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Difficulties of children with ADHD symptoms in solving mathematical problems when information must be updated

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ABSTRACT

It has been hypothesized that ADHD is associated both with difficulties in mathematical problem solving and in updating information in working memory. However, the relationship between updating and performance on mathematical word problems has never been studied for children with ADHD. The present study examined these issues comparing the performance of solving mathematical word problems (with no updating request vs high updating request) in a group of 11–12 year old children with ADHD compared to a matched control group with typical development (TD). Results showed that children with ADHD solved fewer problems correctly than typically-developing children; moreover they made more errors in solving problems with updating requirements than those without updating requirements. In contrast, typically-developing children did not show any differences in problems performance on problems with and without updating requirements. Fine grained analyses of children's problem solving processes showed that children with ADHD found more difficult to select the appropriate data prior to calculation and to choose and execute the correct solution than typically-developing children. The difficulty to select the appropriate data results more severe in problems with updating requirements. Overall, these results support the hypothesis that the learning difficulties of children with ADHD are related to their executive dysfunctions, that negatively affect complex tasks requiring updating of to-be-processed information.

What this paper adds

The relationship between updating and performance on mathematical word problems has never been studied for children with ADHD. This paper showed that the request of updating information impaired the problem solving ability of children with ADHD with respect to children with typical development. In addition, fine grained analyses of children's problem solving processes showed that children with ADHD found more difficult to select the appropriate data prior to calculation and to choose and execute the correct solution than typically-developing children. Our results support the view that updating is problematic in ADHD children and that updating influences their problem solving ability.

1. Introduction

One of the main goals of mathematical education is to develop students' ability to solve mathematical word problems. This ability is important both for academic success and for problem solving in everyday life. However, mathematical word problem solution is very demanding and difficult for many students (Mayer & Hegarty, 1996). Solving mathematical word problems may be particularly difficult for children with atypical development, such as those with ADHD symptoms, but the issue has not been deeply studied (Marzocchi, Cornoldi, Lucangeli, De Meo, & Fini, 2002), whereas more attention has been devoted to other mathematical abilities of children with ADHD, with partly contradictory results. Indeed, although, several studies showed a significant negative correlation between mathematics and ADHD symptoms (Benedetto-Nasho & Tannock, 1999; Greven, Kova,

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Willcutt, Petrill, & Plomin, 2014; Thorell, 2007), not all studies found this negative relations (for a review see Tosto, Momi, Asherson, & Malki, 2015).

The primary purpose of this study was therefore to determine whether 6th graders with ADHD (aged 11–12 years) are impaired in solving mathematical word problems, compared to typically-developing children of same age and grade. A second goal of the study was to test the hypothesis that the difficulty of children with ADHD is related to their weaknesses in working memory, specifically, in updating processes necessary to build the correct mental model of the problem. A third goal of the study was to examine which steps of the problem solving process were specifically disrupted for the ADHD group.

1.1. Mathematical word problem processes

In the school setting, mathematical word problems are typically presented as a short story that includes relevant numerical information (e.g., "data") and a question (e.g., John bought 4 pizzas with 8 slices each. He and his friends Bruce ate 12 slices of the pizzas. How many slices were left?). The solution of the problem requires the use of arithmetic operations (i.e., addition, subtraction, multiplication, or division), and the execution of several different cognitive processes, as now we will describe. Initially, in the understanding phase, children must formulate a cognitive representation of the information drawn from the text of the problem. This initial cognitive representation requires discriminating relevant from irrelevant information. Subsequently, in the solution phase, they need to formulate a plan for solving the problem (Lee, Ng, & Ng, 2009; Mayer & Hegarty, 1996; Mayer, Larkin, & Kadane, 1984; Riley & Greeno, 1988). Devising a plan involves choosing appropriate sub-goals for the solution and consequently include the choice of the correct arithmetic operations and algorithms. Finally, they have to correctly perform the calculations.

Memory processes related with the Central Executive component of working memory appear to be important for successful solutions of mathematical word problems (Lee et al., 2009; Rassmussen & Bisanz, 2005; Swanson, Jerman, & Zheng, 2008). Although several working memory models have been described in the literature, our research is within the theoretical framework of the widely accepted model of Baddeley and Hitch (1974) see also Baddeley (1986, 1992, 2000). According to Baddeley's model, working memory involves two slave systems, the articulatory loop and visuospatial sketch pad, which store verbal and visuospatial materials, respectively. The activity of these storage systems is coordinated by the Central Executive, a system with supervisory and attentional functions. A fourth component, the episodic buffer, is responsible for integrating information from the working memory storage and long-term memory. However, the outcomes on this component are still very scarce in the area of developmental psychology.

