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Article

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Abstract

Deficits in executive functions have been hypothesized and documented for children with severe mathematics anxiety (MA) or developmental dyscalculia, but the role of inhibition-related processes has not been specifically explored. The main aim of the present study was to shed further light on the specificity of these profiles in children in terms of working memory (WM) and the inhibitory functions involved. Four groups of children between 8 and 10 years old were selected: one group with developmental dyscalculia (DD) and no MA, one with severe MA and developmental dyscalculia (MA-DD), one with severe MA and no DD (MA), and one with typical development (TD). All children were presented with tasks measuring two inhibition-related functions, i.e. proactive interference and prepotent response, and a WM task. The results showed that children with severe MA (but no DD) were specifically impaired in the proactive interference task, while children with DD (with or without MA) failed in the WM task. Our findings point to the importance of distinguishing the cognitive processes underlying these profiles.

Keywords: mathematics anxiety, developmental dyscalculia, inhibitory mechanisms, primary school children

Highlights:

- Children who have math anxiety or developmental dyscalculia (with or without math anxiety) were tested on inhibition-related processes and working memory.
- Children with severe math anxiety (but no developmental dyscalculia) were specifically impaired in a proactive interference task.
- Children with developmental dyscalculia (with or without math anxiety) failed in a verbal WM task.

Separating math from anxiety: The role of inhibitory mechanisms

It has been extensively reported that a large proportion of children and adults have cognitive and/or emotional difficulties with mathematics (Hopko, McNeil, Gleason, & Rabalais, 2002). Children can consequently fail in math for two main reasons: the presence of a math learning disorder (i.e., developmental dyscalculia), or the presence of emotional issues that affect their math performance, such as mathematics anxiety (MA) (Hill et al., 2016). Math anxiety can be broadly defined as a state of discomfort caused by performing mathematical tasks, which can be manifested as feelings of apprehension, tension, and worry (Ma & Xu, 2004; Ashcraft & Ridley, 2005). On the other hand, developmental dyscalculia (DD) is generally defined as a disorder of mathematical ability in individuals whose IQs and language abilities are in the normal range (Shalev & Gross-Tsur, 2001). It is noteworthy that although children with specific learning disorders, DD inclusive, generally have IQs in the normal range, their cognitive profile is not homogenous, and presents impairment in working memory (WM) and processing speed indexes (Giofrè & Cornoldi, 2015; Giofrè, Toffalini, Cornolid, 2017; Toffalini, Giofrè, & Cornoldi, 2017). It is also worth noting that not all people with severe MA perform equally poorly in math, and not all people with DD are characterized by high levels of MA.

In the present study, we therefore aimed to disentangle the differences between low proficiency in arithmetic due to a specific mathematics disorder and low math performance due to emotional aspects (e.g., MA) by analyzing the underlying cognitive deficits, and examining WM and inhibitory mechanisms in particular. Both WM (Baddeley, 2000) and inhibitory mechanisms (Nigg, 2000) seem to be implicated in the impairment of individuals with severe MA and children with DD.

Concerning MA, theories on processing efficiency and attentional control suggest an important role for WM and inhibitory mechanisms in regulating cognitive performance (Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos, & Calvo, 2007; Richards & Gross, 2000). According to processing efficiency theory and attentional control theory, information that is no longer relevant subtracts some of the available WM capacity (Ashcraft & Kirk, 2001; Derakshan & Eysenck, 2009; Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011). In particular, attentional control theory (Eysenck & Calvo, 1992) assumes that anxiety interferes with the efficient functioning of the goal-directed attentional system by hindering attentional control. In other words, anxiety raises an individual's attention to threat-related stimuli. The negative effects of anxiety on processing efficiency are therefore related, according to this theory, to impairments in WM and inhibition (Eysenck, et al., 2007).

Previous studies suggested that children with MA have verbal WM impairments (Mammarella, Hill, Devine, Caviola, Szűcs, 2015; Passolunghi, Caviola, De Agostini, Perin, & Mammarella, 2016). Ashcraft and colleagues (Ashcraft & Faust, 1994; Ashcraft & Kirk 2001) also claimed that no longer relevant information in the thoughts (i.e., intrusive thoughts) of math-anxious adults interferes with their ability to perform mathematical tasks by usurping their WM resources; this results in a failure to inhibit attention to these worrying thoughts (Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998; Hopko, McNeil, Gleason, & Rabalais, 2002). A recent narrative review, beyond providing an inclusive summary of the literature, also offers an extensive analysis of this inability to suppress attention to disturbing information, a deficit that would not be dependent on the experience of numerical content *per se* and that has mainly been tested through numerical Stroop tasks (Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). To the best of our knowledge, however, no study to date has directly contrasted WM and inhibition-related functions in children or adults with severe MA. In fact, this study would foster better understanding of the cognitive mechanisms linked to emotional impairment as it relates to mathematics.

