout the lists.

Results

All children completed the task. As in Experiment 1, we computed the number of words correctly recalled and the number of errors, and we obtained for the main indexes separate scores for the first half and second half of trials. Responses were considered correct only if they were given according to the order of presentation. We again distinguished between two main categories of error; we calculated the number of delayed intrusions and the number of immediate intrusions. As in Experiment 1, there were some errors due to interference of visual material not included in the list of words, some order errors, and some inventions. These errors were infrequent, so we collapsed the data (other errors). Regarding errors, we also computed intrusion errors due to the recall of items from preceding lists.

Correct recall

A 2×2 mixed ANOVA design (Group \times Block of Trials) on correctly recalled words revealed a significant main effects of group, $F(1, 58) = 46.58$, $p < .001$, $\eta^2 = .443$, and block of trials, $F(1, 58) = 14.39$, $p < .001$, $\eta^2 = .199$, and an interaction between these variables, $F(1, 58) = 5.001$, $p < .05$, $\eta^2 = .079$. Post hoc comparisons using Tukey's method showed that the block of trials effect was significant only for poor comprehenders ($p < .01$). Their performance improved from the first block to the second block, whereas that of good comprehenders did not. However, the performance of good comprehenders was always better than that of poor comprehenders.

Because the number of updates in each list was different in this experiment, it was possible to verify whether the number of required updates affected performance. A 2×4 ANOVA (Group \times Number of Updates) confirmed the main effect of group, $F(3, 174) = 46.45$, $p < .001$, $\eta^2 = .445$, and revealed a main effect of number of updates, $F(3, 174) = 13.04$, $p < .001$, $\eta^2 = .184$, whereas the interaction between group and number of updates was not significant ($F < 1$). Post hoc comparisons using Tukey's method ($p < .05$) showed that the mean number of correct responses when the number of updates was 1 ($M = 14.38$, $SD = 2.66$) was significantly greater than when the number of updates was 2 ($M = 13.08$, $SD = 2.84$), 3 ($M = 12.28$, $SD = 3.69$), and 4 ($M = 12.93$, $SD = 3.32$) (Fig. 2).

Errors

As in Experiment 1, the number of intrusion errors from previous lists and the number of other errors were very low (Table 3). For this reason, we could not carry out statistical analyses on these data. However, the rate of immediate exclusion

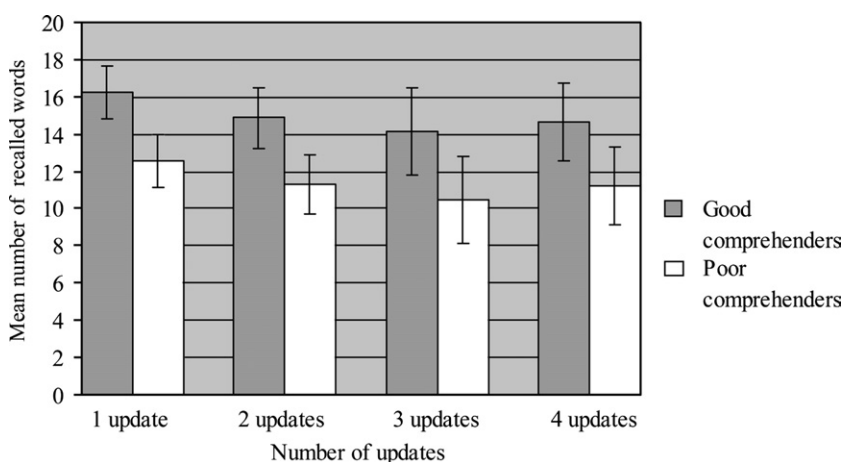


Fig. 2. Mean numbers of correctly recalled words (correct recall) as a function of number of updates by poor and good comprehenders in Experiment 2. Bars represent the 95% confidence interval.