According to Miyake et al. (2000), the Central Executive component of Baddeley's model is related with three main executive functions: inhibition, updating, and shifting. Inhibition involves the ability to suppress dominant or prepotent responses, shifting involves the ability to shift strategies when attending to multiple tasks or mental processes and updating involves the ability to replace outdated and irrelevant information by maintaining only a restricted set of elements in working memory.

1.2. Updating and mathematical word problem

Research is still scarce about the influence of the executive components of working memory on the solution of arithmetic word problems. Previous research has shown a relationship between the ability to inhibit irrelevant information stored in working memory and problem solving (Passolunghi & Siegel, 2001, 2004; Passolunghi, Cornoldi, & De Liberto, 1999). Specifically, Passolunghi and Siegel (2001, 2004) found that, compared to good problem solvers, poor problem solvers found it difficult to suppress information that was irrelevant to the problem solving task. With regard to updating, several authors have suggested that updating could also be a key cognitive process for solving mathematical word problems (Blessing & Ross, 1996; Iglesias-Sarmiento, Carriedo López, & Rodríguez Rodríguez, 2015; Kotsopoulosa & Leeb, 2012; Passolunghi & Pazzaglia, 2004). In fact, word problem solving requires the maintenance of information and the construction of a mental model that may also need to be modified at each step of the problem-solving process (Blessing & Ross, 1996; Hegarty, Mayer, & Monk, 1995; Passolunghi & Pazzaglia, 2004). This updating process mirrors a similar process in reading comprehension, where readers need to construct a mental representation of the contents of the text, a process that requires integrating information from the text with previous knowledge (Gernsbacher, 1993), and updating it when new information appears (Gernsbacher, 1993). Accordingly, the mechanisms involved in this process include the enhancement of new relevant information and the inhibition of information already processed but no longer relevant.

When they are comprehending mathematical word problems, problem solvers have to process all of the information derived the problem text. Information that is not relevant to the problem solution should be inhibited. Other information will be connected in a coherent mental model that may be successively modified in response to new information. This mental model will be complete when all the information relevant to solving the question is integrated. Updating is a complex process that includes selecting information to retain or exclude from the model maintained in working memory. On this respect Passolunghi and Pazzaglia (2004) found that fourth grade children with low updating functioning showed worse performance on arithmetic problems than a control group matched for intelligence but with higher updating ability. Comparable results in studies using similar tests have been reported in reading comprehension (e.g. Chiappe, Hasher, & Siegel, 2000; Palladino, Cornoldi, De Beni, &

Pazzaglia, 2001) and in problem solving with children with typical development (respectively, 5th graders in Iglesias-Sarmiento et al. (2015), and 8th graders in Kotsopoulosa & Leeb, 2012).

1.3. Updating and mathematical word problems in children with atypical development

A study with poor comprehenders (Cornoldi, Drusi, Tencati, Giofrè, & Mirandola, 2012) found that they also had problem solving difficulties related with their updating difficulties. Passolunghi and Pazzaglia (2005) compared the performance in updating ability in two groups of 4th grade children with and without poor problem-solving ability. They found the main difficulties of poor problem solvers were not in memory storage, but in updating and the strategic control of information.

In summary, there is evidence suggesting that success in mathematical problem solving is associated with the efficient use of working memory updating processes. This conclusion has implications for the children with ADHD, as several studies provided support to the hypothesis that children with ADHD have poor working memory, in particular in suppressing irrelevant information and updating relevant information (Armstrong, Hayes, & Martin, 2001; Barkley, 1997; Mariani & Barkley, 1997). Cornoldi et al. (2001) hypothesized that the reason children with ADHD symptoms have lower performance and higher number of intrusion errors both in verbal and spatial working memory tasks is because they are not capable of suppressing information that initially has to be processed, and subsequently excluded from the memory system. This deficit could contribute to the poor performance on children with ADHD in mathematics, in combinations with their difficulties in other processes, including calculation (Mayes & Calhoun, 2006; Sella, Re, Lucangeli, Cornoldi, & Lemaire, 2012 Zentall, Smith, Lee, & Wieczorek, 1994). Consistent with the view, children with ADHD are impaired in solving math word problems that include irrelevant information that must be inhibited for successful solution, as suggested by Marzocchi et al. (2002) and Passolunghi, Marzocchi, and Fiorillo (2005). However, these two previous studies only considered the case of exclusion of irrelevant information, and did not examine the case, present in school problem solving and p narticularly frequent in everyday life, in which old information maintained in working memory must be not only excluded but also substituted with new one. Therefore, in the present study we focused on updating processes in mathematical word problems. In fact, updating requires not only the exclusion/inhibition of irrelevant information of the problem, but also its substitution with a new relevant information,