A large body of literature has extensively studied the role of domain-general cognitive processes involved in mathematics achievement. Research on arithmetic achievement has considered several cognitive mechanisms, but particular attention has been drawn to the role of WM and executive functions (see Cragg and Gilmore, 2014; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Peng, Namkung, Barnes, & Sun, 2016; Raghubar, Barnes, & Hecht, 2010 for a review). As far as WM is concerned, one of the most influential models was proposed by Baddeley and Hitch (1974). Baddeley (2000) added a third slave system to his model, *the episodic buffer*, which allows the communication between working memory and long-term memory. In this model, WM consists of two short-term storage systems (or slave systems) and a central executive component that allows the information to be stored and manipulated in the two slave-systems. This model has received a strong support, and several independent studies with children indicated that it was superior compared to numerous alternative WM models (Alloway, Gathercole, & Pickering, 2006; Giofrè, Mammarella, & Cornoldi, 2013). The importance of WM also relies on this construct's good predictive value. Indeed, several studies revealed that WM can be considered a strong predictor of mathematics performance in simple arithmetic (Caviola, Mammarella, Lucangeli, & Cornoldi, 2014; Fuchs et al., 2010), and in arithmetical and geometrical problem solving (Giofrè, Mammarella, Ronconi, & Cornoldi, 2013; Passolunghi, Mammarella, & Altoè, 2008). In addition, WM impairments have been demonstrated in participants with DD (Krajewksi, & Schneider, 2009; Mammarella, Caviola, Lucangeli, & Cornoldi, 2013; Passolunghi & Siegel, 2001; Schuchardt, Maehler, & Hasselhorn, 2008).

Taken overall, these results seem to indicate that WM plays a very important role in mathematics, although some WM tasks seem to be more strongly related to mathematical achievement than others. Specifically, tasks requiring the simultaneous information storage and processing (e.g., complex span tasks) are considered to require more attentional resources and to have stronger predictive power for mathematics achievement (Friso-van den Bos et al., 2013; Peng, et al., 2016).

As far as the relationship between mathematical achievement and inhibition is concerned, both children with typical and atypical development have consistently presented impairment in these mechanisms (Bull & Lee, 2014; Bull & Scerif, 2001; Cragg, Keeble, Richardson, Roome, & Gilmore, 2017; Lee & Bull, 2016; St Clair-Thompson & Gathercole, 2006). Inhibition of irrelevant information in mathematical abilities has manifested in different ways. It may for example involve the suppression of immature or inappropriate strategies, such as addition when multiplication is required, or suppression of irrelevant information, for example information from a word-problem that is irrelevant to the problem itself (Bull & Scerif, 2001). It has also been demonstrated that a stronger relationship exists between mathematics and performance on numerical tasks, as opposed to non-numerical inhibitory tasks (Gilmore, Keeble, Richardson, & Cragg, 2015). It is worth adding that most of the previously-conducted studies testing children with DD investigated their ability to block cognitive responses automatically activated by the stimulus presented, i.e. to inhibit prepotent responses (Bull & Scerif, 2001; Censabella & Noel, 2005, 2007; van der Sluis, de Jong, & van der Leij, 2004). The results were mixed and inconclusive: Zhang and Wu (2011) reported impairments in children with DD on both a color-word and a numerical Stroop, whereas Censabella and Noel (2005), and van der Sluis et al. (2004) found no such impairments on the numerical Stroop. Additionally, van der Sluis et al. (2004) could find none on an object version of the Stroop either. Using a numerical Stroop and the Stop signal task, Szűcs, Devine, Soltesz, Nobes, & Gabriel (2013) found cases of DD more susceptible than controls on the effect of task-irrelevant information.

The present study

The results mentioned above seem to indicate that WM and inhibition represent the cognitive mechanisms underpinning both MA and DD. It is worth noting, however, that these studies focused individually on each of these factors in isolation. With regard to the inhibitory mechanisms, the literature only considered the inhibition/control of prepotent responses. It would therefore be of a particular interest to investigate these cognitive processes (i.e., WM and inhibition) in-depth, to identify which functions are selectively impaired in children with MA or DD.

The objective was to analyze these cognitive-related mechanisms and distinguish a low proficiency in arithmetic due to a specific mathematics disorder from poor mathematics performance due to severe MA. To facilitate this analysis, four groups of children were identified according to their performance in several standardized tests. Two groups were matched for high levels of MA, but these groups differed in terms of their math proficiency; one group's performance in mathematics was poor (developmental dyscalculia: DD), while the other had an average performance (the MA-DD and MA groups, respectively). The other two groups had low levels of MA and differed in their math proficiency; one group had DD, while the other had an average performance, or typical development (the DD and TD groups, respectively). In other words, for the first time we directly compared children with MA or DD only, together with children with a co-occurrence of MA and DD (and children with TD).

Thus, the main goal of the present study was to compare these four groups of children by using a complex-span measure of WM and two inhibition-related functions. In particular, our children were presented with a WM task to confirm whether children with MA and/or DD were impaired in situations that involve both the active storage and the manipulation of information. Regarding the inhibition mechanisms, a proactive interference task (adapted from Borella, Carretti, & Pelegrina, 2010) was used to examine the ability to delete information that was no longer relevant, i.e. the resistance to proactive interference. Finally, children were also administered with the Hayling Sentence Completion task (adapted from

Shallice, et al., 2002) to ascertain the efficacy of the prepotent response inhibition mechanism, since the dominant information has to be prevented from gaining control in this task (see Friedman & Miyake, 2004). To do so, we examined the “resistance to proactive interference” (adopting the taxonomy proposed by Friedman and Miyake, 2004), i.e. the ability to limit the activation of no longer relevant items and thus resist memory intrusions; and the “prepotent response inhibition” which blocks dominant and prepotent cognitive responses automatically activated by the stimulus presented.

