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STRENGTHEN THE WORKING MEMORY. A HYPOTHESIS TO CREATE A COGNITIVE TRAINING

POTENZIARE LA WORKING MEMORY. UN'IPOTESI PER LA COSTRUZIONE DI UN TRAINING COGNITIVO

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Abstract

Working Memory plays a fundamental role in cognitive development and is essential for many learning processes, such as comprehension and problem solving. These processes involve both the linguistic and mathematical areas and contribute to define the level of competence that a pupil can express through a cognitive test, such as a standardized INVALSI test. This work represents the first step in a broader study aimed to create a cognitive training for the empowerment of Working Memory in children from 6 to 10 ages, when executive functions are developing. Hereby, we present a qualitative analysis of the elements of the INVALSI tests in Italian and mathematics for the 2018-2019 school year for primary schools that are considered suitable for the construction of the training hypothesis, as they particularly affect the components of working memory.

La working memory ha un ruolo fondamentale nello sviluppo cognitivo ed è essenziale per molti processi di apprendimento, quali la comprensione e il problem solving. Questi processi investono sia l'area linguistica sia quella matematica e concorrono nel definire il livello di competenza che un alunno può esprimere attraverso una prova cognitiva, come è una prova standardizzata INVALSI. Questo lavoro è il primo step di uno studio più ampio finalizzato alla la creazione di un training cognitivo per il potenziamento della working memory nei bambini dai 6 ai 10 anni, quando cioè si sviluppano le funzioni esecutive. Viene presentata l'analisi qualitativa degli elementi delle prove INVALSI di italiano e matematica dell'a.s. 2018-2019 per la scuola primaria che, investendo in modo particolare le componenti della working memory, sono ritenuti idonei per la costruzione del training ipotizzato.

Keywords

Working Memory – Cognitive training – Learning – Primary school
Working memory – Training cognitivo – Apprendimenti – Scuola primaria

1 The "Introduction" and the "First conclusions" are the joint work of both authors. The paragraphs "The design of the research" and "The selection of questions" are to be attributed to Author 1, the paragraphs "The theoretical framework", "The qualitative analysis of Italian questions" and "The qualitative analysis of mathematics questions " are to be attributed to Author 2. The opinions expressed in the works are attributable exclusively to the authors and do not in any way engage the responsibility of the Institute to which they belong. In citing issues, it is therefore not correct to attribute the arguments expressed therein to INVALSI or its top management.

Introduction

Among the executive functions, Working Memory (WM) plays a crucial role in cognitive development and in curricular school activities, as it is of fundamental importance for learning processes such as understanding and problem solving. This is, as a matter of fact, a high control function, which is responsible for maintaining and processing several pieces of information simultaneously (Baddeley 1974, 1986 and 2003; Alloway et al. 2004; Alloway & Copello, 2013; Cornoldi & Vecchi, 2003; Gathercole et al. 2004).

As is known, reading comprehension is the product of a complex interaction between acquired knowledge, coding skills, vocabulary and syntactic and semantic processes In order to operate these operations, this interaction needs high control functions, such as WM It is a control function whose importance is not limited to the resolution of tasks that is subject to the discovery of a new solution (*discovered solution*), but also intervenes in those tasks that require those who perform them to respond correctly, making use of the skills and procedures learned (*derived solution*).

These are some of the cognitive processes that are solicited by the INVALSI tests, the purpose of which is to measure the learning outcomes obtained by students in different moments of their school career with respect to some skills defined as fundamental (INVALSI 2018a and 2018b). As these tests are standardized and calibrated according to age and school grade, they were used in this study as starting material for constructing cognitive training aimed at enhancing WM in primary school pupils, i.e. in the period in which executive functions are most developed and developing (Friso-Van den Bos et al. 2013; Gathercole et al. 2004; Mammarella et al. 2008; Elliott et al. 2010; Alloway et al. 2004).