1.4. The present study

In the present study, we examined the mathematical word problem solving ability of 6th grade children with reported symptoms of ADHD (referred to as children with ADHD), compared to children with typical development. The children were asked to solve mathematical word problems containing 1–3 to be updated data (presenting numerical information that initially had to be processed, but had, in a second time, to be updated with other relevant numerical information according to the goal of the problem). The texts were read to the children in order to simulate typical everyday situations where there is no written text and also to emphasize the role of working memory (see the detailed procedure and materials in the Method Section).

Our aims were to determine whether children with ADHD symptoms have lower performance on math word problems, whether they found problems requiring updating more difficult than problems which did not require updating, and to determine which solution process are involved when the children experienced difficulties. In particular we focused on four processes represented by: a) the data report (i.e., if the child had written all the data mentioned by the experimenter); b) the correct selection of data (i.e., if the data used by the child in solving the problem were the appropriate ones or the child became confused, for example in problems with updating, and selected the old data); c) the choice of arithmetic operation (i.e., if the child had chosen the appropriate operations for solving the problem) and d) the execution of the algorithm (i.e., if the child had correctly made the calculations). Our hypothesis was that children with ADHD would have lower performance on math word problems than children with typical development. Further, we hypothesized that children with ADHD symptoms might experience a more severe difficulty on problems with updating where their difficulties might be related with the correct selection of data, due to the fact that they should not be able to substitute the old irrelevant wrong data with the new updated data.

2. Method

2.1. Participants

Participants included 14 children with ADHD symptoms and 14 typically-developing children (TD). Groups were matched for schooling (all children were sixth-graders), gender (10 males and 4 females in each group), sociocultural context (all children were native Italians and lived in the same medium size town of the Italian region of Puglia), intelligence (assessed with the Figure Grouping subtest of the PMA Battery – Primary Mental Abilities (Thurstone & Thurstone, 1963) and age. Because an explicit diagnosis of ADHD is rarely used in the area where the study was carried out, the ADHD group was in first place identified through a teacher rating scale (SDAI – "Scala per i Disturbi di Attenzione/Iperattività per Insegnanti," *ADHD rating scale for teachers* – (Marzocchi, Re, & Cornoldi, 2010)). Teachers were also interviewed to collect further information on the children. The SDAI Scale is similar in organization and scope to scales used in other countries to identify children with ADHD (e.g. DuPaul et al., 1998). Teachers are shown the 18 ADHD symptoms (described by DSM-IV and DSM-5) and asked to rate the frequency and intensity of those symptoms on 4-point items (9 for the subscale of inattention and 9 for the subscale of hyperactivity-impulsivity) for each child. For each subscale, the cutoff is at 14 points. All the children included in the ADHD group scored above the cutoff in at least one scale (inattention or hyperactivity-impulsivity). The scale has been validated and standardized for the Italian population (Marzocchi et al., 2010) and has good inter-rater reliability ($r = 0.95$) and test–retest reliability ($r = 0.80$).

During the interviews, teachers were asked for further information on the presence of ADHD symptoms in the ADHD group children in different life contexts. Teachers were interviewed to confirm the characteristics of the groups, i.e. the presence of ADHD symptom and the absence of other associated problems. Teachers were also asked to rate any general cognitive weakness, oppositional and aggressive behavior, anxiety and depressive behavior, using the COM scale (COM – "Comorbidity scale", Marzocchi et al., 2010), which has the same format as the SDAI and has also revealed good psychometric properties (e.g. an inter-rater reliability of r = 0.97, Marzocchi et al., 2010). Other exclusion criteria were: use of medication; a previous diagnosis of a learning disorder, a history of neurological disorders, sensory problems, motor impairments, or any neurodevelopmental disorder other than ADHD. In particular children who had a diagnosis of Learning Disabilities were excluded (in Italy all children who have a LD have to present a diagnostic certificate according to a specific Italian law). Mean ages and scores of the two groups in the intelligence and rating scales are reported in Table 1.