Table 3

Mean numbers and standard deviations of items recalled by poor and good comprehenders in Experiment 2

	Good comprehenders	95% CI	Poor comprehenders	95% CI
Correct recall ^a	59.60 (4.42)	57.95–61.24	45.30 (10.65)	41.32–49.27
Percentage of correct recall	82.78 (6.13)	78.63–86.92	62.92 (14.79)	58.78–67.06
Delayed intrusions ^b	4.57 (2.10)	3.78–5.35	12.20 (12.18)	7.65–16.75
Immediate intrusions ^c	3.10 (1.96)	2.33–3.80	4.13 (3.04)	2.99–5.27
Other errors	0.53 (1.14)	0.11–0.95	0.40 (0.56)	0.19–0.61
Intrusions from previous lists	0.60 (0.77)	0.31–0.89	1.03 (1.21)	0.58–1.49
Omissions	3.07 (2.93)	1.97–4.16	8.37 (8.59)	5.16–11.58

Note. Standard deviations are in parentheses. Values describe the summed number of items recalled in the 24 lists.

^a Correct recall = items to be remembered.

^b Delayed intrusions = intrusions from items to be forgotten successively.

^c Immediate intrusions = intrusions from items to be forgotten immediately.

intrusions was higher than in Experiment 1, perhaps because the new procedure emphasized this type of item. Also, the number of omissions was higher than in Experiment 1. The ANOVA of the influence of the number of updates on omissions, with group as a between factor, showed a main effect of group, $F(1, 58) = 11.1$, $p < .01$, $\eta^2 = .161$, and no other effect or interaction. Thus, omissions did not increase as a function of the number of updates.

To understand the role of inhibition in working memory, we distinguished within the category of errors “intrusions from the same list” due to words that participants had to maintain for some time (delayed intrusions) or words that they could immediately exclude (immediate intrusions). A $2 \times 2 \times 2$ ANOVA (Group \times Block \times Kind of Intrusion) on the mean number of intrusion errors showed main effects of group, $F(1, 58) = 13.64$, $p < .001$, $\eta^2 = .190$, block, $F(1, 58) = 4.15$, $p < .05$, $\eta^2 = .067$, and kind of error, $F(1, 58) = 16.41$, $p < .001$, $\eta^2 = .221$, and an interaction between group and kind of error, $F(1, 58) = 7.76$, $p < .01$, $\eta^2 = .118$ (Table 3). Post hoc comparisons with Tukey’s method showed that poor and good comprehenders did not differ in the number of immediate intrusions; however, they did differ in the number of delayed intrusions ($p < .01$).

A 2×4 ANOVA (Group \times Number of Updates) on delayed intrusions showed a main effect of group, $F(1, 58) = 11.92$, $p < .001$, $\eta^2 = .171$, and a main effect of number of updates, $F(3, 174) = 5.69$, $p < .001$, $\eta^2 = .089$. The interaction was not significant. Poor comprehenders made more intrusion errors than did good comprehenders. The number of updates affected the performance of both groups; in particular, a higher number of intrusions was made when three updates were requested ($p < .01$) (one update: good comprehenders, $M = 0.77$, $SD = 0.82$, poor comprehenders, $M = 2.13$, $SD = 1.76$; two updates: good comprehenders, $M = 1.07$, $SD = 0.94$, poor comprehenders, $M = 2.73$, $SD = 2.45$; three updates: good comprehenders, $M = 1.47$, $SD = 1.25$, poor comprehenders, $M = 3.73$, $SD = 4.57$; four updates: good comprehenders, $M = 1.20$, $SD = 0.92$, poor comprehenders, $M = 2.97$, $SD = 3.43$).

Reliability and stability of updating measures

In this study, we also examined the psychometric properties of the main measures obtained with the updating tasks. The reliability of the measures was calculated using a split-half method corrected with the Spearman–Brown formula. We found good values for both the recall measures (.78 in Experiment 1 and .86 in Experiment 2) and the delayed intrusions (.73 in Experiment 1 and .90 in Experiment 2).