Far from attributing an improper function to the national tests or making arbitrary use of them, it was felt that some elements of these tests could be used to construct a working tool for the enhancement of executive functions in primary school pupils, applicable in an extracurricular context.

The theoretical framework

Working Memory is one of the executive functions that most influences both learning and academic achievements that a student achieves during his/her educational process (Alloway et al., 2004; Vecchi et al. 2005; Elliott et al. 2010; Alloway & Copello, 2013; Giofré et al. 2018). It is defined as a mental ability to store and process information for a short period of time. Among the theoretical models that explain its functioning, the most accredited is that of Baddeley & Hitch (1974), who divide Working Memory into three components: the *central executive*, the *phonological loop* and the *visuospatial sketchpad*.

The *central executive* processes the information flow allowing the WM to work correctly (Alloway, Gathercole & Pickering, 2006), it coordinates the access and recall of information from long-term memory and checks that all cognitive activities are functioning correctly (Baddeley 1986 and 2000).

The *phonological loop* enables the encoding of verbal material. Closely related to the next one but independent from it, the visuo-spatial sketchpad is composed by a phonological store - responsible for keeping the acoustic and verbal information for a short time - and by a repetition mechanism; this allows to mentally recall the sound of the word (subvocalic articulation) and to encode in phonological code words, writings or figures (Baddeley 2003; Nouwens et al. 2017).

The *visuospatial sketchpad*, on the other hand, has the function of retaining the visuospatial characteristics of the incoming information and holds the task of visualizing and manipulating mental images. It is divided into two sub-components: the *Visual Cache*, a temporary and passive warehouse for the visual recognition of objects, and the Inner Scribe, which allows you to temporarily maintain movements and process the spatial information stored in memory through the Visual Cache (Logie & Pearson, 1997; Mammarella, 2008).

Baddeley (2000) introduced a fourth component, the episodic buffer, which is responsible for retrieving information from long-term memory stores and integrating it with information

from either of the WM systems. This is defined as *episodic* as it is capable of storing episodic information contextualised in space and time, and it is called a *buffer* because of its function as a temporary interface with the two subsystems (Baddeley 2003; Mammarella, 2008).

Other research has offered further contributions to Baddeley's model to explain how the various subcomponents of Working Memory can work differently depending on the type of task proposed (Bruyer & Scailquin, 1999; Vecchi, Richardson & Cavallini 2005). Cornoldi, with the Continua model, underlines how Working Memory is a complex function, which requires the implementation of both passive processes (memorization and recall of information) and more active processes, which instead involve participation and a degree of high control by WM (Vecchi & Cornoldi, 1999; Cornoldi & Vecchi, 2003). Of course. there is no clear distinction between the two types of tasks: in the passive ones, the material can be kept in memory through repetition processes; in active tasks, on the other hand, it may be necessary to memorize internal representations before processing them to achieve a certain goal.

The design of the research

All the components we have talked about play an important role in learning, both in a formal context such as school and in informal and non-formal situations. As a matter of fact, their insufficient development does not only reverberate on academic success, but it also has a more extensive impact on a wide range of daily activities.

Our attention has turned to and focused on the age group 6-10 years, that is, the one that sees children engaged in the primary education cycle and in which executive functions develop. There is certainly no lack of training tools in the literature; however, it seemed appropriate in designing cognitive training to introduce a greater use of ecological exercises, enhancing reality tasks that are closer to the daily life activities of children. As a matter of fact, we believe that this can both involve them in the training and motivate them in the effort that they must undoubtedly make, and at the same time help the generalization of the achievements (Baldacci 2005). It is precisely the search for tasks of this type that has directed our attention towards INVALSI tests, as we will discuss shortly.

The project we propose is divided into three phases: 1) the qualitative analysis of the four paper files of INVALSI tests, two in Italian and two in mathematics, for grades 2 and 5 of the primary school, administered in the 2018-2019 school year, the last one before the Covid-19 pandemic; 2) the construction of the path and training tools for strengthening working memory; 3) experimentation with children of the age group in question, observation and discussion of the results obtained.