2.2. Materials

The materials included 12 word mathematical problems, 6 without and 6 with information that required updating in the course of solving the problem. The six problems without updating, created *ad hoc* for the present study, were typical of problems administered in the area of mathematics to Italian sixth-graders, representing the variability in arithmetic and geometric knowledge a sixth-grader would be faced with in math word problems. On the basis of these problems, we created six additional problems that required updating. These involved similar reasoning and arithmetic operations, but with the inclusion of numerical information that, when presented, seemed necessary for the solution of the problem, but subsequently had to be updated with new information. In order to have problems of similar length and difficulty, the text of the problems without updating required more verbal elaboration and could include other minor difficulties. For example, the first problem without updating was the following: "Before starting his work, the gardener must calculate the perimeter of a beautiful and great garden having the shape of a trapezoid isosceles. The major base of the garden is 50 m long, the minor base is 35 and the sides are long 28 m each. How long is the perimeter of the garden?" The text of the corresponding problem with updating was the following: "You must calculate the perimeter of a field having the shape of a rectangle. When the field was measured, its sides were 32 and 27 m, respectively for the base and the height. However, when the garden was measured a second time, the actual length of the base was 29 m. How long is the perimeter of the field?" In this example, the numerical data had to be updated with the new measurement. There were 2 problems with 1 information to be updated, 2 problems with 2 information to be updated, and 2 problems with 3 information to be updated. A preliminary control confirmed that the problems with and without updating were of similar difficulty for typically developing children.

2.3. Procedure

Children were individually tested in a small quiet room of their school. Before starting to solve the problems, children were assessed on the basic geometrical rules necessary for computing areas and perimeters of the forms present in the geometrical problems included in the battery. As all the children resulted familiar with these basic rules, we moved on and asked the children to complete an example problem (without updating) and then proceed with the experimental problems.

Problems were orally presented at a slow rate of approximately 2 s for one content word in such a way that the child could not write the entire text of the problem, but could take notes and write the numbers involved in the problem. Children were in-

Table 1
Mean (*M*) and Standard Deviation (*SD*) of age, intelligence, and SDAI rating scales of the two groups of children with ADHD and typically-developing (TD).

	Group	N	M	SD	p
Age	ADHD	14	132.42 (months)	2.35	>0.05
	TD	14	132.42 (months)	2.30	
SDAI	ADHD	14	16.79	0.83	<0.001
Inattention	TD	14	1.37	0.47	
SDAI	ADHD	14	7.53	1.04	<0.001
Hyperactivity	TD	14	0.95	0.41	
ODD	ADHD	14	0.63	0.17	>0.05
	TD	14	0	0	
Anxiety	ADHD	14	1.95	0.35	>0.05
	TD	14	0.89	0.70	
PMA	ADHD	14	18.42	0.56	>0.05
	TD	14	19.26	0.62	

SDAI = "Scala per i Disturbi di Attenzione/Iperattività per Insegnanti," *ADHD rating scale for teachers* – Marzocchi et al., 2010. ODD = Oppositional Defiant Disorder; PMA = Primary Mental Abilities (e & Thurstone, 1963).

structed that the problem could not be read a second time and therefore were invited to pay great attention and take notes of the data. Furthermore, the experimenter controlled that the children were carefully following the reading of the text and eventually paused in order to facilitate them. After the presentation of each problem, the child was invited to solve without time limitations the problem in a written form including all the solution steps. When s/he reported having solved the problem, the next problem was presented. Problems were presented in a fixed order, starting with the simplest one and finishing with the most complex one, alternating problems with and without updating. This approach was used to minimize the possibility that children would find the problems too difficult and become frustrated.

3. Results

All children paid attention to the presented problems and were able to complete all the problems. Fig. 1 presents the mean numbers of the problems (with and without updating) correctly solved by the two groups. Number of problems solved correctly was analyzed in a 2 (Group: Typical, ADHD) × 2 (problem type: no updating, updating) mixed ANOVA. There was a significant main effect of group, F (1, 26) = 15.46, $p < 0.001$, $\eta^2_p = 0.37$. Children with ADHD symptoms solved fewer problems correctly than control children (Problems correctly solved by ADHD: M = 4.57, SD = 3.11; problems correctly solved by TD: M = 9.07, SD = 2.95). There was also a significant interaction between group and problem type, $F(1, 26) = 5.79$, $p = 0.023$, $\eta^2_p = 0.18$. The interaction occurred because the difference in accuracy between problems with and without updating was significant only in the case of the children with ADHD symptoms (respectively M = 1.86, SD = 1.75; M = 2.71, SD = 1.59, Bonferroni post- hoc comparison p = 0.011, see Fig. 1). Thus, as predicted, children with ADHD symptoms were more affected by the requirement to update problem information than were typically-developing children.

