Reading Comprehension and Working Memory's Executive Processes: An Intervention Study in Primary School Children

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Introduction.

Working Memory (WM) is a central component of the cognitive neuroscience view of the human mind. WM capacity refers to the number of items that can be recalled during a complex working memory task. From a conceptual perspective, there is no general agreement about the definition of WM capacity, namely because there are diverse theories that show some basic agreement but emphasize different aspects of working memory (see Miyake & Shah, 1999). Nevertheless, there is no question that one of the most influential of these theories is the Multiple Component Model proposed by Baddeley and Hitch (1974; Baddeley, 1986, 2000, 2007).

According to this theoretical model, the working memory system includes two domain-specific storage structures or slave systems (the phonological loop and the visuo-spatial sketchpad), an episodic buffer that links the two prior components with long term memory, and a central executive. The central executive is the main component of the working memory system. It not only has to co-ordinate the other components, but it is also in charge of the attentional control of information.

There are also two related and influential recent models of WM: Cowan´s Embedded-Processes Model (Cowan, 1999) and Engle´s General Capacity Model (Engle, 2001; Unsworth & Engle, 2007). Unlike Baddeley's Multiple Component model, both models neglect the existence of domain specific components in WM. In Cowan´s Model there is just one basic memory repository (similar to long-term memory) in which information can be activated at different levels. According to Cowan, working memory entails an 'embedded' subset of activated information which is more salient by bringing it into the focus of attention. On the other hand, Engle and colleagues define working memory more explicitly as a system consisting of highly activated long-term memory traces that are active above threshold as short-term memory representational components. In spite of their differences, Baddeley, Cowan and Engle's models all share the idea of a domain general central executive whose main functions are to focus and switch attention, to activate and update representations, and to inhibit automatic processes and discard irrelevant information (see Baddeley, 2007; Cowan, 2005; Engle, 2002; Miyake, Friedman, Emerson, Witzki & Howerter, 2000). The executive functions of WM during reading comprehension are the main focus of this paper.

Working memory is closely related to general intelligence as a number of studies have shown (see, for instance, Ackerman, Beier & Boyle, 2005; Colom et al., 2008; Kyllonen & Christal, 1990). However, the exact nature of the processes that underlie and explain this relation is a matter of debate among researchers. One main piece of evidence established is the relationship between working memory and fluid intelligence, that is, the individual's ability to reason with novel problems (see Cornoldi, 2006; Kane et al., 2004; Oberauer, Schulze, Wilhelm, & Süß, 2005). According to Engle and colleagues (Engle, Tuholski, Laughlin & Conway, 1999; Kane & Engle, 2002; Unsworth & Engle, 2005), executive control is the crucial component in the explanation of the relations between working memory and fluid intelligence: the individual's ability to maintain attentional control in complex tasks that require one to resist and control interfering information. But not all the executive functions seem to be equally related to intelligence; Friedman et al. (2006; see also Chen & Li, 2007) found that updating predicted fluid intelligence in young adults better than inhibition or switching. In more recent work, Belachi, Carretti & Cornoldi (2010) investigated the role of updating and other various WM measures in predicting fluid intelligence measured by means of the Raven Coloured Matrices test in children aged 5-11 years. The results showed a strong relation between fluid intelligence and diverse measures of WM capacity and executive processes, but the best predictor of fluid intelligence was updating. These findings throw light on another focus of our paper, the relationship between WM's executive processes and fluid intelligence in children.

Reading comprehension demands that people store text information recently decoded and that they apply complex processes of meaning construction in order to arrive at an integrated representation or situational model (e.g. Kintsch, 1998). In other words, we consider text comprehension as a highly demanding cognitive task that implies the simultaneous process of extracting and constructing meaning (Snow & Sweet, 2003). In order to extract and construct meaning, readers must engage in a process of knowledge activation and use which we call making inferences (Kintsch, 1998). As numerous authors have maintained, working memory plays a crucial role in storing the intermediate and final products of readers' computations, as well as coordinating the processes of constructing and integrating the semantic representation from a text (e.g. Cain, 2006; Ericsson & Kintsch, 1995; Gathercole & Baddeley, 1993; Just & Carpenter, 1992).

Some authors (see Britton & Graesser, 1996; García Madruga, Martín Cordero, Luque & Santamaría, 1992; Kintsch, 1998; van Oostendorp & Goldman, 1999) have stressed the importance of active processing during reading in order to achieve this semantic representation. The key idea is that comprehension depends essentially on the reader's active use of knowledge that guides his or her strategies towards the construction of meaning from textual information (García Madruga, 2006). This active process of building meaning, as well as the necessary metacognitive monitoring during reading (Baker, 1989; Wagoner, 1983) underscores the importance of attentional control and enhances even more the role of executive control processes in reading comprehension.

It is hence unsurprising that learning to read comprehensively is often a rather complicated acquisition. It demands that the perception and identification of letters and words is automated so that cognitive resources are left free to be assigned to the construction of meaning and the representation of the situation that the text describes. However, even if the superficial tasks implied in reading are adequately automated, some difficulties may appear at higher levels of comprehension (see Oakhill, & Cain, 2007).

The relationship between working memory span and reading comprehension has been well established in the literature (see, for instance, Daneman & Merikle, 1996). Working memory (WM) capacity is closely related to diverse reading comprehension skills (e.g. De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000). Moreover, children with high WM scores typically show good comprehension reading skills; and, conversely, children with poor WM scores tend to perform below average on reading comprehension measures (see Baddeley, 2007; Cain, Oakhill & Bryant, 2004; Swanson and Howell, 2001; Vukovic & Siegel, 2006). For example, Cain, Oakhill & Bryant (2004) reported data from a longitudinal study that addresses the relationship between working memory capacity and reading comprehension skills in children aged 8, 9, and 11 years. At each point in time, working memory and component skills of comprehension predicted unique variance in reading comprehension after controlling for word reading, vocabulary and verbal abilities. More recently, Vukovic & Siegel (2006) extended these findings by demonstrating that working memory plays an important role in reading comprehension even after controlling for phonological awareness and rapid naming.

As for the involvement of the diverse WM components in reading comprehension, verbal working memory is an obvious component as shown by studies that have used Daneman & Carpenter's Reading Span test (RST, e.g. Daneman & Carpenter, 1980; García-Madruga, Elosúa, Gutiérrez, Gárate & Luque, 1999; Hannon & Daneman, 2004). RST is a good measure of verbal working memory, but since it requires some kind of attentional control, RST is also a measure of WM's central executive (see Engle & Oransky, 1999; García-Madruga, Gutiérrez, Carriedo, Luzón & Vila, 2007; Whitney, Arnett, Driver & Budd, 2001). Along this line, recently, an increasing number of authors have underscored the role of the diverse yet interrelated executive processes of WM in reading comprehension. In particular, Swanson, Howard & Saez (2006) have pointed out that the executive function of coordinating cognitive operations is required by the integration of information from text and long-term memory (2001; see also Carretti, Cornoldi , De Beni & Romanó, 2005). Palladino, Cornoldi, De Beni & Pazzaglia have linked WM's updating to reading comprehension skills; and De Beni & Palladino (2000, see also Carretti, Borella, Cornoldi & De Beni, 2009) and Savage, Cornish, Manly & Hollis (2006) have underscored the function of inhibiting and discarding information in reading comprehension.

In this paper, we consider that the comprehension of difficult texts such as those read by children at school requires readers to apply all of the executive processes of WM: focusing on complex reading tasks and switching attention between diverse textual information and the required cognitive tasks, activating knowledge from long term memory and updating an integrated representation of the meaning of the text, and inhibiting possible representations and discarding irrelevant information.