By using these measures, we aimed to investigate whether: 1) children with MA and DD only differed in the previously mentioned cognitive-related mechanisms (i.e., WM or in inhibition tasks); 2) the co-occurrence between MA and DD could shed further light on the underlying cognitive profiles related to the presence of a math learning disorder or emotional issues. With regards to question 2), in agreement with the literature, we expect that children with DD should show WM impairments, whereas inhibitory mechanisms should be impaired in children with MA.

Method

Screening

The initial screening involved a sample of 366 children (193 M, 173 F) aged 8 to 10 years (mean= 116.13 months; SD=11.5), with 124 children from 3rd grade, 97 from 4th grade, and 145 from 5th grade, all from families with a medium socio-economic status.

After obtaining ethical approval and permission from local schools in an area of northern Italy, parental consent forms were collected for the children who took part in the present study. Children with intellectual disabilities or an insufficient command of the Italian language were excluded from the study.

The four groups of children were identified on the basis of their mathematical achievement and anxiety levels as measured using several tests administered during the screening phase. Mathematical achievement was assessed with a standardized test battery (AC-MT 6-11, Cornoldi. Lucangeli & Bellina, 2012) and a standardized measure of math fluency (Caviola, Gerotto, Lucangeli, & Mammarella, 2016).

Mathematics anxiety was measured with the Abbreviated Math Anxiety Scale (AMAS, Caviola, Primi, Chiesi, & Mammarella, 2017; Hopko, Mahadevan, Bare, & Hunt, 2003), and general anxiety was tested with the Revised Children's Manifest Anxiety Scale - 2nd Edition (RCMAS-2, Reynolds & Richmond, 2012). Finally, to control for general cognitive skills, we assess the students' verbal competence with the Vocabulary subtest of the WISC IV battery (Wechsler, 2004).

The children were grouped according to strict inclusion criteria as summarized in Table 1. For the MA-DD children the inclusion criteria were: (a) scores more than 1 SD lower than average (<16th percentile) in both the standardized mathematical achievement battery and in math fluency; (b) scores more than 1 SD higher than average for mathematics anxiety (>84th percentile); (c) average scores for general anxiety (i.e., ± 1 SD); (d) average scores in vocabulary and block design (Wechsler, 2004). In our sample, 57 children obtained scores below the 16th percentile in both mathematical batteries, but only 25 of them also obtained scores above the cut-off for the MA. Finally, 6 children were excluded because their scores in general anxiety and general ability measures, resulting in a sub-sample of 19 children.

The inclusion criteria for the MA group were: (a) average scores in the standardized mathematical achievement battery and for math fluency (i.e., ± 1 SD); (b) scores more than 1 SD higher than average for mathematics anxiety (>84th percentile); (c) average scores for general anxiety (i.e., ± 1 SD); (d) average scores in vocabulary and block design. In our sample, 48 children obtained scores above 1 SD in the MA questionnaire, but 28 of them were excluded (22 obtained scores below the 16th percentile in some of the mathematical subtests and 6 exceeded the cut-off of general anxiety), giving us a total of 20 possible children belonging to the MA group.

The inclusion criteria for the DD group were: (a) scores more than 1 SD lower than average (<16^{th} percentile) in the standardized mathematical achievement battery and for math fluency, (b) average scores for mathematics anxiety (i.e., ± 1 SD); (c) average scores for general anxiety (i.e., ± 1 SD); (d) average scores in vocabulary and block design. From the previous sub-sample of 57 children with low performance in mathematical achievement, only 32 children matched the criteria of having an average MA score. Finally, 14 children were excluded because of their scores in general anxiety and general ability measures, resulting in a sub-sample of 18 children who matched the criteria to belong to the DD group.

Finally, the inclusion criteria for the TD group were average scores in all the above-mentioned measures. In our sample, 176 children obtained average scores in all the above-mentioned tasks, and from these we randomly allocated 20 children to the TD group to obtain a comparable number of participants in each group.

Table 1 about here

Participants

Our final sample was composed of 19 MA-DD children (10 F), 20 MA children (12 F), 18 DD children (9 F), and 20 TD children (12 F). The groups' characteristics and statistics are shown in Table 2.

Statistical analyses showed a main effect of group on mathematical achievement $F(3,70) = 22.55$; $p < .0001$ $\eta^2_p = .48$, and math fluency, $F(3,70) = 55.62$; $p < .0001$ $\eta^2_p = .70$, revealing that the MA-DD and DD groups differed in mathematical achievement from the

MA and TD groups (*p*s < .001). Conversely, the MA-DD and MA groups revealed much higher levels of math anxiety than the DD or TD groups, $F(3,70) = 139.83$; $p < .0001$ $\eta^2_p = .85$. The groups did not differ in terms of general anxiety levels ($p > .19$), vocabulary (*p*s > .23), or block design (*p*s > .21). They were also matched for age ($F < 1$), and gender, $\chi^2(3, N=77) = 0.61$, $p = .894$, Cramer's V = .089.