In order to better understand the sources of the difficulties for children with ADHD symptoms, we considered the children's protocols and we examined to which of the solving phases errors were due. In particular we focused on the following categories: the data report (i.e., if the child had written all the data mentioned by the experimenter), the correct selection of data (i.e., if the data used by the child in solving the problem were the appropriate ones), the choice of arithmetic operation (i.e., if the child had chosen the appropriate operations for solving the problem) and the execution of the algorithm (i.e., if the child had correctly made the calculations, independently from the numbers s/he had decided to use). These aspects were scored by considering, for each problem, the proportion of correct elements within each step with respect to the number of involved elements. For example if a problem involved 4 numbers and the child wrote down only three of the numbers, the proportion of data was 0.75. The proportions calculated for each problem, separately for problems without and with updating request, were then summed.

Table 2 presents the mean summed proportions of elements of the six problems that were correctly included by the child in the written protocol for each category described above. The main differences between the two groups were in the correct selection of data and in the choice of the appropriate arithmetic operation. In particular, in the correct selection of data, children with ADHD symptoms obtained a score of 4.02 with the problems with updating largely below the controls who had a score of 5.41, i.e. used a proportion of 0.90 (vs 0.66 of children with ADHD symptoms) of the data they had actually to use. In fact, four 2 × 2 ANOVAs (groups × updating) separately calculated for the four categories of the solution process showed different patterns. In the case of data report, we did not find any significant effect either in the comparison between the two groups [$F(1,26) = 1.36$, $p > 0.05$] or the kind of problems [$F(1,26) = 1.46$, $p > 0.05$] or interaction [$F(1,26) = 1.13$, $p > 0.05$]. In the category of the correct selection of data, we found a significant main effect of the updating [$F(1,26) = 11.71$, $p = 0.002$, $\eta^2_p = 0.310$], a significant effect of group [$F(1,26) = 11.50$, $p = 0.002$, $\eta^2_p = 0.307$] and a significant interaction [$F(1,26) = 5.39$, $p = 0.028$, $\eta^2_p = 0.172$]. Post hoc analysis showed that in the ADHD group the comparison between problem with versus problems without updating was significant ($p < 0.001$).

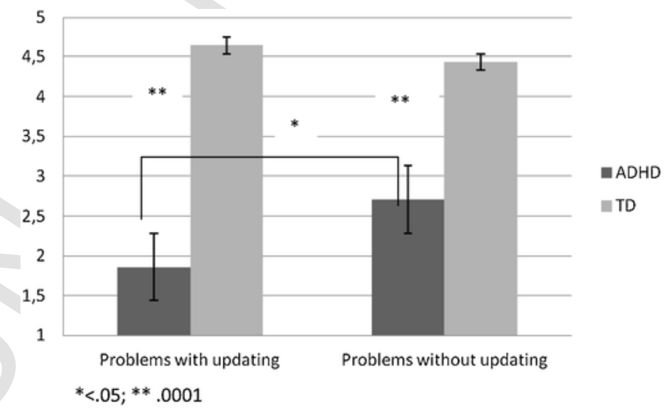

Fig. 1. Mean numbers of the problems with and without updating correctly solved by the children with ADHD and Typically-Developing (TD) children (error bars are Standard Deviations). Maximum score was 6.0.

Table 2
Means (*M*) and Standard Deviations (SD) of the scores obtained for the four categories of the problem solving process for problems with and without updating, in children with ADHD and typical development (TD).

	Problems without updating				Problems with updating			
	ADHD		TD		ADHD		TD	
	M	SD	M	SD	M	SD	M	SD
Data report	5.71	0.39	5.78	0.47	5.47	0.81	5.78	0.41
Correct selection of data	5.06	0.65	5.61	0.80	4.02	1.32	5.41	0.64
Choice of arithm. operations	3.00	1.28	4.53	0.88	2.55	1.41	4.19	0.94
Execution of the algorithms	3.69	1.14	4.77	0.95	2.81	0.93	3.36	0.55

The choice of arithmetic operation category showed a significant main effect of problems [$F(1,26) = 7.89$, $p = 0.010$, $\eta^2_p = 0.240$] and a significant main effect of group [$F(1,26) = 14.45$, $p = 0.001$, $\eta^2_p = 0.366$], but there was not an interaction. We found the same pattern of results also for the category of the execution of the algorithms (i.e., a significant main effect of problems [$F(1,26) = 40.08$, $p < 0.001$, $\eta^2_p = 0.616$] and a significant main effect of group [$F(1,26) = 9.19$, $p = 0.006$, $\eta^2_p = 0.269$], but not a significant interaction.