In the last decade some authors have highlighted the importance of having the teaching of WM and its executive processes embedded into the classroom curriculum. For instance, Gathercole, Lamont & Alloway (2006) defended the importance of identifying WM problems as a source of learning difficulty in individual children and of reducing the opportunities for learning failures by minimizing WM demands in classroom activities. As a way to achieve this goal with first and second graders, school staff received guidance in order to identify WM failures in the classroom, as well as instruction about how to minimize this kind of failure in individual children (e.g. cutting down the processing load of the task, using external memory aids, ensuring that the child can remember the task). Along the same line, Meltzer, Pollica & Barzillai (2007) developed a strategy-based classroom intervention based on teaching strategies that address executive functions in the classroom. Likewise, Gaskins, Satlow & Pressley (2007) addressed a systematic and goal-oriented approach to teach reading comprehension strategies in elementary school. Their approach promotes the use of different executive processes to enable readers to monitor whether what they read makes sense and to take charge of whether they understand what they read.

Some other authors have even shown that children of different ages, with and without ADHD, and young adults can reach a sustained enhancement on diverse WM and intelligence measures after going through an intensive adaptive WM training program (see Jaeggi, Buschkuehl, Jonides & Perrig, 2008; Jaeggi et al., 2010; Klingberg, Forssberg & Westerberg, 2002; Thorell, Lindqvist, Bergman Nutley, Bohlin & Klingberg, 2009). In spite of the close relationship between WM and reading comprehension, most of these latter studies on WM training did not analyze their effect on reading comprehension. In our knowledge, there is only one study (Dahlin, 2011) that showed an increase in reading comprehension after WM training. In Dahlin’s work, primary school children with special needs were trained using a procedure based on Klingberg, Forssberg & Westerberg (2002) for ADHD children. After daily individual training at school for 30–40 min, over a period of 5 weeks, the results showed a substantial improvement in reading comprehension tasks.

There are, however, some recent publications that have questioned the efficacy of training on WM. Two of them are particularly relevant: Melby-Lervåg & Hulme (2012) and Shipstead, Redick and Engle (2012). The first is a meta-analytic review of thirty-three studies with clinical and typically developing samples of children and adults. Melby-Lervåg & Hulme (2012) conclude that these training programs yield only near-transfer effects, and that there is no evidence that these effects are durable. Likewise, these authors cast doubt on the relevance and theoretical basis of studies seeking to train WM in order to enhance cognitive functioning. They claim that they "do not appear to be based of any clear theory of the processes involved or any clear task analysis" (2012, p. 13). As Melby-Lervåg & Hulme explicitly acknowledge, the problem with meta-analyses is that they bring together studies that widely differ in their characteristics and theoretical perspectives. As we have just claimed, some of the studies included in the Melby-Lervåg & Hulme's meta-analysis are relevant towards the enhancement of cognitive functioning and also are theoretically sound. However, in agreement with Melby-Lervåg & Hulme, in some of the training programs a clearer analysis of the processes involved and the tasks used is missing. In this paper we attempt to be more precise in the analysis of the processes involved and the tasks used in training.

The second critical paper is that of Shipstead, Redick & Engle (2012). It undertakes a more theoretically based analysis and review of studies that focus on the training of working memory. These authors pose three main general concerns of studies on WM training: a) the use of single tasks to decide a change in one ability; for instance, only utilizing the Reading Span test for WM or the Raven Matrices for fluid intelligence; b) the lack of a consistent use of valid WM tasks, different from those used in training, in order to evaluate WM training effects; they rightly also criticize the use of simple Short-term memory tasks instead of complex WM span tasks; and c) the use of non-contact control groups, in which individuals "participate in pre- and posttest sessions but are not otherwise engaged in the experiment"; the especial involvement and higher motivation of experimental participants can affect the results of training groups. Shipstead et al., (2012) conclude that the results found in these studies are preliminary; although they are in some respects clearly promising, they do not provide sufficient evidence of the efficacy of working memory training. We also attempt in this paper to avoid at least some of the above criticisms by using more appropriate WM span tasks (not short-term memory tasks), different tasks in the pre- and posttest than used in training; as well as more than one measure for one ability (WM's executive processes) and active contact groups, when possible.

The main aim of the present paper is to train normally developing children on WM's executive processes involved in reading in order to improve their reading comprehension abilities. Our perspective shares many features with that of the WM training programs just discussed, but it is also partially different: we have not trained participants using WM tasks (except for the case of Anaphora and Analogies WM tasks). Instead, we have trained them with text processing tasks that demand high attentional control; that is, reading comprehension tasks in which WM's executive processes are particularly involved (focusing, switching, connection with knowledge, semantic updating in WM, and inhibition).

Experiment 1

In this experiment we evaluated reading comprehension, working memory and intelligence in two groups of primary school students and carried out an intervention to improve reading comprehension. Likewise, as a measure of children's ability to recognize written words, we assessed their orthographic ability. Thus, the aim of the study was to evaluate the impact of a training program designed to improve reading comprehension by boosting the main functions of the central executive (CE) related to it: focusing, switching, the activation of long-term representations and updating, and the inhibition of irrelevant information. We were also interested in assessing possible transfer effects of training to intelligence and WM's executive processes measures.

Our hypotheses were twofold:

1. In the Experimental group we predict a significant increase after training in the posttest measure of reading comprehension. The increase in the Experimental group in reading comprehension will be significantly higher than that obtained in the Control group.
2. There will be positive correlations in the pretest among the three cognitive variables studied: reading comprehension, working memory and intelligence.

Method

Design and Participants

We used an intervention design with pretest and posttest measures and an active control group. Thirty five third-grade students from a middle socio-economic level school in Alcobendas (Madrid) participated in the experiment. Data are reported from the thirty-one children aged between 8 and 9 years that completed the training program (M = 8.42; SD = .46). They were randomly assigned either to the Experimental Group (n= 15; M = 8.52; SD = .49) or the Control Group (n= 16, M = 8.32; SD = .42)

Procedure

The pretest evaluation was carried out at the end of the third-grade course (May 2009), whereas the intervention and posttest evaluation were performed by students during their fourth-grade course. Children in the Experimental group were trained for 12 days in their normal classroom for 50 minutes, over a period of 4 weeks. They carried out a number of reading comprehension tasks that are directly related to one or more of the functions of the central executive. During the training process all participants received a workbook that included the diverse exercises to be performed in each session. Participants were asked to write their responses to the diverse exercises in these workbooks, which were collected by experimenters at the end of each session. Children in the Control group received normal classes from their teacher in Spanish Language and reading comprehension instead of experimental training. All participants were assessed on measures of reading comprehension, WM and Intelligence, before and after training.

Pretest and posttest measures

Reading comprehension

To measure reading comprehension, we used a Spanish version of the Diagnostic Assessment of Reading Comprehension (DARC; August, Francis, Hsu & Snow, 2006; Francis et al., 2006). This new test is based on a theoretical analysis of reading comprehension and consists of four main components (Hannon & Daneman, 2001). The task requires children to silently read three short texts and answer 44 related comprehension questions. Presented in narrative-style, the texts consist of four small paragraphs that describe transitive relations among a set of real and artificial entities. For instance, "Maria likes to eat fruit. Most of all, she likes to eat nuras. A nura is like an orange. But a nura is bigger than an orange". Combining the information in the text with world knowledge should, in principle, allow for the construction of a five-entity-long linear ordering along a dimension that is likely to be familiar to all children. Three of the entities are unknown to all readers (artificial terms) and they are presented as nonsense words, whereas two of the entities referred to are likely to be known by all children (real terms) and which differ strikingly on the critical dimension. After each text, readers are asked a series of sixteen “yes-no-I don´t know” questions. The comprehension questions are designed to assess readers´ performance on four central components of the comprehension processes: (a) *knowledge* access, i.e., accessing relevant prior knowledge from long-term memory (e.g., “An orange has a peel”); (b) *text memory*, i.e., recalling from memory new information presented in the text (e.g., “Maria likes to eat fruit”); (c) *inferences,* i.e., making novel inferences based on information provided in the text but without prior knowledge (e.g., “A nura is smaller than an orange”); and (d) *integration*, i.e., integrating accessed prior knowledge with new text information (e.g., “You peel a nura to eat it”). Participants are encouraged to read the text carefully at their own pace and to answer the comprehension questions without having the text in front of them. The task is preceded by a practice text and some comprehension questions across each category. The scores are based on the number of correct answers in the four categories of questions related to the basic processes underlying reading comprehension. For the Spanish version of the DARC, the coefficient of reliability for the total score was .87.