In the first phase of study, the subject of this article, we chose to follow a qualitative approach in consideration of the complexity of the aspects identified, of which we want to grasp the relationships - some explicit, others implicit - in order to discover the meanings that children can develop from experience (Cicognani, 2002).

The activities carried out were: the creation of a catalogue with the characteristics of all the questions drawn from the *Guide alla Lettura* for primary schools compiled by INVALSI; the selection of the questions included in the files considered on the basis of different criteria for the two disciplines of Italian and mathematics; the selection of the questions included in the files considered on the basis of criteria established a priori, different for the two disciplines, taken from the *Quadri di Riferimento* (INVALSI 2018a and 2018b); the qualitative analysis of the chosen questions.

The selection of questions

The paper-pencil test files are proposed to the children according to the same administration protocol for both subjects. Four of them were analysed, two for Italian and two for mathematics. The Italian primary school tests for the school year 2018-2019 consist of 17 questions for grade 2 and 34 questions for grade 5. The first, dedicated to reading comprehension, presents an exposition text and a narrative text, with questions focusing on three specific macro-aspects

to which it is possible to refer some of the cognitive operations involved in reading and text comprehension tasks. The second part, on the other hand, proposes exercises that test aspects linked to reflection on language (INVALSI, 2018a).

The second part of the test was excluded from the analysis, since it includes questions that privilege linguistic and grammatical knowledge and affect the WM to a lesser extent.

The choice of the questions therefore focused on the first part of the tests and examined the questions according to textual genre. Expository or informative texts, which can contain iconic elements and thus combine written text with graphics or images, were included. Continuous narrative texts, whose structure makes them less suitable for adaptation to training, were excluded. Fourteen questions were extrapolated with a view to the future construction of a training, four of which were grade 2 and ten grade 5.

For what concerns mathematics, the files examined are composed of 59 questions in total, 25 questions for grade 2 and 34 questions for grade 5. Each question is inserted within one of the three dimensions indicated in the *Quadri di Riferimento* and investigates a given area: Numbers, Space and Figures, Data and Forecasts, and Relations and Functions (INVALSI, 2018b).

The choice of test items fell on questions relating to the argumentation and problem-solving dimensions for both grades. Questions involving more complex tasks and requiring a greater contribution from working memory were therefore considered. Only those questions that contain visual-spatial stimuli useful for the construction of cognitive training for the strengthening of non-verbal WM were selected. The selection resulted in a pull of 51 questions, 23 for grade 2 and 28 for grade 5.

The analysis of Italian questions

The first expository text chosen is made up of several boxes with passages accompanied by a picture, while the second is a piece taken from a manual, divided into paragraphs with three pictures. Being able to work on this kind of text allows us to deepen our reflection on the tasks to be included in the training we are going to carry out. Before subjecting the child to questions related to text comprehension, it is possible to create tasks that require an active manipulation of the textual material, which implies a high degree of control by WM and not only a storage of information (Vecchi & Cornoldi 1999; Vecchi et al. 2005). It is therefore possible to use this material, modifying its structure, in order to stimulate certain components of working memory and decide to work first on reading processes and only later on comprehension processes. An expository text also allows the task to be calibrated according to the child's abilities and level of cognitive development. As a matter of fact, in a cognitive training, it is necessary to create a series of exercises with gradually increasing levels of difficulty and to choose a mode of administration suitable for the subject according to his/her characteristics (Baldacci, 2005). Through reading tasks, children will have to rely both on processes linked mainly to the language system and verbal WM and on those that require the involvement of non-verbal WM (Baddeley 2003; Gathercole et al. 2004). If the phonological loop deals with transforming written words into a phonological code, maintaining and processing verbal information through the phonological store and subvocalic repetition, the visual-spatial notebook will preside over the transformation into a mental image of the parts of the text with spatial references or that describe environments (Bruyer & Scailquin, 1999; Mammarella 2008). It will also be responsible for keeping in memory the representation of the page containing the text in order to orientate the movement of the eyes appropriately (Baddeley, 2003).