4. Discussion

Although mathematical learning disabilities are highly comorbid with ADHD (; Mayes, & Calhoun, 2006), knowledge about the abilities of individual with ADHD to solve mathematical problems is scarce. The main aims of the present research were to examine whether of children with ADHD symptoms present mathematical problem solving difficulties and to verify if the request of updating information further impairs the problem solving ability of children with ADHD symptoms with respect to children with typical development. As it is well known from literature, children with ADHD symptoms have problems in executive functions (e.g., Barkley, 1997), including the use of the executive controlled component of working memory (Cornoldi, Giofrè, Calgaro, & Stupiggia, 2013) and this difficulty has severe consequences for different aspects of their learning. Thus, children with ADHD symptoms present problems in learning tasks, especially when their regulative deficits (i.e., attentional or working memory control, planning, organization, monitoring, etc.) are in conflict with the task requests. For example, children with ADHD symptoms perform worse than control children in expressive writing (e.g. Mayes & Calhoun, 2006; Re, Pedron, & Cornoldi, 2007; Re, Caeran, & Cornoldi, 2008), presumably because writing involves various complex executive functions, such as planning, working memory, organization, monitoring, and attention. The evidence of the present study shows that these difficulties also occur for children with ADHD symptoms in mathematical problem solving.

The word problem solution requires several cognitive processes such as the construction of a mental model and its progressive updating when going on to the next step (Blessing & Ross, 1996; Hegarty et al., 1995; Passolunghi & Pazzaglia, 2004). We hence hypothesized that children with ADHD symptoms, due to their executive working memory weaknesses, would meet particular difficulties in problems with updating than children with typical development. Our results confirmed this hypothesis showing that children with ADHD symptoms could solve fewer problems than children with typical development. In particular, children with typical development did not show any difference in solving problems with or without updating, while children with ADHD symptoms showed a worse performance in solving problems with updating than those without updating. Indeed, a child who has to update information during a problem solving task has to select relevant information, to inhibit information already processed but no longer relevant, and to substitute the no longer relevant information with a new one (Passolunghi & Pazzaglia, 2004). Our results support the view that updating is problematic in ADHD children and may be a further source of their difficulty when solving mathematical problems. On this respect their impairment in the ability to update information should not differ from the updating difficulties present in other children with specific learning difficulties in mathematics (Passolunghi & Pazzaglia, 2004).

To better understand the difficulties experienced by children with ADHD symptoms in problem solving, we examined the children's written work, which allowed us to examine different steps in the problem solving process. We analyzed: a) the data report (i.e., whether child had written all the data mentioned by the experimenter); b) the correct selection of data (i.e., whether the child selected the appropriate data to solve the problem); c) the choice of arithmetic operation (i.e., whether the child had chosen the appropriate operations for solving the problem and d) the execution of the algorithm (i.e., whether the child correctly calculated the answer, independently from the numbers s/he had decided to use).

Results of this analysis showed that differences between children with ADHD symptoms and typically-developing children varied according to the solution step. Both groups were successful in writing down most of the numbers that were mentioned in the story problem. This result further confirms that all children actually paid attention to the presented material and were able to register the necessary numerical information. In contrast, children with ADHD symptoms were less likely to use the correct numbers in their calculation for updating problems than the typically-developing children. On the other two problem steps the children with ADHD symptoms were also less likely to choose the correct solution procedure and were less likely to execute it accurately. These patterns of results confirm that an important role of the difficulties encountered by children with ADHD symptoms in the problem solving is probably due dysfunctions in the executive processes involved in the selection and controlled use of the procedure. However, the ability to update information resulted critical in differentiating the groups. Research (e.g. Carretti, Cornoldi, & Pelegrina, 2007) has shown that mathematical updating involves different aspects, including the comparison between old and new information, the elimination of old to-be-updated information, its substitution with new information. Future research should therefore examine which updating components may in particular affect an updating difficulty of ADHD children.

In conclusion the present study offers for the first time clear evidence on the general difficulties children with ADHD symptoms may encounter in solving mathematical problems and on the specific implications of the updating request typically involved in many school problems, but especially in everyday life problems where the exact data (e.g. times, locations, values, prices) are continuously changing. However, due to the limited size and the specific age of the sample and the specific characteristics of the task and materials, these results should be replicated with different and larger samples of children with a diagnosis of ADHD and also with other type of materials and tasks, including a larger selection of mathematical word problems. Furthermore, although evidence concerning a working memory deficit is already large, as for example shown by the meta-analysis of Martinussen and colleagues (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), measures of working memory could be collected in order to confirm the presence of a deficit and examine their relationship with the impairment due to the updating request. Despite the study limitations, results of the present study offer new insight on the difficulties met by children with ADHD symptoms in mathematical problem solving and useful information also for intervention. In fact, due to the importance of problem solving in school learning and also in everyday life, difficulties of ADHD children due to updating processes should be considered more deeply and intervention programs focused on the weaknesses should be carried out.