To verify the stability of the updating problems for the children involved in our studies, we computed the correlations between the two main indexes obtained in the two versions of the updating task for the overall sample (60 children) in the two experiments. The correlation between the correct recalls in the updating tasks of Experiment 1 and Experiment 2 was rather high ($r = .66$), and we also found a weaker but significant correlation ($r = .42$) between the two measures of delayed intrusion errors. These results suggest that the poor comprehenders' difficulty in controlling the activation of information in working memory on the basis of its relevance with the task lasts over time and is generalized to different updating measures.

Discussion

Experiment 2 confirmed the main results of Experiment 1 concerning the working memory updating deficit of poor comprehenders. In fact, poor comprehenders had a lower recall and a higher number of intrusion errors than did good comprehenders. Furthermore, the experiment clearly showed that the degree of item activation in working memory affects the efficiency of the updating process because the items to be excluded later were recalled more frequently than were those to be excluded immediately. This conclusion is particularly evident for participants with reading comprehension difficulties. Results of the second experiment converge toward an interpretation where the poor comprehenders' difficulty is due to inefficient control mechanisms. Indeed, an inspection of Table 3 suggests that poor comprehenders' impairment seems to be related more to a difficulty in controlling interference from material currently encoded than to a capacity deficit. However, in Experiment 2 another error measure was capable of distinguishing between good and poor comprehenders' performance, namely the number of omissions. Poor comprehenders made more omissions than did good comprehenders. This increase in the number of omissions could be due to differences in the strategies used in the two experiments, for example, bringing some children to wait until the end of the list before detecting the last three items (Ruiz et al., *in press*). Consistent with this view, we found that the effect of number of updates slightly affected recall performance in correspondence with an increase in the number of updates. The number of updates also moderately influenced the frequency of delayed intrusion errors but not the number of omissions. In the case of intrusions, their number was particularly high when three updates were requested, but there was no difference in the pattern of errors between groups.

General discussion

The main goal of the experiments was to clarify the relation between reading comprehension and updating in working memory. The results of our two experiments offer further information on the nature of the difficulties some people encounter in working memory tasks and on the underlying processes. In fact, our findings confirm the general observation that people with reading comprehension difficulties have problems in working memory tasks (Swanson & Ashbaker, 2000). Of course, finding an association between working memory and reading comprehension does not necessarily imply a causal relation. But it does suggest that the association is reliable and can be generalized to different working memory tasks.

We focused our attention on the process of updating in working memory considering its close relation with reading comprehension, and we found evidence showing that children, carefully selected for a specific reading comprehension problem, also showed poor working memory in two different updating tasks, thereby giving support to the preceding observations in the same direction (Palladino et al., 2001). The reliability of this relation was questioned in a study on situation models (Radvansky & Copeland, 2001, 2004). Obviously, situation model updating goes beyond the simple maintenance of information in working memory, involving different sets of cognitive operations. The results of Radvansky and Copeland (2001) suggest the need to better clarify the mechanism that operates in working memory to establish its supposed relation with reading comprehension. Studying the updating process, which in some ways also involves the ability to suppress irrelevant information, could add new insights to this topic.

The results of both experiments show that poor comprehenders have difficulty in carrying out a task that requires selecting relevant information and suppressing irrelevant information. Their performance is particularly poor when information that was initially relevant then becomes irrelevant, as shown by the fact that the only type of intrusion error that differentiated poor comprehenders from good comprehenders was the frequency of delayed intrusion errors. This result seems to indicate that the main problem for poor comprehenders is the ability to control activated information (Carretti et al., 2004; De Beni et al., 1998).