Working memory

A Spanish version of the Reading Span test (RST; Daneman & Carpenter, 1980; Spanish version, Orjales, García-Madruga & Elosúa, 2010) for primary school children was used. In this task, participants are asked to read a series of sentences presented on a computer screen out loud and then to recall the last word of each sentence in the correct order. The sentences were very simple and easy to read, using familiar words. The task includes diverse levels in which the number of sentences progressively increases from 2 to 6. There were 3 series of sentences in each level. The scoring procedure was developed by Elosúa, García-Madruga, Gutiérrez, Luque & Gárate, (1997) for the RST. This procedure scores the number of words that participants are able to remember with minimum consistent performance. In each of the three series at each level, participant's performance can be (1) correct (accurate words, correct order), (2) half correct (accurate words, incorrect order), and (3) incorrect. The minimum consistent performance at each level is reached when a participant performs at least half of the maximum: that is, either three series of words half-correct; or one series of words correct, one half-correct, and one incorrect. Every performance better than the minimum consistent performance, at the same or higher levels was scored by the addition of decimals. In the same level, each supplementary correct response would add two decimal points and each supplementary half-correct response one decimal point. For instance, minimum consistent performance at the third level is 3, and maximum performance at the third level is 3.3; if a participant remembers only two of the three series of three words (level 3) accurately and in the correct order, his scoring would be 3.1. At a higher level, a supplementary correct response would add 5 decimal points and a supplementary half-correct response 4 decimal points. For example, if the previous participant also remembers a series of 4 words (level 4), but in the incorrect order, his scoring would be 3.1 + .4 = 3.5.

Intelligence

We used the Matrices Subtest of the Kauffman Brief Intelligence test (KBIT; Kaufman & Kaufman, 2000). This test evaluates non-verbal fluid intelligence: it assesses a child's ability to solve new problems by perceiving relationships and completing abstract analogies. Because items contain pictures and abstract designs rather than words, you can assess nonverbal ability even when language skills are limited. Full-color items appeal to children, particularly those who are reluctant to be tested. For the Spanish version of the Matrices subtest, in 8 years old children, reliability coefficient was .80.

Training Program

Children engaged in training on a variety of reading tasks which were especially designed to tap into the four executive functions (i.e. focusing, switching, connecting with long-term knowledge and updating of mental representations, and the inhibition of irrelevant information) for approximately 50 minutes a day during 12 days over a four-week period.

The battery of tasks included in the training enabled us to systematically vary demands on the executive abilities required to perform these successfully in different proportion. The focusing function is present in all the tasks. This is because it demands children to focus their attention on specific and relevant information to resolve the task. The switching function is particularly required on the tasks in which readers have to shift back and forth between diverse pieces of information, or when the task includes diverse sub-tasks. Connecting with long-term knowledge is particularly necessary when performing tasks that require combining information from the task with information from long-term memory. The function of updating mental representations is particularly present in those tasks which require monitoring and coding incoming information relevant to the task at hand, and then appropriately revising the items held in working memory by replacing old, no longer relevant information with newer, more relevant information (Morris & Jones, 1990). Finally, the inhibition of irrelevant information concerns tasks in which children need to inhibit or override the tendency to produce a more dominant or automatic response. The tasks used to tap into each executive function are presented in Table 1. Their content and students' demand are described below.

The training was carried out by two researchers in the classroom during an ordinary scholastic period. At the beginning of each session, students received a workbook in which they had to fill out the solutions to the tasks completed during the session. In the first session one of the researchers explained in a detailed and direct way the component processes as well as the outcome of reading comprehension. For this purpose, the instructor used a sentence from George Miller (1977: "The Smith saw the Rocky Mountains while they were flying to California"), adapted to the cultural features of Spanish children living in Madrid: "Laura vió la Sierra de Navacerrada mientras volaba a Barcelona".

Participants understood and agreed that comprehending this sentence implies the participation of diverse mental processes and the integration of text information and prior knowledge in order to build a representation that shows a child, "Laura", seeing the "Sierra de Navacerrada" through the small window of an airplane.

Researchers tried to gradually increase the difficulty of the tasks and the items within each task, adopting an adaptive training perspective despite the obvious limitations of collective training in a classroom setting. Children performed different tasks each day, selected from a bank of ten kinds of tasks: Vignettes in Order, Sentences in Order, Decoding Instructions, Anaphora and Analogies, Inconsistencies, Inferences, Main idea, Changing Stories and Integrating Knowledge.

In the *Vignettes in Order* and *Sentences in Order* tasks children were asked to organize either series of vignettes or series of sentences into the correct order to create a coherent story. The *Decoding Instruction* task requested them to interpret and perform complex written instructions involving the integration of a sequence of actions. To do that, they had to read the instructions presented on a screen and then either write down or draw the information received in their workbooks. In the *Anaphora* and *Verbal analogies* tasks children had to solve either syntactic and semantic anaphora or analogy problems, and then store and remember the word solution in a growing series of inferential problems (for a complete presentation of the Anaphora and Analogy WM tasks and materials, see Gutiérrez, García-Madruga, Carriedo, Vila & Luzón, 2005). They had to read to themselves the anaphora and analogy problems presented on a screen, and then recall the word solution of each anaphora (or analogy) problem and write them down in the correct order. The *Inconsistencies* task requested students to act as a detective whose job consisted of looking for mistakes in the texts. They read texts containing an internal inconsistency (i.e. an inconsistency between two ideas expressed within the text) and an external inconsistency (i.e. information that conflicted with their prior knowledge), and their assignment consisted of detecting one inconsistency of each type within each text. When performing the *Inferences* task, students had to read different short texts presented on a screen and answer embedded questions that either required the integration among individual sentences in the text (i.e. text-based inferences) or demanded the integration of general knowledge with information in the text (i.e. elaborative inferences). In the *Main idea* task they had to either locate the more important ideas of different reading passages or to select the best summary from the passage. In the *Changing Stories* task, children read different texts including a stream of information in which the relevant facts are constantly changing. They were asked to actively keep track of the information as they read it because, at several points of the story, they were requested to determine the state of different aspects of the story at that time (e.g. order of the horses in a race, the state of the scoreboard during a football match). Finally, the training program included the *Integrating Knowledge* task. This activity demanded children to focus and switch their attention to different units of information presented on a screen in different formats (i.e. text, video, pictures) in order to be able to answer several questions that required the integration of multiple sources of information.

All tasks consisted of several items that were presented in order of increasing difficulty. Each task was trained by means of four modes of instruction: 1) explicit instruction in the executive functions related to the tasks; 2) modelling examples, 3) guided practice, and 4) independent practice. We review each of these in what follows.

Explicit instruction was provided by one of the researchers who explained to the children how to perform each task as well as requested them to reflect upon how one might use the different executive functions to perform them effectively. In order to make each executive function concrete and easy to understand, icons (or symbols) were used to represent them. These icons were illustrated graphically and presented to the students throughout the training program. Concretely, *Focusing* was illustrated as a magnifying glass, *Switching* as two eyes looking in different directions, *Connection with* long-term knowledge as a fishing rod with a globe, *Updating of mental representations* as a fishing rod with a book, and finally, *Inhibition of irrelevant information* was illustrated with a stop-sign (see Table 1).