References

Armstrong, C.L., Hayes, K.M., Martin, R., 2001. Neurocognitive problems in attention deficit disorder: Alternative concepts and evidence for impairment in inhibition of selective attention. Annals of the New York Academy of Science 931, 196–215.

Baddeley, A.D., Hitch, G.J., 1974. Working memory. In: In: Bower, G.A. (Ed.), Recent advances in learning and motivation, Vol. 8. Academic Press, New York, pp. 47–89.

Baddeley, A.D., 1986. Working memory. Oxford University Press, Oxford, UK.

Baddeley, A., 1992. Human memory. Theory and practice. Erlbaum, Hillsdale, NJ.

Baddeley, A.D., 2000. The episodic buffer: A new component of working memory. Trends in Cognitive Sciences 11 (4), 417–423.

Barkley, R.A., 1997. Behavioral inhibition, sustained attention: And executive functions: Constructing a unifying theory of ADHD. Psychological Bulletin 121, 65–94.

Benedetto-Nasho, E., Tannock, R., 1999. Math computation: Error patterns and stimulant effects in children with Attention Deficit Hyperactivity Disorder. Journal of Attention Disorders 3, 121–134.

Blessing, S.B., Ross, B.H., 1996. Content effects in problem categorization and problem-solving. Journal of Experimental Psychology, Learning Memory and Cognition 22, 792–810.

Carretti, B., Cornoldi, C., Pelegrina, S.L., 2007. Which factors influence number updating in working memory? The effects of size distance and suppression. British Journal of Psychology 98, 45–60.

Chiappe, P., Hasher, L., Siegel, L.S., 2000. Working memory, inhibitory control and reading disability. Memory and Cognition 28, 8–17.

Cornoldi, C., Marzocchi, G.M., Belotti, M., Caroli, M.G., Meo, T., Braga, C., 2001. Working memory interference control deficit in children referred by teachers for ADHD symptoms. Child Neuropsychology 7, 230–240.

Cornoldi, C., Drusi, S., Tencati, C., Giofrè, D., Mirandola, C., 2012. Problem solving and working memory updating difficulties in a group of poor comprehenders. Journal of Cognitive Education and Psychology 11, 39–44.

Cornoldi, C., Giofrè, D., Calgaro, G., Stupiggia, C., 2013. Attentional WM is not necessarily specifically related with fluid intelligence: The case of smart children with ADHD symptoms. Psychological Research 77, 508–515.

DuPaul, G.J., Anastopoulos, A.D., Power, T.J., Reid, R., Ikeda, M.J., McGoey, K.E., 1998. Parent ratings of attention-deficit/hyperactivity disorder symptoms: Factor structure and normative data. Journal of Psychopathology and Behavioral Assessment 20, 83–102.

Gernsbacher, M.A., 1993. Less skilled readers have less efficient suppression mechanisms. Psychological Science 4, 294–298.

Greven, C.U., Kovas, Y., Willcutt, E.G., Petrill, S.A., Plomin, R., 2014. Evidence for shared genetic risk between ADHD symptoms and reduced mathematics ability: A twin study. Journal of Child Psychology and Psychiatry 55, 39–48.

Hegarty, M., Mayer, R.E., Monk, C., 1995. Comprehension of arithmetic word problems: A comparison of successful and unsuccessful problem solvers. Journal of Educational Psychology 87, 18–32.

Iglesias-Sarmiento, V., Carriedo López, N., Rodríguez Rodríguez, J.L., 2015. Updating, executive function and performance in reading comprehension and problem solving. Anales de Psicologia 31 (1), 298–309.

Kotsopoulosa, D., Leeb, J., 2012. A naturalistic study of executive function and mathematical problem-solving. Journal of Mathematical Behavior 31, 196–208.

Lee, K., Ng, E.L., Ng, S.F., 2009. The contribution of working memory and executive functioning to problem representation and solution generation in algebraic word problem. Journal of Educational Psychology 101, 373–387.

Mariani, M.A., Barkley, R.A., 1997. Neuropsychological and academic functioning in preschool boys with attention deficit hyperactivity disorder. Developmental Neuropsychology 13, 111–129.

