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Combined Intervention of Working Memory and Arithmetic Reasoning in Students with ADHD

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ABSTRACT

This study compared the effects of a combined intervention of working memory (WM) and arithmetic reasoning (AR) *vs* WM intervention alone on the arithmetic reasoning performance of students with ADHD. Third- and fourth-grade elementary school students (n = 46) completed measures for AR, mathematical calculations, and WM. Participants were randomised using a minimisation approach taking age and IQ as variables of interest and assigned to one of the two groups: Combined Intervention (CI, n = 24) and Working Memory Intervention (WMI, n = 22). The results using GEE analysis indicated a significant group × time interaction (Waldχ^2 = 6.414; gl = 2; p = 0.04) in AR performance in the immediate post-test. CI students showed significantly better performance on AR than WMI students immediately after intervention (p_B = 0.042). There was an effect of time on mathematical calculations in the post-test (Waldχ^2 = 48.305; gl = 2; p < 0.001). Despite the fact that the results for AR were not maintained in the deferred post-test, a combined intervention of WM and AR seems to be more efficient in improving arithmetic reasoning in ADHD students than a WM intervention alone. Nevertheless, this is not the case with other mathematical issues, such as calculation, where there was no significant difference between groups, but the effects had been maintained in the deferred post-test for both.

KEYWORDS

ADHD; arithmetic; arithmetic reasoning; combined intervention; intervention; learning; school performance; working memory

Introduction

School performance is often impaired in students with significant attention deficits, associated or not with hyperactivity (Dorneles et al., 2014; Fortes et al., 2016; Wu & Gau, 2013) and one of the most affected learning areas is mathematics. The rates of comorbidity between Attention Deficit/Hyperactivity Disorder (ADHD) and mathematics learning disability (MLD) range from 5% to 30% in different studies. However, more than 40% of pupils with ADHD perform poorly in mathematics (Dorneles et al., 2014; Zental, 2007).

The impaired performance of students with ADHD may be related to the core symptoms of the disorder, especially inattention (Tosto, Momi, Asherson, & Malki, 2015; Wu & Gau, 2013; Zental, 2007) and cognitive impairments in areas that are important for learning, such as the working memory (WM) (Wang et al., 2013). WM is a memory system, with a limited

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capacity, that provides the temporary storage and processing of information (Baddeley, 2012). Among the WM models described in the literature, Baddeley's multicomponent model is prominent. The model has four components. The phonological loop stores auditory-verbal information. The visuospatial sketchpad stores visual and spatial information. The episodic buffer temporarily stores information in a multidimensional code and is able to combine information from the phonological and visuospatial components with information retrieved from the long-term memory in a single-episode representation. And the central executive, the manager of WM, is responsible for attention control (Baddeley, 2012). The WM has been considered an important cognitive resource for mathematics performance (Kyttälä, 2008; Passolunghi, Vercelloni, & Schadee, 2007) and there is evidence that this function is impaired in students with ADHD (Alderson et al., 2015).

Recently, there have been considerable efforts to find alternative ways to help students with ADHD face school challenges such as learning mathematics. The greatest efforts have focused on WM computer training and specific mathematics intervention programmes aiming to improve mathematics performance in specific topics (Costa, Rohde, & Dorneles, 2015; Holmes et al., 2010; Mautore, DuPaul, & Jitendra, 2005). Also, studies have shown positive results with minor pedagogical changes (Bolic, Lidström, Thelin, Kjellberg, & Hemmingsson, 2013), specific pedagogical and psychoeducational interventions (Costa et al., 2015), and intervention focusing on cognitive factors, such as attention (Steiner, Frenette, Rene, Brennan, & Perrin, 2011).

Working Memory Intervention

Several studies support WM as an important ability to learn mathematics (Corso & Dorneles, 2012; González-Castro, Rodríguez, Cueli, Cabeza, & Álvarez, 2014; Passolunghi et al., 2007). Some of these studies have identified an increased risk of mathematics difficulties in children with WM impairments compared to their typically developing peers (Swanson, Moran, Lussier, & Fung, 2013), while others suggest that children with mathematics difficulties have WM deficits (Melby-Lervåg & Hulme, 2013). Although these studies have different samples, they all come to the same conclusion that there is a potential relationship between WM and mathematical ability.

Accepting this relationship as true, studies have sought to find ways to improve WM capacity. Some researchers have developed open-access WM computer-training programmes, such as the one devised by Nunes, Barros, Evans, and Burman (2014). This training programme includes computer games designed by the researcher. Subjects are taught rehearsal strategies that combine linguistic and visual-spatial encoding and web-based games. They play without a tutor but receive feedback from the computer after each answer. The results showed positive effect with deaf children, who often have WM deficits (Nunes et al., 2014; Nunes, Evans, Barros, & Burman, 2011). Witt (2011) also showed positive results for typically developing children after completing a 6-week training programme based on WM tasks. The training programme includes games designed to help learning strategies for the storage and retrieval of information in the short term. Positive outcomes included improved performance in mathematics, as measured by the number of errors made in a task with addition problems. However, neither of the two studies included children with ADHD.

The most relevant WM intervention studies of children with ADHD involve the use of Cogmed WM training, a commercially available computer programme. However, in the literature, the benefits of Cogmed, when present, are limited to uncontrolled or poorly controlled studies or rely exclusively on unblinded parent ratings, without positive effects on school performance (Chacko et al., 2014). Thus, considering that WM is an important aspect of mathematical competence, it becomes relevant to investigate the effects of other WM intervention programmes on students with ADHD, who often have impairments in WM and mathematics performance.