The second vehicle of instruction was *modelling examples*. Experimenters, after providing explicit instruction, completed the two first items of each task aloud, making sure that children understood what they had to do. The third mode of instruction was *guided practice*. This mode asked students to perform some items included in the task (i.e. two or three, depending on the task) while receiving visual feedback from the experimenters about the correct answers. Finally, students completed each task performing a set of items as *independent practice*. It should be noted that the first day of the program, training on each task included all four of these modes of instruction (i.e.

explicit instruction, modelling, guided practice and independent practice). From the second day of each task, the children participated in the training by completing the items independently. Thus, the focus of the training was independent practice. In order to be sure that students remember what they had to do while performing each task, the second and the subsequent days of each task started with the solution of the last item completed the previous day.

(Insert Table 1 about here)

To keep children motivated throughout the program, at the end of each session they performed the *Motoric Instructions*. To do this, they had to read some instructions presented on a screen and then execute funny postures and movements with their body. Additionally, at the end of each week of training, children were awarded with a diploma and a small gift.

Results

The results of the four variables in the control and experimental groups can be seen in Table 2. All the statistical comparisons were two-tailed, unless otherwise stated. In pretest, there were no reliable differences between the two groups for any of the variables: reading comprehension, working memory and intelligence (Mann-Whitney's tests: DARC: $U = 116$, $p = .87$; RST: $U = 114$, p = .81; KBIT: $U = 81.5$, $p = .13$).

(Insert Table 2 about here)

In the Control group, the light gains obtained in posttest in DARC, RST and KBIT were not reliable (Wilcoxon tests: $z = -.42$, $p = .67$; $z = -.82$, $p = .41$; $z = -.69$, $p = .49$; respectively). On the contrary, in the Experimental group there were reliable gains after intervention in the posttest for reading comprehension (DARC: $z = -2.179$, $p = .029$, $d = .67$). There were also gains in the measure of intelligence (KBIT: $z = -2.642$, $p < .01$, $d = .86$), but none were found for working memory (RST: $z = -1.219$, $p = .22$, $d = .30$). Moreover, the gain in reading comprehension was reliably higher for the Experimental than for the Control group (DARC: $U = 66$, $p = .032$, $d = .72$), and the gain in intelligence was also higher for the Experimental than for the Control group, but it did not reach the significance level (KBIT: $U = 78.5$, $p = .10$, $d =. 68$).The gain found in favor of the Experimental group for working memory was light and not reliable ($U = 116.5$, $p = .89$, $d = .07$).

As predicted there was a clear pattern of positive correlations in pretest between reading comprehension, working memory and intelligence. Reading comprehension reliably correlated with WM ($r = .34$, $p < .05$, one tailed), however, the positive correlation with intelligence did not reach the significance level ($r = .21$). The correlation between WM and intelligence, although positive, also did not reach the significance level ($r = .21$).

Discussion

In this experiment we have applied to intervention the cognitive theory that points to the role of executive processes in reading comprehension. The results suggest that it is possible to improve text comprehension by training young children on executive processes during the reading process. There was a reliably higher pre- to posttest gain in the Experimental group, compared to that of the Control group, for reading comprehension, and this effect was between medium and large. This gain was yielded because of the training program. Thus, our results demonstrate that it is possible to develop interventions to promote reading comprehension by boosting the CE functions during the process of reading comprehension. There is another relevant result, as found in other studies (see Klingberg et al., 2002; Jaeggi et al., 2008): the intervention on executive functions may also improve fluid intelligence measures, in particular on the Visual Matrices scale of the KBIT (Rueda, Posner & Rothbar, 2005; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). The gain in this measure of intelligence was higher, though not reliably so, for the Experimental group than for the Control group, and this effect was almost as large as that found for reading comprehension. In posttest we have not found any gain in RST for the Experimental group. The lack of improvement in this WM measure might be due to the particular characteristics of RST. As we said in the Introduction, RST is a WM capacity measure that loads mainly on storage and verbal components. We need some better measures of WM's executive processes, that demand more attentional resources, in order to test an improvement in WM's executive processes.

We have also confirmed our predictions about positive correlations between the studied variables. Reading comprehension is reliably related to WM, and not significantly with Intelligence. The positive correlation between WM and intelligence also did not reach the significance level. This low correlation can be explained by the kind of measures used for WM and intelligence. As we have just mentioned, RST is a central executive measure but it loads mainly on storage and verbal components of WM. These components of working memory are not particularly related to fluid intelligence as measured by KBIT matrices.

This experiment has some obvious limitations, particularly, the reduced number of participants, the lack of a more complete measure of WM, and the large time lapse between pre and posttest measures. In Experiment 2 we intend to overcome these limitations using a larger Experimental group, three diverse measures of WM and the

Central Executive, and a shorter time period (less than 3 months) for the entire pretest-intervention-posttest period. The main aim of Experiment 2 was to analyze in a detailed way the effect and the process of training on participants according to their prior reading comprehension abilities. It also attempts to relate pre and posttests measures with some measures of the training process itself. Moreover, from the experience of applying the training program in Experiment 1, in the new experiment some modifications in the process of training were also included.

Experiment 2

There were three objectives of this experiment. First, we intend to confirm the efficacy of the training program and to analyze in a deeper way the tasks used in the program and their relations with the efficacy of the intervention. For this purpose, during the training process we scored and analyzed participants' performance in each of the tasks used to improve reading comprehension. Second, we wanted to check the possible diverse effect of training on participants according to their prior abilities on reading comprehension. In order to achieve this goal we divided the global group of participants into two groups of low and high reading comprehension abilities, according to their DARC scores in pretest. Third, we were also interested in the particular effect of training on each of the three main components of reading comprehension measured by DARC, namely, memory, inferences and integration.

As mentioned above, apart from using the same measure of intelligence (visual Matrices of K-BIT), we used a lightly modified version of DARC and three new measures of WM and executive processes: a verbal Analogy span test, a Semantic Updating span test, and a Visuo-spatial selective span test. These three measures load more control executive processes than the RST used in Exp. 1. As in Exp. 1, our objective was to assess the possible transfer of training to measures of intelligence and WM's executive processes.

Our hypotheses were:

1. There will be a significant increase after training in the posttest measure of reading comprehension (DARC) and its component measures. We also predicted a pre-posttest increase in the Matrices test of Intelligence and in the new measures of WM and executive processes.
2. Given that training was collectively carried out in the classroom, training is particularly adapted to the low reading comprehension abilities group. Therefore, the increase in reading comprehension will be higher in the low reading comprehension group than in the high reading comprehension group.
3. There will be positive correlations in the pretest between reading comprehension, working memory and intelligence. Likewise, we predicted positive correlations between pretest measures in reading comprehension, working memory and intelligence measures and participants' performance on the training task.

Method

Design and Participants

We used an intervention design with pre-training and post-training measures with an Experimental group. Forty-six third-grade students from the same school as in Experiment 1, aged between 8 and 9 years, participated in the experiment. The final number of participants that completed at least 9 of the 10 training sessions was forty (*M* = 8.61; *SD* = .28). In order to evaluate our second hypothesis, we divided participants into two groups according to the median score obtained in the DARC pretest: Low (n=21; Mean age=8.49, Mean DARC in pretest: 18.62) and high (n=19; Mean age=8.70; Mean DARC in pretest= 30.89) groups in reading comprehension abilities.

Procedure

The children were trained for 10 days in their classroom, for a four week period, on a number of reading comprehension tasks that are directly related to one or more of the central executive functions (see a description of the tasks in Experiment 1). During the training process, as in Experiment 1, all participants received a workbook that included the diverse exercises to be performed in each session. These workbooks were collected by experimenters at the end of each session. Participants were assessed on three measures of WM (Analogy, Semantic Updating and Visuo-spatial tests), and on measures of intelligence (matrices of KBIT) and reading comprehension (DARC), two weeks before and two weeks after training.

Pretest and posttest measures

Reading comprehension

To assess reading comprehension, we used the Spanish version (EDICOLE) of the DARC, as in the previous experiment. However, we introduced a light modification to EDICOLE. In particular, we asked for three different relations between real/unreal entities in all of the texts, so that in this experiment the test had the same number of questions per category (i.e., prior knowledge, text memory, inference and integration) across texts, even though the number of total comprehension questions per text did not vary with respect to the first version. As almost 100% of participants performed correctly on the prior knowledge items, to calculate the overall score of DARC we did not consider the knowledge scores in Experiment 2. For the new version of the DARC, the coefficient of reliability for the total score was .84.