Questions on comprehension of expository text, which involve the active participation of different components of WM, may require cognitive operations such as: tracing explicitly given information within the text, constructing a representation of the literal meaning of the text, or understanding the content beyond the literal meaning, or even to appreciate stylistic and formal features (INVALSI, 2018b). All these operations involve the active participation of different components of the working memory. During the text comprehension process, children have to link the sentences they have just read to the material previously contained in the text and, at the

same time, to the knowledge stored in long-term memory. The verbal information, previously encoded and recognised during the reading process by the sub-components of the phonological loop, will then have to undergo further processing by the WM systems in order to give meaning to the text being read and to answer the proposed questions. This means that, in addition to retrieving the information in the phonological store, it will be necessary to draw on the semantic store to understand what is being read. This store, accessible through the episodic buffer and the central executive, seems to be the one most involved in comprehension processes and is the element that would explain individual variation in text comprehension processes (Baddeley 2000 and 2003; Nouwens et al. 2017; Verhoeven & Van Leeuwe, 2008).

The analysis of mathematics questions

The mathematics questions, structured differently from the Italian ones, have been taken as a starting point for the construction of exercises that stimulate the visual-spatial components of WM (Friso-Van den Bos et al. 2010; Meyer et al. 2010; Mammarella 2008). In the first set of selected questions, related to the dimensions problem-solving and argumentation, we are presented with complex tasks. These are not limited to the mere manipulation and processing of visual-spatial material, but also require more complex elaboration processes, which most likely demand the intervention and support of those components most closely related to text comprehension (Hambrick et al. 2003). When solving tasks, children need to maintain a high level of attention in order to allow the various components of WM to fix and process both verbal and visual-spatial information simultaneously. Consequently, in this type of task the verbal component will influence the functioning of the cognitive operations stimulated by WM as it will help to attribute meaning to the mathematical task. A study by Meyer and colleagues (2010) with primary school children showed that the central executive and the phonological components of WM appear to be most involved during mathematical reasoning and problem comprehension tasks, whereas the visuo-spatial components seem to come into play later, during those exercises that solicit the use of the arithmetic skills possessed and the manipulation of the material presented. The non-verbal component also makes it possible to plan and organise the necessary steps to achieve the correct answer and to keep active all the information essential for carrying out a given task. Finally, through the episodic buffer and the central executive, knowledge stored in long-term systems is retrieved and integrated with new information in order to give meaning to the figures in the task (Baddeley 2000; Mammarella et al. 2008). The second set of questions, related to the knowledge dimension, contains numerous visual-spatial stimuli; it is conceivable that a good part of these stimuli could be used to create exercises that require the child, for example, to move within a path, to mentally rotate objects to identify their correct positioning or to actively work on certain types of tasks (drawing, copying, completion).

First conclusions

The construction of cognitive training aimed at strengthening working memory requires, in our opinion, the predominant inclusion of reality tasks. These are preferable to exercises in which the training activity - although necessary - can more incisively stimulate the use of some components of this fundamental executive function by linking them to activities and situations close to the children's lives. The starting point for this construction was the analysis of the INVALSI tests for the 2018-2019 school year, carried out a priori on the basis of criteria taken from the Italian and mathematical Reference Frameworks.

Although the purpose for which we have used them bears a totally different connotation from that which they assume in the scientific field to which they belong, namely the evaluation of school learning outcomes, the work carried out in the first phase of the project has provided the coordinates for using the stimuli identified in the test files for primary school. This use is not, of course, the mere application of the original material in a different context, but rather provides the appropriate manipulation for the construction of the training hypothesis. It is undoubtedly an articulated and complex work, which, in the analysis of the questions presented

in this contribution, has laid the theoretical and methodological foundations for the subsequent development of the course and the enhancement materials.

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