Table 2 about here

Materials

Working memory task

Listening Span Task (LST). This test engages the participant in a dual task: the child has to judge whether a sentence is true or false, and also has to retain the final word in the sentence. The sentences are arranged in sets of sentences of different length (from 2 to 5 sentences per set, with 2 sentences for each length). At the end of each set of sentences, immediately after saying whether the statement was true or false, participants were asked to recall the final word in each of the sentences (in their order of presentation), and to be careful to avoid naming non-final words. The proportion of accurately recalled words was computed (i.e., the partial credit score, see Conway, et al., 2005; Giofrè & Mammarella, 2014).

Inhibitory measures

Resistance to proactive interference (PI). A proactive interference task (adapted from Borella, et al. 2010; see also Borella, Carretti & Mammarella, 2006) was used. The task consists of three sets of three lists of six words each, belonging to three different categories: fruits, animals, and occupations. Each set consisted of three lists included two lists containing words from the same category (e.g., animals) and one, which served as a "release from PI" list, contained words from another category (e.g., fruits). The lists were presented orally at a rate of one word per second. Between the presentation of each list and the recall phase, participants performed a rehearsal-prevention task (they counted backwards from different starting points, aloud and accurately for 10 seconds). At the end of the rehearsal prevention task, children had 20 s to recall as many words as possible in any order, and they were encouraged to continue attempting to recall the words for the whole time available.

For each participant we calculated the number of correctly recalled words and a PI index using the formula: (List 2 – List 1) (see Borella et al., 2006). This latter variable represents an index of interference susceptibility, considering the recall in list 1 as a baseline in the assessment of the proactive interference build-up in list 2 (list 3 was used as a control for testing the release of proactive interference). A lower score thus implied a greater susceptibility to proactive interference.

Prepotent response inhibition. The Hayling Sentence Completion (HSC) task (adapted from Shallice, et al., 2002) consists of high-cloze sentences in which the last word is missing. Participants were asked to complete the sentences either with an expected word (initiation condition) or with a word that made the sentence meaningless (interference condition). Twenty-eight sentences were administered, 14 sentences for each condition. In the first condition (initiation), 14 high-cloze sentences had to be completed with the expected word. In the second (inhibition), the other 14 sentences had to be completed with a word unrelated to the sentence content, but grammatically appropriate. The order of presentation of the sentences in each condition was fixed: initiation, inhibition. A practice phase (three sentences) was presented before each test condition. The scoring for the initiation condition was the sum of correct words (i.e., one point was assigned for the correct response), differently, for the inhibition condition a score of 0 was assigned if the child completed the sentence with a related word, and a score of 1 for an unrelated word (maximum score 14 both for the initiation and the inhibition condition). In addition, a prepotent response inhibition index was calculated from the differences between the initiation and the inhibition phases (initiation - inhibition). A higher score thus implied a greater difficulty in producing the unrelated word in the inhibition condition, or in other words in inhibiting dominant but irrelevant information.

Procedure

Children were tested at three different sessions. During the first session, lasting approximately an hour, they were tested as a group in their classroom with the following tasks: the AC-MT 6-11 standardized arithmetic battery (Cornoldi, et al., 2012); the AMAS (Hopko, et al. 2003) and the RCMAS-2 (Reynolds & Richmond, 2012) questionnaires, for measuring math anxiety and general anxiety respectively. During the other two sessions, lasting approximately 30 minutes each, the children were tested individually in a quiet room away from their classroom, where they were administered the math fluency tasks (Caviola, et al., 2016), the vocabulary and block design subtests of the WISC IV (Wechsler, 2004), and the WM and inhibition measures. The WM and inhibition tasks were mixed with the WISC IV subtests. They were presented on a 15” laptop and were programmed using E-Prime II software (Psychology Software Tools, Inc., Pittsburgh, PA, USA). Each task began with two training trials and the task presentation order was counterbalanced.

Results

Working memory task

Listening Span Task (LST). A 2 MA [high and low MA] × 2 DD [with or without DD] between groups ANOVA was conducted on the proportion of words correctly recalled in the LST (see Table 3 and Figure 1). The main effect of MA was not statistically significant, *F*(1, 73) = 0.07, $p = .797$, $\eta^2_p = .0001$, with an extremely small effect size, while the effect of DD was statistically significant, *F*(1, 73) = 15.21, $p < .0001$, $\eta^2_p = .172$, with a medium effect size. The interaction between math anxiety and dyscalculia was not statistically significant, *F*(1, 73) = 0.50, $p = .487$, $\eta^2_p = .007$, with an extremely small effect size.

Inhibition measures

Resistance to proactive interference. A 3 word list [list1, list2, list3] × 2 MA [high and low MA] × 2 DD [with or without DD] mixed ANOVA was conducted (see Table 3 and Figure 1). As far as the main effects are concerned, the following is held true: the effect of word list was statistically significant, *F*(2, 146) = 34.76, $p < .001$, $\eta^2_p = .323$, with a very large effect size; the effect of MA was not statistically significant, *F*(1, 73) = 0.65, $p = .425$, $\eta^2_p = .009$, with a very small effect size; the effect of DD was statistically significant, *F*(1, 73) = 4.66, $p = .034$, $\eta^2_p = .060$, with a small effect size. As for the two-way interactions, we found a statistically significant interaction between list and MA, *F*(2, 146) = 3.24, $p = .048$, $\eta^2_p = .042$, with a small effect size. The interaction between list and DD was not statistically significant, *F*(2, 146) = 2.25, $p = .109$, $\eta^2_p = .030$, with a small effect size. Comparably, the interaction between MA and DD was not statistically significant, *F*(1, 73) = 0.16, $p = .692$, $\eta^2_p = .002$, with a very small effect size.