Working memory and executive processes

Working memory

A new Analogy test of working memory for primary school children (Orjales & García-Madruga, 2010) was used to assess students' working memory capacity. In this task, participants are asked to read out loud and solve a series of verbal analogies and then to recall the word-solution of each analogy in order. The verbal analogies are very simple and easy to solve, for instance: "Teacher is to school as doctor is to: a) medicine; b) hospital". The structure of the task is very similar to RST. However, in this case participants, instead of only reading out loud and automatically selecting the last word of each sentence, they have to solve a verbal analogy inference and store and remember the correct word-solution. The task includes diverse levels in which the number of verbal analogies to be resolved by participants progressively increases from 2 to 5. There were 3 series of verbal analogies in each level. The scoring procedure was different from Experiment 1. We gave a point for each word- remembered in a correct series in which participants remembered all the words in correct order. When participants remembered all the words of a series, but changed the order of some words, these words changed in order were scored as .5 points. The recall of correct words when participants did not remember all the words of a series was not considered.

Semantic Updating test

Based on the work of Palladino, Cornoldi, de Beni & Pazzaglia (2001), we developed the Semantic Updating test for Primary School children, in which the updating process relies on a semantic criterion to make the task as similar as possible to the updating process involved in reading comprehension. This task assesses the recall of a variable number of items following a specific semantic criterion in a list of words. Participants are presented with nine lists that include eight concrete and highly familiar words that refer to objects or living being entities measurable by size. They are required to select and remember a limited and predefined number of the biggest elements that were named in the word list, while suppressing the rest of elements. The nine lists are divided into three levels of increasing trials, varying by the number of relevant elements to be recalled (i.e., two, three, or four words). The lists are presented in a fixed order. The words in a list (e.g., elephant, pea, light-bulb, phone, glasses, train, tooth, pencil) are presented written on a computer screen, at an approximate rate of 2 seconds per word, while they are also named aloud by the experimenter. The end of the list is signaled graphically on the screen, and the participant is immediately required to report on the two, three or four words in the task referring to the biggest objects or animals following the order in which they were presented in the list. The instructions emphasize that the participant would be presented with lists that includes eight nouns referring to animals or objects, the size of which has to be considered in order to select at each moment the predefined number of the biggest elements. Participants are not informed about the range of positions within the list where the target items are going to appear, such that they must pay attention to all positions. To carry out the task successfully, participants have to change the content of memory by updating old irrelevant items with relevant incoming items (the biggest element). The task is preceded by three practice lists of two-word strings participants must remember. Returning to the example given in this section, the participants would have to recall "elephant- train". The scoring procedure was the same as in the previous Analogy WM test.

Visuo-spatial WM test

A new test of visuo-spatial WM was used for assessing students' visuo-spatial WM capacity and the executive processes related to the control of the dual task. The Visuo-spatial test is a Spanish adaptation of the Visual Span Task developed by Cornoldi et al. (2001). The test consists of a series of locations of several black dots presented in 4 X 4 (16 cells) white matrices in which one of the rows and one of columns from the matrix randomly appears colored in gray. Positions of dots are randomly distributed in the cells' matrix and held visible for two seconds on the screen. When the last dot of each series is displayed, a bell rings to inform participants of the end of each series. The task has three levels of difficulty. Each level consists of three series of increased number of trials (i.e. positions of dots in the matrix) ranging from two to four trials. Participants are asked to do two tasks simultaneously: 1) to press the spacebar when the black dot appears on a gray cell from the matrix (and not press it when the dot appears on a white cell); and 2) to remember, at the end of each series, the positions of the last dots of each series in order of appearance and to identify them on a new blank matrix. Thus, the positions of dots participants have to remember are only those that appear in the matrix when the bell rings: two dots at level two, three in level three and four on the fourth level. The scoring procedure was the same as in the Analogy and Semantic Updating test, except what counts is remembering the dots in their positions, not words. The remembering of correctly placed dots in an incorrect order was also scored as .5 points.

Intelligence

We used the same Matrices subtest of the Kaufman Brief Intelligence test (KBIT; Kaufman & Kaufman, 2000) as in Experiment 1.

TRAINING PROGRAM

The training program described in the Experiment 1 was reviewed in order to design a more adjusted and shorter program (i.e., ten sessions instead of twelve). The criteria used to improve the intervention were the following: 1) To eliminate those tasks and items with less satisfactory results by considering the difficulty and homogeneity indices obtained for task training scores; 2) To reformulate the statements of some items, while taking into account the misunderstandings observed in some of the children who participated in Experiment 1; 3) To adjust the level of difficulty of each task in order to avoid ceiling and floor effects that were detected in some of the items; and 4) To increase the number of items of guided and independent practice for those tasks that showed better statistical results. Table 3 shows the changes resulting from this revision.

(Insert Table 3 about here)

The new intervention program consisted of ten sessions of 50 minutes distributed across four weeks. As shown in Table 3, the *Main idea* and *Analogies* tasks were not present in this new version of the intervention, thus the number of tasks was now at 8. The order of items and tasks was rearranged in order to adjust the increasing level of difficulty of items and tasks to children's performance.

Participants were trained on each task by using the same mode of instruction and following the same procedure as described in the previous training program. The *Motoric Instructions* to be performed throughout the program, as well as the diploma and a small gift awarded at the end of each week were also maintained to ensure children's motivation in this new training program. In the last session of training we illustrated and had students reflect on the utility of the four basic executive processes for diverse daily intellectual activities; likewise, we insisted on the idea that the repeated practice of the four basic processes were developed such that students could become "mental athletes". In this final session a personal diploma was presented to each of the students.

Results

Table 4 shows the effect of training on reading comprehension measures. As in Experiment 1, all of the statistical comparisons were two tailed unless otherwise stated. There were reliable gains after training on the three reading comprehension measures of memory, inferences and integration, as well as on the overall measure of DARC. The effects of training on the diverse component measures of reading comprehension were around medium size; larger and more significant effects were found for integration and inferences, and smaller and less significant effects were found for memory. The effect size for the overall DARC was large and greater than in Experiment 1.

(Insert Table 4 about here)

The effect of training on the rest of the measures can be observed in Table 5. As in Experiment 1, there was a reliable increase after training on the Visual Matrices of K-BIT and the effect was medium to large. The gains of the Semantic Updating and the Visuo-spatial tests were also reliable and the effect was from medium to large. The gain obtained in the Analogy WM test after training did not reach the significance level and its effect was small.

(Insert Table 5 about here)

Regarding the second hypothesis, Figure 1 shows the scores of low and high reading comprehension groups in DARC and Intelligence. As can be observed, there were clear differences between both groups in both variables, although in opposite direction. The main increase in reading comprehension was obtained by the Low reading comprehension group, whereas the main increase in intelligence was obtained by the High reading comprehension group. The gain in reading comprehension of the Low group was greater than the gain of the High group and the effect was very large (Mann-Whitney's test; $U = 73.5$, $p < .001$; $d = 1.34$); on the contrary, the gain in intelligence was greater for the High reading comprehension group than for the Low reading comprehension group, and the effect was medium to large ($U = 123.5$, $p <. 05$; $d = .69$). In order to test in a stricter way this new finding, that there was a greater gain in intelligence by the High reading comprehension group, we calculated the Posttest-Pretest/Pretest scores in both groups. The means (and standard deviations) were: .15 (.15) for the High group and .06 (.16) for the Low group. The Mann-Whitney test showed the difference once again, although now it was marginally reliable ($U = 128$, $p = .053$; $d = .58$). There were no significant differences between the two groups in the gains for the three WM measures: Analogies, Semantic Updating and Visuo-Spatial span.