Martinussen, R., Hayden, J., Hogg-Johnson, S., Tannock, R., 2005. A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. Journal of the American Academy of Child & Adolescent Psychiatry 44 (4), 377–384.

Marzocchi, G.M., Lucangeli, D., De Meo, T., Fini, F., Cornoldi, C., 2002. The disturbing effect of irrelevant information on arithmetic problem solving in inattentive children. Developmental Neuropsychology 21 (1), 73–92.

Marzocchi, G.M., Re, A.M., Cornoldi, C., 2010. BIA – Batteria Italiana per l'ADHD [Italian battery for the assessment of ADHD]. Erickson, Trento.

Mayer, R.E., Hegarty, M., 1996. The process of understanding mathematical problems. In: Sternberg, R.J., Ben-Zeev, T. (Eds.), The nature of mathematical thinking. Erlbaum, Hillsdale, NJ, pp. 29–53.

Mayer, R.E., Larkin, J.H., Kadane, J.B., 1984. A cognitive analysis of mathematical problem-solving ability. Erlbaum, Hillsdale, NJ.

Mayes, S.D., Calhoun, S.L., 2006. Frequency of reading, math, and writing disabilities in children with clinical disorders. Learning and Individual Differences 16 (2), 145–157.

Miyake, A., Friedman, N., Emerson, M., Witzki, A., Howerter, A., Wager, T.D., 2000. The unity and diversity of executive functions and their contributions to complex frontal lobe tasks: A latent variable analysis. Cognitive Psychology 41, 49–100.

Palladino, P., Cornoldi, C., De Beni, R., Pazzaglia, F., 2001. Working Memory and updating processes in reading comprehension. Memory and Cognition 29 (2), 344–354.

Passolunghi, M.C., Pazzaglia, F., 2004. Individual differences in memory updating in relation to arithmetic problem solving. Learning and Individual Differences 14, 219–230.

Passolunghi, M.C., Siegel, L.S., 2001. Short term memory, working memory: And inhibitory control in children with specific arithmetic learning disabilities. Journal of Experimental Child Psychology 80, 44–57.

Passolunghi, M.C., Siegel, L.S., 2004. Working memory and access to numerical information in children with disability in mathematics. Journal of Experimental Child Psychology 88, 348–367.

Passolunghi, M.C., Cornoldi, C., Di Liberto, S., 1999. Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. Memory and Cognition 27, 779–790.

Passolunghi, M.C., Marzocchi, G.M., Fiorillo, F., 2005. Selective effect of inhibition of literal or numerical irrelevant information in children with Attention Deficit Hyperactivity Disorder (ADHD) or Arithmetic Learning Disorder (ALD). Developmental Neuropsychology 28 (3), 731–753.

Rassmussen, C., Bisanz, J., 2005. Representation and working memory in early arithmetic. Journal of Experimental Child Psychology 91, 137–157.

Re, A.M., Pedron, M., Cornoldi, C., 2007. Expressive writing difficulties in children described by their teacher as exhibiting ADHD symptoms. Journal of Learning Disabilities 40, 244–255.

Re, A.M., Caeran, M., Cornoldi, C., 2008. Improving expressive writing skills of children rated for ADHD symptoms. Journal of Learning Disabilities 41, 535–544.

Riley, M.S., Greeno, J.C., 1988. Developmental analysis of understanding language about quantities and of solving problems. Cognition and Instruction 5 (1), 49–101.

Sella, F., Re, A.M., Lucangeli, D., Cornoldi, C., Lemaire, P., 2012. Competent ADHD children may make correct mental calculations, but do not choose the better strategy. Journal of Attention Disorder

Swanson, H.L., Jerman, O., Zheng, X., 2008. Growth in working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. Journal of Educational Psychology 100 (2), 343–379.

Thorell, L.B., 2007. Do delay aversion and executive function deficits make distinct contributions to the functional impact of ADHD symptoms? A study of early academic skill deficits. Journal of Child Psychology and Psychiatry 48, 1061–1070.

Thurstone, T.G., Thurstone, L.L., 1963. Primary mental abilities. Science Research Associates, Chicago. Italian edition, 1981.

Tosto, M.G., Momi, S.K., Asherson, P., Malki, K., 2015. A systematic review of attention deficit hyperactivity disorder (ADHD) and mathematical ability: Current findings and future implications. BMC Medicine 1–14.

Zentall, S.S., Smith, Y.N., Lee, Y.B., Wieczorek, C., 1994. Mathematical outcomes of attention-deficit hyperactivity disorder. Journal of Learning Disabilities 27, 510–519.