The results also shows a statistically significant three-way interaction between word list, MA and DD, *F*(2, 146) = 3.20, $p = .044$, $\eta^2_p = .042$, with a small effect size. Post-hoc comparisons using Bonferroni's correction showed statistically significant differences between list 1 and 2 in all groups, as follows: MA-DD (high math anxiety with dyscalculia) ($p = .046$), in the group with MA only ($p < .001$), in the DD group ($p = .006$), and in the TD group ($p = .014$). There was also a statistically significant difference between list 2 and three in the MA ($p < .001$), DD ($p < .001$) and TD ($p < .001$) groups. Ultimately, in all groups, differences between list 1 and 3 were not statistically significant (*p*s > .05). In addition, on list 1, children with high MA and DD (i.e., MA-DD) and with DD had the poorest performances (M=7.98, M=7.30, respectively) and did not differ (p=1.00). Furthermore, both groups performed worse than children with high MA and controls (i.e., TD) (M=10.25, M=8.40, respectively).

A 2 MA [high and low MA] × 2 DD [with or without DD] between groups ANOVA was conducted for the PI index. As for the main effects of MA, $F(1, 73) = 4.19$, $p = .044$, $\eta^2_p = .054$, and DD, $F(1, 73) = 5.87$, $p = .018$, η^2_p =.074, two significant differences were observed, both with small effect sizes. The two-way interaction between MA and DD was statistically significant, $F(1, 73) = 8.34$, $p = .005$, $\eta^2_p = .103$, with a medium effect size, revealing that the MA-DD group suffered more interference than the other groups.

Prepotent response inhibition. A 2 condition [initiation and inhibition] × 2 MA [high and low MA] × 2 DD [with or without DD] mixed ANOVA was conducted (see Table 3). The main effect of condition was significant, $F(1, 73) = 473.05$, $p = .0001$, $\eta^2_p = .866$, with a very strong effect size, indicating a better performance in the initiation condition than in the inhibition condition; while the effects of MA, $F(1, 73) = 0.27$, $p = .608$, $\eta^2_p = .004$, and DD, $F(1, 73) = 0.73$, $p = .397$, $\eta^2_p = .010$, were not statistically significant, with very small effect sizes. None of the two-way interactions were statistically significant (*F*s < 0.35, *p*s > .608), with extremely low effect sizes (η^2_ps < .003). The three way interaction between condition, MA and DD was not statistically significant, $F(1, 73) = 0.35$, $p = .558$, $\eta^2_p = .005$, with a very small effect size.

A 2 MA [high and low MA] × 2 DD [with or without DD] between groups ANOVA was conducted for the PRI index (initiation – inhibition), but the main effects and the interactions were not statistically significant, *F*s < 0.5, *p*s >.557, with extremely low effect sizes (η^2_ps < .005).

Table 3 and Figure 1 about here

Discussion

It is worth noting that mathematics likely builds both on domain general (cognitive) abilities and domain specific abilities (Krajewski & Schneider, 2008; Geary, 2011), sometimes conditioned by negative emotions (such as feelings of apprehension, dislike, tension, worry, frustration and fear) caused by performing mathematical tasks. Thus, the main aim of this study was to disentangle the differences between low arithmetic proficiency due to a specific cognitive impairment vs. low proficiency due to emotional aspects, such as MA. In particular, this study is the first to have investigated in depth the efficiency of WM and inhibitory mechanisms in children with DD and/or MA. In fact, while WM impairments have been widely studied, both in participants with DD and also in individuals with MA (e.g., Ashcraft & Kirk, 2001), very few studies have been conducted on the inhibitory mechanisms. Many of the studies of inhibitory mechanisms focused only on prepotent response inhibition. Moreover, as far as we know, no research has investigated children with different profiles by considering the presence of MA or DD alone or as a co-occurrence of both problems (MA, DD and MA-DD).

As mentioned above, most of the previous research conducted on children with DD has dealt primarily with prepotent response inhibition (e.g., Censabella & Noel, 2005; Szűcs, et al. 2013), albeit with discordant results. The main aim of the present study was therefore to confirm WM impairments in children with MA and/or DD profiles and to examine the different inhibitory deficits, particularly focusing on proactive interference and prepotent response inhibition. Thus, four groups of 8- to 10-year-old children were drawn from a large sample: one group had both developmental dyscalculia and math anxiety (MA-DD group); one had severe MA but no DD (MA); one had DD but no MA (DD), one was a control group of typically developing children with neither condition (TD). Our group selection procedure ensured that we could separate mathematics impairments from math-related anxiety.