(Insert Figure 1 about here)

The correlations between reading comprehension, intelligence and a composite measure of WM are shown in Table 6. The composite measure of WM was the mean of z-scores of the three measures: Analogy, Semantic Updating and Visuo-spatial tests. As predicted, reading comprehension reliably correlated with working memory ($r = .29$, $p <$

.05; one tailed) and intelligence ($r = .39$, $p < .01$; one tailed). However, the correlation between WM and intelligence—although positive—did not reach the significance level ($r = .15$). Table 6 also shows the correlations of the three components, the overall measure of DARC with the three WM measures, the composite measure of WM, and the K-BIT measure of intelligence. As can be observed, the correlations between the three component measures of DARC and WM measures confirmed our hypothesis, except for the unsurprising case of the visuo-spatial measure. The Analogy test significantly correlated with memory and inferences, and the Semantic Updating test correlated significantly with the inferences and integration. K-BIT reliably correlated with the three component measures of DARC.

(Insert Table 6 about here)

The results obtained by participants in the diverse training tasks during the process of intervention, as well as the correlations with reading comprehension, semantic updating and intelligence can be observed in Table 7. Arranging *Vignettes in Order* was the easiest task, whereas arranging *Sentences in Order* was the most difficult. An analysis of the inter-correlations between the diverse training tasks showed that *Vignettes in Order* did not correlate significantly with any other task. The inter-correlations between the other seven tasks were always positive, and all were significant except for two cases. Likewise, all the training tasks, except for the *Vignettes in Order* task, correlated significantly with reading comprehension in the pretest. Semantic updating in the pretest also clearly correlated with the diverse training tasks and we can observe that its correlation with the overall training task is almost as high as that obtained by reading comprehension. The correlation between KBIT in the pretest and the overall training tasks was also reliably positive; the correlations with the diverse component measures of training were also positive, although in most cases did not reach the significance level. In order to assess the predictive capacity of these three pretest tasks on children's performance in the training tasks overall, we carried out a multiple regression analysis following the stepwise method. The results showed that reading comprehension and semantic updating explained 43% of the variance of the performance in training tasks (F (2, 37) = 15,722, p <. 0001); both variables, DARC and Semantic Updating, were significant (β = .43, p < .0002; β = .42, p < .0002; respectively).

(Insert Table 7 about here)

Finally, the correlations between participants' overall performance on the training tasks and the four DARC measures, intelligence and composite WM, on the pretest and posttest can be seen in Table 8. There was a clear pattern of positive correlations between the diverse measures with a range between .18 and .56. As predicted, the correlations between the diverse reading comprehension measures and the overall training tasks score were positive and significant both in pretest and posttest, except for the memory measure. Likewise, the correlation between the composite working memory and intelligence and the overall training tasks score were positive and significant.

(Insert Table 8 about here)

Discussion

The results clearly confirmed the first hypothesis showing reliable increases after training across the three components of the reading comprehension text: memory, and particularly in inference and integration. It is unsurprising that a training program based on the executive processes involved in reading comprehension yield greater benefits on inference and integration than on memory (the size effects are almost doubled). In comparison with memory, the inference and integration components of reading comprehension are more difficult: they require an extra mental operation and therefore executive control is more involved .The changes introduced in the training program seem to have improved it since the effect size is larger than that obtained in Experiment 1, and with two fewer sessions.

Results also confirmed the finding of Experiment 1 regarding the increase in participants' fluid intelligence after training the executive processes involved in reading comprehension. Moreover, in this case the transference is extended to WM measures: we also found a reliable increase after training in Semantic Updating and Visuo-spatial WM tasks and a no significant gain on the Analogy test. The use of the new tasks has allowed us to find reliable gains in WM's executive processes, though we are unable to find an easy explanation for the lack of reliability in gains in the Analogy task. These kind of transfer effects whereby WM training improves intelligence is interpreted by some authors as consistent with the evidence of a probable common or overlapping fronto-parietal cortical network involved in intelligence, WM and executive processes (see Klingberg, 2010; Duncan, 2010).

The second hypothesis regarding the differential efficacy of the training program according to participants' prior reading comprehension abilities has been also confirmed. The Low reading comprehension group reached a very clear and reliably greater gain after training than the High reading comprehension group. Since our training program was particularly adapted to the Low reading comprehension group, this result provides further evidence in favor of adaptive training. As for the differential performance of Low and High reading comprehension groups, we have found a rather new result that, if confirmed in new studies, may be particularly interesting: Participants with high reading comprehension abilities seem to have used our training program to improve their fluid intelligence rather than their reading comprehension abilities. In order to shed some light on this result, we also divided the whole group of participants by the median in KBIT pretest scores, and compared the gains of the resulting High and Low pretest intelligence groups. The increase was reliably higher for the Low intelligence group than for the High intelligence group (*Mean*=4.48, *SD*=4.27; and *Mean*=.84, *SD*=3.35; respectively; Mann-Whitney's U=109.5; $p<.02$; d=.96). Therefore, the gain after training in KBIT seems to be greater for children with Low intelligence and High reading comprehension abilities. These results suggest an interesting role of reading comprehension on improving intelligence.

Our third hypothesis has been confirmed on the whole. The correlations between diverse measures in pretest were in the predicted direction although, as in Experiment 1, WM and fluid Intelligence were not reliably correlated. As we said before, this result seems to be related with the kind of measures used for intelligence and WM. This explanation is consistent with positive significant correlations found in the posttest between fluid intelligence (KBIT matrices) and visuo-spatial WM (r=.28, $p<.05$; one tailed). Another interesting result is the lack of correlation in the pretest between reading comprehension and visuo-spatial WM (see table 6). This result is relatively common (see, for instance, Seigneuric et al., 2000), although there are also some studies that show a relationship between reading comprehension and visuo-spatial working memory (Goff, Pratt & Ong, 2005). Again, a possible explanation of these contradictory results relies on the differences among the diverse measures used for the variables.

The results obtained by children in the training tasks provide global support to the training program: The overall level of difficulty of diverse tasks is adequate and there is a good consistency among the tasks, except for the *Vignettes in Order* task. This is unsurprising since this task, while similar to other tasks, is not exactly a reading comprehension task. To adequately solve the *Vignettes in Order* task people only have to understand each picture and apply their long-term memory script knowledge about social situations. In spite of its peculiarities, the use of the *Vignettes in Order* task is in our opinion recommended because it is quite attractive to children: it has a clear motivational value within the training program, particularly in the first two sessions in which children have to perform it.

The most interesting result regarding the training tasks is the pattern of positive correlations found with the pretest reading comprehension and semantic updating measures. Given that the overall training score is an on-line measure of the training process, the medium-high correlation obtained with reading comprehension confirms that the training tasks are indeed acting on reading comprehension, something that provides consistency to our training procedure. The other result that deserves to be mentioned is the positive and reliable correlations found between training tasks and the semantic updating task. The correlation between participants' overall performance on the training task and the semantic updating task is over .50, and of the same magnitude as the correlation found with reading comprehension (see Table 7). Moreover, the results of regression analysis confirm that children's performance on the training tasks strongly depends not only on their prior reading comprehension abilities, but also on their semantic updating capacity. These results provide new evidence in favor of the crucial role that updating has in reading comprehension (see Palladino et al., 2001; Carretti et al., 2005), and illustrates in particular its relationship with improvements in reading comprehension, that is with semantic learning.

General Discussion

In a recent paper, Klingberg distinguishes between two types of WM training. The first he calls implicit because it is only based on "repetition, feedback and often gradual adjustment of difficulty." The second is an explicit type based on teaching metacognitive strategies to improve performance (2010, pp. 317-18). The training used in this paper shares features of both types. We have developed a training procedure based on repetition, feedback and the gradual adjustment of difficulty. We have not explicitly trained on any particular strategy, but our training explicitly demands from students their active and conscious engagement throughout all of the training process, from the first to the final session. In fact, the main focus was not to train reading comprehension itself but the training of WM's executive processes; that is, the conscious control of cognitive processes involved in reading comprehension. This is a key difference between the main previous approach in the field of reading intervention programs and the approach presented in this paper (see Elosúa, García-Madruga, Vila, Gómez-Veiga & Gil, 2012). Obviously, as a final outcome, our proposal of using repetitive practice was intented to achieve some kind of automated behavior but always under the control and monitoring of executive processes. This is exactly the objective of using the "mental athletics" metaphor to characterize our kind of perspective: The conscious use of repetitive training exercises to improve students reading comprehension abilities.