An alternative explanation could attribute to a poorer memory the phenomena of intrusion errors. In this case, poor comprehenders, because of more limited capacity, would not have been able to maintain the three target items simultaneously. So, during the retrieving phase, they would have had to guess to remember all three items. This explanation would predict that poor comprehenders would try to compensate for their memory losses with any encoded information. However, the higher frequencies of delayed intrusions with respect to the other types of intrusion errors suggest that something more is needed to explain the poor comprehenders' performance. We think that the hypothesis of a less efficient inhibition mechanism could be a way of accounting for the results observed.

The plausibility of this conclusion is also supported by previously collected data (De Beni et al., 1998). De Beni and colleagues (1998) demonstrated that the recall performance of poor comprehenders was exactly the same as for good comprehenders in

carrying out a double task that did not require controlling for irrelevant information. The authors concluded that when partialing out the request for inhibiting information that is no longer relevant, there was no difference between poor comprehenders and good comprehenders.

Converging evidence also comes from looking at the errors in Experiment 1; omissions were comparable in the two groups and were less frequent than delayed intrusions. In Experiment 2, poor comprehenders made more omissions, but omissions again were less frequent than delayed intrusions. If the updating difficulties had concerned storage, omissions would have been more frequent than delayed intrusions. However, although results of the two experiments are generally consistent, the increase in the number of omissions in Experiment 2 suggests that other factors, related either to storage or to specific strategies (Ruiz et al., *in press*), affected the performance of poor comprehenders. For example, it is likely that instead of adopting an active processing strategy, dropping the irrelevant items in favor of relevant items, some poor comprehenders tried to postpone updating toward the end of the list.

The role of specific strategies could also have produced the modest decrease in updating performance with an increase in the number of required updates. In the current study, an increase in the number of items to be selected moderately affected recall and intrusions of the two groups. This result is mostly unexpected but is similar to that obtained in the first experiment of Palladino and colleagues (2001). In their first experiment, they adopted Morris and Jones's (1990) procedure, which could only require a selection based on a recency criterion. Indeed, participants could use a strategy of waiting to memorize items from the second or the third position, thereby making an incomplete updating. Carrying out the updating task in such a manner could lead to a smaller, or even a null, effect of the number of updates in the final recall. In any case, the results are consistent with the idea that the problem of poor comprehenders is not due to a capacity deficit because the number of to-be-recalled words remained nearly the same across all of the lists independently of their length.

Results from the regression analyses assigned an important role to the inhibition mechanism in the relation between reading comprehension and working memory. Indeed, results revealed that inhibition could be considered the mediator between reading comprehension and working memory recall.

The correlation analysis in Experiment 2 suggests that the poor comprehenders' updating difficulties persist. Furthermore, both experiments showed a small increase in poor and good comprehenders' performance from the first block to the second block, probably due to the effect of learning or strategy use. Thus, a change in the strategies used to carry out the task should enhance the poor comprehenders' performance, confirming the importance of strategic knowledge and use, even in a working memory task (see, e.g., McNamara & Scott, 2001). We think that this is interesting from a practical point of view because it suggests the possibility of enhancing the poor comprehenders' ability to select relevant information using metacognitive training methods (see, e.g., Lucangeli, Galderisi, & Cornoldi, 1995).

As mentioned earlier, the effect of proactive interference in updating tasks was modest. Previously learned information did not interfere with new information. In fact, the higher disturbing effect was due to currently processed information that

interfered with relevant information during the retrieval phase. Our results are consistent with Bellezza's (1982) research showing that the updating task is not susceptible to the disruptive effect of previously learned information.

To summarize, we collected new evidence regarding the importance of updating processes and inhibition mechanisms in the relation of working memory to reading comprehension. With respect to inhibition, we found that the degree of items activation influences memory performance of participants; poor comprehenders showed more sensitivity to interference of the more activated items than did good comprehenders. In agreement with Friedman and Miyake's (2004) results, our data suggest that inhibition mechanisms are important for a successful working memory performance (Carretti et al., 2004), but they also highlight the need to better clarify the mechanisms underlying updating and to devise tasks that allow better control of the strategies used to manage items in working memory.

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