Our findings showed that the MA, MA-DD, and DD groups revealed different patterns of difficulties. First, in agreement with previous studies, we found that children with DD failed in a WM task in which they were asked not only to recall, but also to manipulate and process previously presented information (Mammarella, et al., 2013; Passolunghi & Siegel, 2001; Schuchardt, et al., 2008; Swanson & Sachse-Lee, 2001; Szűcs, 2016). It is also well known that the general cognitive profile of children with specific learning disorders shows impairment in WM and processing speed indexes (Giofrè & Cornoldi, 2015; Toffalini, et al. 2017). Additionally, to better understand the role of WM impairments in DD and MA groups, we compared their performances with the combined group (i.e., MA-DD). The results highlighted that the MA-DD and DD groups did not differ in this task, meaning that WM performance was much the same in children with severe MA associated with DD and in those with DD but no MA. This finding seems to suggest that it is the presence of DD - rather than the presence of MA - that is linked to the children’s WM impairments.

As suggested by Szűcs (2016), DD is related to weak processing in various parts of a complex WM network (Fias, Menon, & Szűcs, 2013; Szűcs, Devine, Soltesz, Nobel, & Gabriel, 2014). In addition, the presence of WM difficulties in children with DD may be due to the main characteristics of mathematical tasks, which typically require people to retain partial sequential information in their memory to reach the final result. Based on our own findings, we can speculate that our MA-DD children developed MA in the context of a profile of DD, given that their performances are more similar to that reported by children with DD. However, the opposite pattern is also possible, i.e., failure in mathematics due to high general anxiety (see Carey, Devine, Hill, & Szűcs, 2017). Furthermore, in our study we matched our groups for general (trait) anxiety, and perhaps for this reason, in our MA-DD group, we selected only children who developed DD first and then subsequently developed state anxiety specifically related to mathematical tasks (see the Defict Thoery, Ma & Xu, 2004). Finally, although our findings seem to partially contradict previous results that indicated children with high MA showed WM impairments (Maloney, Risko, Ansari & Fugelsang, 2010), it is worth noting that the methodological differences between our study compared and Maloney, et al. study do not allow for easy, direct comparison. Most notably, Maloney et al. (2010) tested undergraduate students, did not control for general anxiety in selecting groups of participants with high and low MA, did not compare these groups directly to a group with DD and, finally, used different measures of verbal WM. Specifically, Maloney and colleagues used the backward digit span, in which no differences emerged between groups, and the backward letter span. Finally, as suggested by Carey, et al. 2017, different latent profiles of anxiety can develop according to the level of predisposition toward general anxiety.

Where inhibitory mechanisms are concerned, we found that children with MA (but no DD) were more susceptible to proactive interference than the other three groups. Both DD and MA-DD groups performed very poorly in recalling the first list of words. In other words, looking at the average resistance to the proactive interference task, is clear that both DD and MA-DD groups had poor retrieval performance of the first list. These results are coherent with the WM deficit demonstrated by these two groups in the Verbal WM task. In contrast, the MA group had more difficulty in resisting interference from information that was initially relevant to the task at hand but became irrelevant when the requirements of the task changed (from list1 to list2). This result is consistent with previous studies suggesting that anxiety influences explicit memory (see Williams, Watts, MacLeod, & Mathews, 1997; Rinck &

Becker, 2005), and is also consistent with attentional control theory (Eysenck, et al., 2007), which states that anxiety impairs processing efficiency because it reduces attentional control.

This finding strengthens our hypothesis that children with MA-DD have developed a state of worries and tension specifically related to mathematical tasks, after having encountered severe and continuous difficulties in dealing with math. Such difficulties are likely due to their specific impairment, and importantly, by controlling for their general anxiety. This observation is derived from the fact that the other group of children with DD (without MA) showed a pattern of results more similar to children with a co-occurrence of MA and DD, compared to children with MA only. Although we could expect that in presence of both high MA and DD, the impairments in the underlying cognitive mechanisms will aggregate, causing greater problems, our findings seem to show that this does not happen. In our view, a direct comparison between MA and DD - all without general anxiety – allows us to distinguish between two underlying cognitive profiles: children with high MA, who showed a high proactive interference, and children with DD (with/without MA), who showed low WM performances. However, in order to study in depth the presence of different profiles of anxiety, future studies should try to replicate our results, while further exploring the difference between children with MA only, and children with DD who have developed MA in absence of general anxiety (Carey, et al. 2017).

No differences emerged between the groups in the prepotent response inhibition task, however. Children with MA (with and without DD) and children with DD performed similarly to TD children in the Hayling Sentence Completion task. Previous studies exploring the relationship between prepotent response inhibition and mathematics used tasks that involve the inhibition of both domain-relevant (i.e., numerical) and domain-irrelevant (i.e., non-numerical) information, producing mixed results. For example, Bull and Scerif (2001), and Navarro et al. (2011) found that performance in the number–quantity version of the

Stroop task, but not in the color–word version, correlated with math achievement. Similarly, in children with DD, both Szűcs et al. (2013) and Wang et al. (2012) found that group differences were only significant for numerical Stroop tasks, not for the non-numerical versions. Szűcs et al. (2013) found a domain-specific effect in a task involving Arabic digit stimuli, i.e., a number-size Stroop task in which participants were asked to choose the numerically highest digit while ignoring the physical size of the digits on the screen. Other studies failed to find any domain-specific effects using either Stroop tasks (Zhang & Wu 2011) or go/no-go tasks (De Weerdt, Desoete, & Roeyers, 2013). Unlike some previous research (Szűcs et al., 2013; Wang et al., 2012), but consistently with van der Sluis et al. (2004) and De Weerdt et al. (2013), through our use of using a non-numerical Stroop task, we found no prepotent response inhibition deficit in children with DD. In fact, a verbal task that not require mathematical competence, in which children were asked to complete sentences with an expected word, was used to better capture the nature of any inhibition-related deficits in our sample.