All the training tasks used in this work, even the WM tasks (Anaphora and Analogy in Exp. 1; Anaphora in Exp. 2), required that children understand written text: for this reason, they are also reading comprehension tasks. However our training was not a reading comprehension program aimed to instruct readers on particular skills or strategies embodied in reading comprehension. From the first to the last session, our training sought an improvement in children's mental activation such that they might apply the four WM executive processes previously mentioned to reading itself.

Likewise, particular training tasks were not selected and arranged for their relevance to directly improving reading comprehension, but for the involvement of executive processes. In other words, because they require increasingly higher attentional control resources and can hence improve children's use of executive processes during reading. If our aim is to train readers using WM executive processes, we cannot train them in the abstract. Moreover, if we want to improve reading comprehension, it seems appropriate to use some form of a reading comprehension task. It is difficult therefore to separate the specific differential weight of WM's executive processes training with that of reading comprehension practice in order to properly explain the improvement of reading comprehension found in this study.

The results of our two studies provide support to the training perspective that WM's executive processes facilitate reading comprehension. In Experiment 1 we found a clear gain in reading comprehension in the experimental group, reliably higher than that of the control group. In Experiment 2 we confirmed the efficacy of a simplified and adjusted version of the training programs with a broader experimental group. The results confirmed that the gain was mainly on the inference and integration components of the reading comprehension test, the components that require more active reading comprehension, i.e. the explicit application of executive processes to reading. Likewise, as predicted, we found that the gain was greater for those children with lower pretested reading comprehension abilities. The rationale of this prediction was that our attempt to adapt an item's difficulty to participants was restricted as a result of the collective nature of the intervention: We were forced to focus our training on children with lower ability. Moreover, this differential gain of Low versus High reading comprehension groups cannot be attributed to a kind of ceiling effect on the High group: the mean score of the high group after training (33.9) is not close enough to the maximum score (39), and only two participants reached this maximum score. In any case, the findings of this paper suggest the use of this training perspective as part of classroom instruction mainly to improve reading comprehension in children with poorer abilities.

Nevertheless, the finding confirming the efficacy of the training program in reading comprehension is not the only relevant result of this work. We have also found evidence for a transfer effect of our training on intelligence that may be quite relevant. In both experiments we found a reliable gain after training on our measure of fluid intelligence: KBIT matrices. As mentioned previously, this confirms other similar results found by diverse authors in children with and without ADHD (Klingberg, Forssberg & Westerberg, 2002; Rueda et al., 2005; Rueda, Rothbart et al., 2005), young adults (Jaeggi et al., 2008), and even in the elderly (Borella, Carretti, Riboldi & De Beni, 2010), although some other relevant studies have not found this transfer effect of training on intelligence (Holmes et al., 2009). As we discussed in the Experiment 2, the differential results of a greater gain in intelligence obtained after training by the High reading comprehension group deserves closer attention and further empirical work. In Experiment 2 we also found a transfer effect of training on the executive process measures, having obtained reliable gains in Semantic Updating and Visuo-spatial WM tests, and nearly reliable ones in the case of the Analogy test. In any case, the lack of a control group in this experiment forces us to be prudent, although the size of the effects found tell us that these finding would probably be confirmed with a more complete design.

A new feature of our training procedure is that we obtained scores in the training process itself. That is, in each session participants received a workbook in which they had to solve and record all the problems included in each task. In this way, at the end of the training we had participant scores in each of the tasks used as well as an overall training task score. These training process scores are certainly not posttest measures, but neither are they pretest measures. Instead, they provide us with on-line information about the learning process. As we have shown, these scores allow us to check the consistency of the training procedure and potentially remove particular tasks from the empirical data.

In sum, our new training perspective, based on the improvement of WM's executive functions in reading tasks, seems to be at least as useful as the best of the training programs recently developed, in spite of its being applied collectively to all the students in the classroom. As some authors have claimed (e.g. Duncan, 2010; Jaeggi et al., 2010; Klingberg, 2010; Rueda et alt., 2005), it is unsurprising that performing repeatedly complex cognitive tasks that demand the precise, deep and controlled understanding of increasingly difficult texts yield an improvement on tasks that demand the activation of the same or overlapping cognitive processes and brain structures. In other words, we surmise that any kind of intervention asking participants to face new tasks that require overlapping cognitive processes, particularly ones with high cognitive demands and attentional control, would yield similar results since they also produce some changes in the activity of frontal and parietal brain cortices. Hence, the underlying assumption regarding these transfer effects is brain plasticity, a notable characteristic of a child's brain.

Our results suggest some implications for classroom teaching related to the acquisition of reading comprehension. The first idea, perhaps rather obvious, is that contrary to traditional scholastic conceptions of how to teach reading, comprehension needs to be explicitly taught, at least for some students. The diagnostic assessment of students that require the explicit teaching of reading comprehension is an important preliminary step, and one in which DARC might be a useful tool. The second idea is that this explicit teaching of reading comprehension can be based on promoting the application of WM's executive processes as we do in our training program, in a way similar to the studies of Gaskins et al. (2007) and Meltzer et al. (2007). Likewise, the new training perspective applied in this work can be used to develop computer programs that allow an individual application adapted in a more specific way to children with specific reading comprehension difficulties or even ADHD children.

Limitations

This work has some obvious limitations that we would like to highlight. Following the ideas by Melby-Lervåg & Hulme (2012) and Shipstead et al. (2012) presented in the Introduction, we can pinpoint four main difficulties and problems of WM training studies. The first difficulty concerns the theoretical analysis of the processes involved in the training. Our proposal clearly identifies WM's executive processes, not WM's storage or short-term span, as the crucial component that must be trained in order to achieve an improvement in reading comprehension and other high cognitive abilities. However, apart from the singular function our data seem to afford the process of updating, we cannot be exactly sure what the precise role of each of the executive processes analyzed in our training work is.

The second point refers to the task used in the pre- and posttest, and in training. A clear limitation is the use of single tasks in the pre- and posttest to determine whether or not there is any improvement in cognitive ability, such as in WM capacity, reading comprehension or intelligence. Our work has certainly used only a task to decide that our training program was able to improve intelligence (KBIT Matrices) and reading comprehension (DARC), though DARC includes three different measures of basic components of reading comprehension: Memory, Inferences and Integration. Likewise, in Experiment 2 we used three different tasks to measure working memory (Analogy, Semantic Updating and Visuo-spatial tests). Another main related limitation is the use of the same tasks in pre- and posttest as in training. Our work has avoided this important flaw by using clearly different tasks in training than was used in the pre- and posttest.

The third difficulty concerns the use of active non-contact control groups. This methodological limitation directly affects the results of our first experiment. Given the high personal involvement and motivation of the children in our experimental groups, our results have to be confirmed with new studies using a design with control groups in which children feel as involved in the experiment as do children in the experimental group. For instance, we might compare our training program with two other training groups, one based on training only WM capacity tasks, and the other based on training diverse reading comprehension tasks.

And finally, maintaining these kinds of improvements over time is as important as achieving them in the first place. We will need to investigate these maintenance effects after a delay by means of follow-up measures on the variables. Therefore, given the limitations we have pointed out we consider that our results should be confirmed in further research.