Although it contains insightful findings, this study also has some limitations, however. First, a single measure was considered for each of the inhibitory functions examined. Since all the tasks that we used involve verbal processing, it would be interesting to confirm our results in further studies using domain-relevant (i.e., numerical) tasks too. There is a second limitation of our study; we only tested two types of inhibitory mechanism: proactive interference and prepotent response inhibition. A third inhibitory mechanism, called response to distracter inhibition (which enables attention to be focused on relevant items by ignoring simultaneously presented irrelevant items) should be explored in future research, as in Friedman and Miyake (2004). Unfortunately, due to the limitations imposed by the schools participating in the study, we were only able to individually test a limited number of children, which lead us to adopt a matched subject design. This decision may have resulted in a reduction in statistical power. For this reason, future studies should address this point by considering a larger sample of children, by using latent profile analyses, for example (Pastor, Barron, Miller, Davis, 2007).

It is worth adding that, from a theoretical viewpoint, our results are consistent with previous studies revealing WM and inhibitory deficits in children with MA and DD, but our findings also shed further light on the specificity of these profiles in children, in terms of the inhibitory mechanisms involved. In short, our study is the first to show that children with severe MA (but no DD or general anxiety) had particular difficulty in resisting proactive interference, whereas those with MA-DD or DD alone did not differ when performing a domain-irrelevant task that tested their prepotent response inhibition. Finally, WM deficits seem to be specifically associated with the profile of children with DD, with or without MA, and without general anxiety. Further studies should explore additional specific inhibitory deficits in such groups of children, who fail in math for different reasons. Specifically, future research should better investigate the differences between children with severe MA without math difficulties, and children with DD with or without high levels of MA.

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Figure Captions

Figure 1. Main results of Verbal Working Memory and Resistance to Proactive Interference tasks by group: children with severe math anxiety and developmental dyscalculia (MA-DD), severe math anxiety but no developmental dyscalculia (MA), or developmental dyscalculia alone (DD), and typically developing (TD) controls. Error bars represent 95% Confidence Intervals.

Figure 1

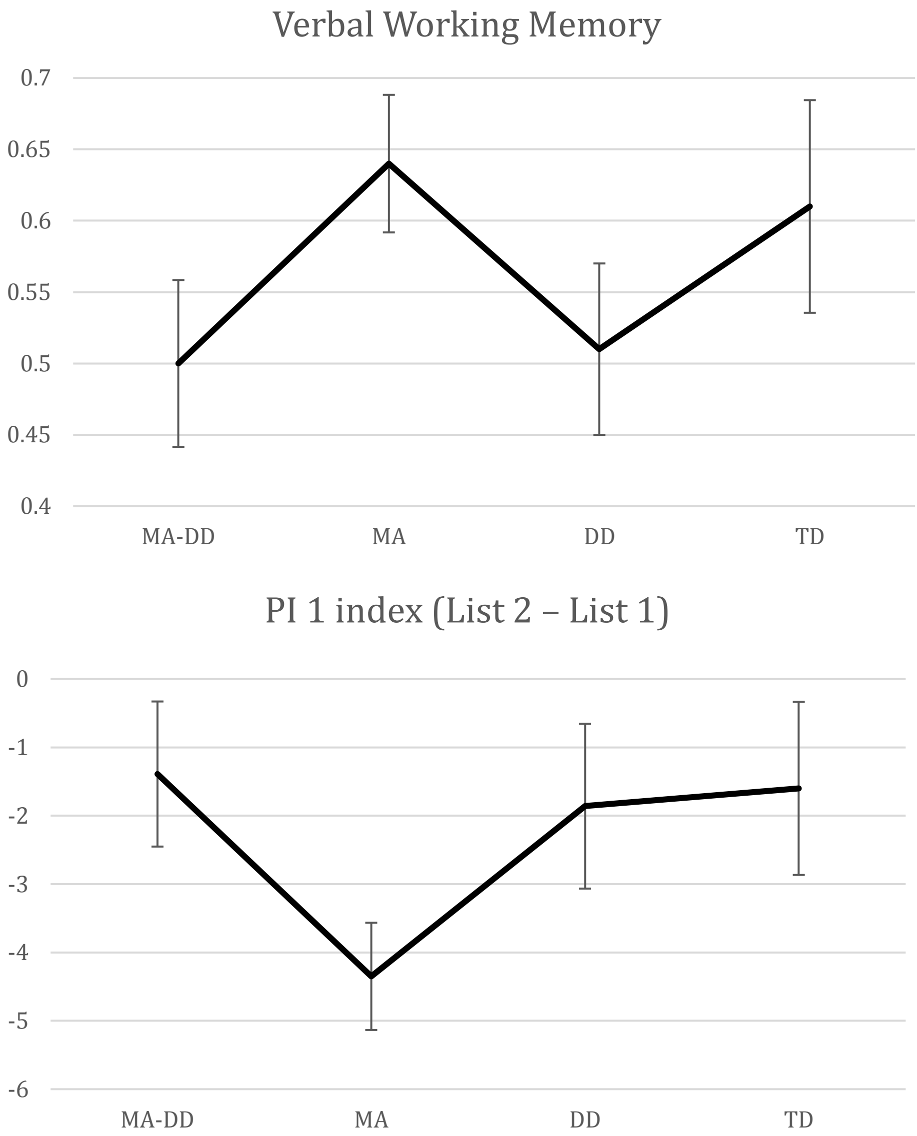
Verbal Working Memory
0.7
0.65
0.6
0.55
0.5
0.45
0.4
MA-DD
MA
DD
TD
PI 1 index (List 2 – List 1)
0
-1
-2
-3
-4
-5
-6
MA-DD
MA
DD
TD

Table 1

Summary of the criteria for inclusion in the groups.

Ability	Groups			
	MA-DD	MA	DD	TD
Math	Low	Average	Low	Average
Math anxiety	High	High	Average	Average
General anxiety	Average	Average	Average	Average
Verbal	Average	Average	Average	Average

Note: MA-DD: severe math anxiety and developmental dyscalculia; MA: severe math anxiety, no developmental dyscalculia; DD: developmental dyscalculia, no math anxiety; TD: typical development, no math anxiety, no developmental dyscalculia

Table 2

Descriptive (M= means; SD=standard deviations) and one-way ANOVAs (df=3,70) between groups: children with severe math anxiety and developmental dyscalculia (MA-DD), severe math anxiety but no developmental dyscalculia (MA), or developmental dyscalculia alone (DD), and typically developing (TD) controls.

	MA-DD	**MA**	**DD**	**TD**	**One-way ANOVA**		
	M (SD)	**M (SD)**	**M (SD)**	**M (SD)**	***F***	***p***	***η²***
Age in months	118.00 (8.94)	115.45 (10.09)	118.61 (11.60)	117.15 (14.09)	.28	.839	.01
RCMAS -2 (T scores)	52.05 (3.39)	52.50 (6.82)	52.67 (5.48)	55.80 (5.02)	1.85	.146	.07
AMAS	30.89 (2.35)	30.35 (1.53)	17.44 (3.79)	17.40 (3.20)	135.83 [a, b, c, d]	<.0001	.85
WISC IV - Vocabulary	9.84 (2.43)	11.65 (2.03)	10.22 (3.49)	10.95 (2.67)	1.73	.173	.07
WISC IV – Block design	9.32 (2.19)	9.70 (2.72)	10.50 (2.36)	11.05 (2.70)	1.89	.139	.07
Academic achievement (z scores)							
Mathematical proficiency, AC-MT battery	-1.10 (.78)	.33 (.38)	-1.36 (1.51)	.44 (.34)	22.55 [c, e, f, g]	<.0001	.48
Math fluency tasks	-1.21 (.40)	.24 (.49)	-1.24 (.75)	.64 (.59)	55.62 [c, e, f, g]	<.0001	.70

Note: AMAS = Abbreviated Math Anxiety Scale (Hopko, Mahadevan, Bare, & Hunt, 2003); RCMAS = Revised Children's Manifest Anxiety Scale - 2nd Edition (Reynolds & Richmond, 2012). Only significant differences emerging from pairwise comparisons with Bonferroni's correction are reported: [a] MA-DD > DD; [b] MA-DD > TD; [c] MA > DD; [d] MA > TD; [e] MA-DD < MA; [f] MA-DD < TD; [g] DD < TD.

Table 3.

Descriptive statistics for the measures of interest by group: children with severe math anxiety and developmental dyscalculia (MA-DD), severe math anxiety but no developmental dyscalculia (MA), or developmental dyscalculia alone (DD), and typically developing (TD) controls.

	MA-DD	**MA**	**DD**	**TD**
	M (SD)	**M (SD)**	**M (SD)**	**M (SD)**
Verbal WM				
Correct words (proportion)	0.50 (0.13)	0.64 (0.11)	0.51 (0.13)	0.61 (0.17)
Inhibitory mechanisms				
Resistance to proactive interference				
List 1	7.98 (2.67)	10.25 (1.55)	7.30 (2.52)	8.40 (2.92)
List 2	6.59 (2.61)	5.90 (2.29)	5.44 (1.38)	6.80 (2.82)
List 3	7.93 (2.57)	8.75 (2.86)	8.14 (2.51)	9.15 (3.27)
PI 1 index (List 2 – List 1)	-1.39 (2.36)	-4.35 (1.79)	-1.86 (2.61)	-1.60 (2.89)
Prepotent response inhibition				
Initiation condition	13.32 (0.82)	13.55 (0.69)	13.33 (.77)	13.50 (0.69)
Inhibition condition	6.68 (2.21)	6.65 (2.01)	6.06 (3.04)	6.70 (2.97)
PRI index (initiation – inhibition)	6.63 (2.54)	6.90 (2.04)	7.28 (3.10)	6.80 (3.29)

Note: PI index= proactive interference index; PRI index= prepotent response inhibition index