Conclusions

Reading comprehension is a highly demanding task in which working memory's executive processes play a crucial role. Our work suggests that reading comprehension can be improved by training the main WM executive processes involved in reading comprehension. The adaptive program was tested in the classroom with Primary school children and the results show that gains in reading comprehension were higher for children with low pretest abilities. It is also found that children improved as well in measures of intelligence and executive processes. This work provides new and promising, though initial evidence confirming the possibility of improving cognitive abilities through the adaptive training of attentional control processes involved in the execution of highly demanding cognitive tasks.

Acknowledgments

This research was conducted with financial support of the research projects: DGICYT PSI2008-00754 and Consolider-Ingenio 2010, CSD2008-00048, both from the Ministry of Science and Innovation of Spain. We thank students who voluntarily participated in this research as well as the Spanish state school "Emilio Casado" of Alcobendas (Comunidad de Madrid). We also thank some people who have discussed parts of this research with us: Alan Baddeley, Erika Borella, Martin Buschkuehl, Barbara Carreti, Cesare Cornoldi, Rossana De Beni, Susan Gathercole, Graham Hitch, Susanne Jaeggi, Carmen López Escribano and Elena Pérez Hernández.

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Figure 1. Mean scores in DARC and Kbit for Low and High reading comprehension groups in pretest and posttest, in experiment 2.

Table 1. The executive processes trained, their icons, and the tasks used in exp. 1.

Executive Function	**Icons**	**Tasks tapping into each executive function**
Focusing		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Analogies, Inconsistencies, Inferences, Main Idea, Changing Stories and Integrating Knowledge
Switching		Anaphora, Analogies, Inconsistencies, Inferences and Integrating Knowledge
Connection with knowledge		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Analogies, Inferences, Main Idea and Changing Stories
Semantic updating in WM		Sentences in Order, Anaphora, Analogies, Inconsistencies, Inferences, Changing Stories and Integrating Knowledge
Inhibition		Vignettes in Order, Decoding Instructions, Sentences in Order, Anaphora, Analogies, Inconsistencies, Main Idea, Changing Stories and Integrating Knowledge

Table 2. Means (and standard deviations) of the four measures in pretest and posttest, and increases, for the Control and Experimental group in experiment 1.

	CONTROL GROUP (N=16)			**EXPERIMENTAL GROUP (N=15)**		
	PRETEST	**POSTTEST**	**INCREASE**	**PRETEST**	**POSTTEST**	**INCREASE**
DARC	31.69 (5.78)	31.81 (5.81)	.13 (3.56)	31.27 (4.83)	34.27 (5.08)	3* (4.47)
RST	2.71 (.53)	2.83 (.62)	.13 (.59)	2.64 (.49)	2.81 (.48)	.17 (.56)
K-BIT MAT.	30.56 (4.13)	31.06 (3.53)	.50 (4.70)	27.73 (4.18)	31.20 (3.55)	3.47** (4.10)

* $p < 0.05$; ** $p < 0.01$.

Table 3. Training tasks, examples, variables manipulated for increasing the difficulty, sessions in which each tasks was performed and number of items, in Experiment 2.

Task	Example of task item	Difficulty	Sessions	*Nº* items	
				Exp 1	***Exp 2***
Vignettes in Order	Arrange the following pictures frames 	Number of frames	1, 2	19	50
Decoding written instructions	*Write your name and two surnames. Then, draw a circle around the last letter of your name and the first letter of your last surname. Do it without lifting your pencil.*	Number of actions to be performed	2, 3, 4, 5, 6, 7, 8, 9,10	45	48
Sentences in Order	Arrange the following sentences: *Maria looks for her place* *Maria buys the ticket* *The movie has started* *Maria waits in the line*	Number of sentences	3, 4	12	26
Anaphora WM	*Robert painted it white before the summer arrived.* *– roof* *– façade*	Number of words to be remember	4, 5	14	14
Detecting textual inconsisten-cies	Internal: *Laura used eyeglasses to read (...) Laura's eyesight was excellent.* External: *Elena was flying in the depths of the lake when he decided to go back.*	*Internal*: distance between sentences *External*: salience of the inconsistency	5, 6, 7	16	30
Making inferences	(Student read the text)… Ask the next questions: *Why did they put the sparrow near to the fireplace?*	*Text-based*: Distance between sentences, *Elaborative:* Memory load	6, 7	16	30
Following changing stories	*In what order were the horses at the end of the race?*	Number of units of information to be followed	8, 9	12	18
Integrating information from different formats.	After watching the video and reading the test, ask the following question: *What type of solar eclipse is presented in that picture?*	Number of units of information to be integrated across sources	8, 9	15	15

Table 4. Means (and standard deviations) of the diverse measures of reading comprehension in the pretest and posttest, and the increase (with Cohen's d), in experiment 2.

N=40	**DARC Memory**	**DARC Inferences**	**DARC Integration**	**DARC**
PRETEST	9.57 (2.02)	6.18 (3.09)	8.70 (3.92)	24.45 (7.78)
POSTEST	10.23 (1.69)	7.53 (2.54)	11.00 (3.07)	28.76 (6.27)
INCREASE	.66* (2.05) d=.33	1.35** (2.24) d=.62	2.30** (3.63) d=.65	4.31** (5.65) d=.79

*** $p < 0.001$; * p=.051*

Table 5. Means (and standard deviations) of the diverse measures in pretest and posttest, and the increase (with Cohen's d), in experiment 2.

N=40	**KBIT**	**Analogy Test**	**Semantic Updating Test**	**Visuo-spatial Test**
PRETEST	28.98 (3.90)	5.55 (3.56)	8.60 (5.00)	13.58 (6.61)
POSTEST	31.73 (4.85)	6.58 (4.49)	12.70 (5.89)	18.94 (5.66)
INCREASE	2.75** (4.24) d=.66	1.03# (4.18) d=.25	4.10** (6.66) d=.62	5.36** (6.98) d=.77

*** $p < 0.001$; # p=.10*

Table 6. Pearson correlations in the Pretest of the four measures of reading comprehension (memory, inferences, integration and overall) with intelligence (K-BIT) and the four measures of working memory (analogy span, semantic updating span, visuo-spatial selective span, and composite score), in experiment 2.

N = 40	**KBIT**	**Analogy Test**	**Semantic Updating Test**	**Visuo-spatial Test**	**Composite WM**
DARC Mem.	.29*	.44**	.05	-.06	.22
DARC Inf.	.31**	.27*	.34*	.01	.31**
DARC Integ.	.29**	.05	.28*	.11	.22
DARC	.39**	.25	.28*	.05	.29*

** $p < 0.01$; * $p < 0.05$; one tailed

Table 7. Percentages of correct responses (means and standard deviations) in the diverse tasks of the training program, and Pearson correlations with reading comprehension (DARC), intelligence (KBIT) and Semantic Updating in Pretest, in exp. 2.

N=40	Mean	SD.	DARC	Semantic Updating Test	KBIT
Vignettes in Order	54	15.24	.16	.34*	.06
Decoding Instructions	75	13.74	.46**	.33*	.35*
Sentences in Order	85	13.53	.36*	.41*	.29*
Anaphora	57	25.80	.53**	.46**	.22
Inconsistencies	80	11.69	.28*	.42**	.04
Inferences	74	8.54	.41**	.32*	.22
Changing Stories	72	23.12	.31*	.33*	.20
Integrating Knowledge	84	20.51	.28*	.21	.08
Overall Training Tasks	73	10.77	.55**	.54**	.28*

** $p < 0.01$; * $p < 0.05$; one tailed

Table 8. Pretest and Posttest's Pearson correlations between the Overall Training Tasks measure and the four measures of reading comprehension (memory. inferences. integration and overall), intelligence (KBIT) and the composite measure of working memory, in experiment 2.

N=40	Overall Training Tasks	
	Pretest	**Posttest**
DARC Memory	.24	.18
DARC Inferences	.56**	.49**
DARC Integration	.52**	.35*
DARC	.55**	.42**
KBIT	.28*	.36*
Composite WM	.29*	.38**

** $p < 0.01$; * $p < 0.05$; one tailed

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