A meta-analysis study criticised the development of training programmes that focus on specific WM components instead of all WM components (Rapport, Orban, Kofler, & Friedman, 2013). Furthermore, some studies point out that, in most WM intervention studies, specific effects are not being generalised to other contexts, beyond WM ability, suggesting the need for broader programmes or for complementing WM intervention programmes with interventions specifically targeting the learning skills intended to be improved (Melby-Lervåg & Hulme, 2013; Rapport et al., 2013). Thus, intervention programmes that are specific to the domain of mathematics also appear to be necessary to improve mathematics performance. This kind of approach seems reasonable, since mathematics learning requires both specific domain skills and general domain skills. The combination of WM interventions with the specific sub-areas of mathematics in which the student demonstrates delays can offer promising results.

Domain-Specific Intervention

The effectiveness of intervention programmes in mathematics performance has been evaluated in several studies involving students with ADHD (Costa et al., 2015; Mautore et al., 2005). Some studies used the Computer Assistance Instruction as an intervention resource and had positive results on mathematics performance of ADHD students from elementary school (Mautore et al., 2005). Other studies used pencil and paper tasks and games to improve one of the arithmetic skills, like counting procedures and strategies (Costa et al., 2015).

There is a set of empirical evidence pointing to the possibility of improving arithmetic reasoning (AR) through specific interventions (Nunes et al., 2007), as well as to the possibility of developing such interventions for students with ADHD (Mautore et al., 2005). However, to the best of our knowledge, there are no studies suggesting positive effects of a combined intervention of WM and AR conducted with children with ADHD.

Considering that WM is an important cognitive ability that influences mathematics performance and knowing that both WM and mathematics performance are often impaired in students with ADHD, the present study aimed to determine the effects of a combined intervention of WM and AR on the AR performance of elementary school students with ADHD. The study seeks to contribute to the literature by developing a combined intervention integrating a WM intervention with a specific intervention on academic skills, since studies have indicated the need for specific interventions on the skills intended to be improved rather than interventions focusing only on domain-general skills (Melby-Lervåg & Hulme, 2013; Rapport et al., 2013). It was hypothesised that the combined WM/AR intervention would result in greater benefits for ADHD students' arithmetic reasoning than a WM intervention alone.

Method

Participants

A total of 46 (male = 23, female = 23) students aged 7 to 11 years with ADHD participated in the study (mean = 9.37 years; SD = 0.89). The students were recruited from 3rd (N = 21) and 4th (N = 25) grades from two public schools in Porto Alegre, Brazil. The schools were selected by convenience, respecting the criteria of similar curriculum content and similar socioeconomic status (middle to low income). The students were not medicated and did not use medication during the whole study. The study was carried out in five steps (details in Figure 1):

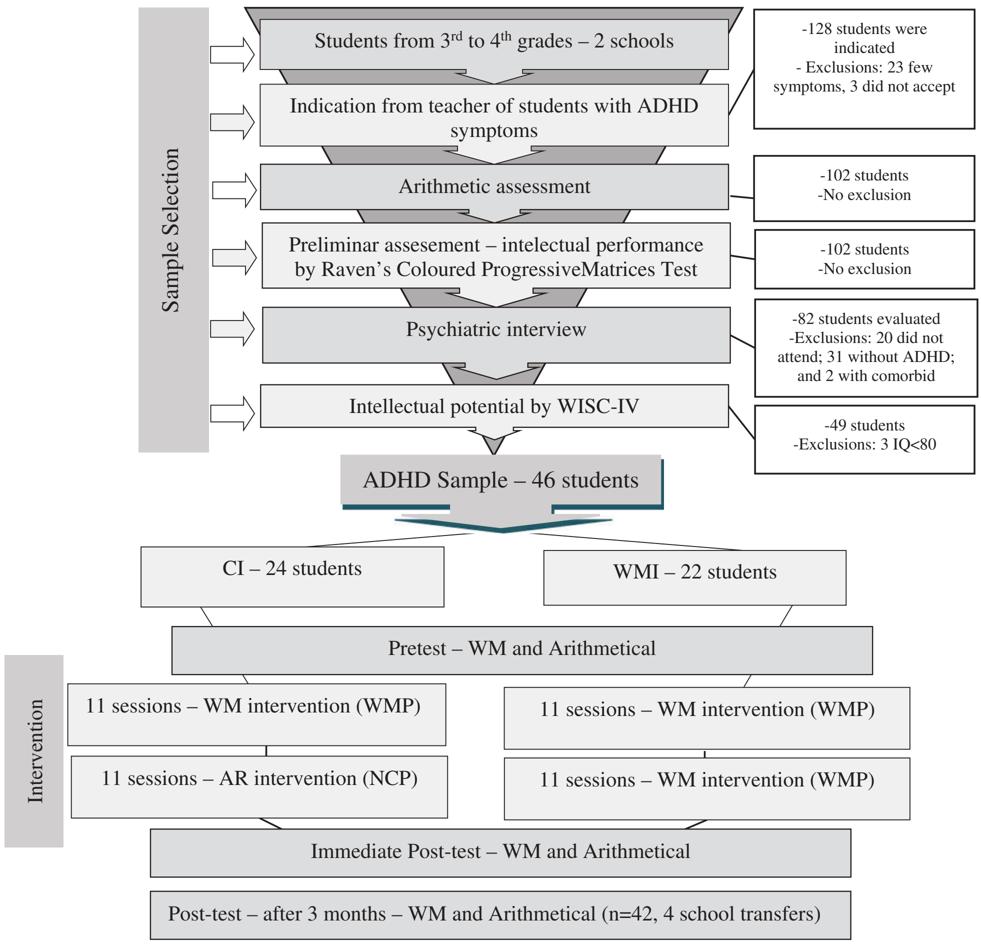

Figure 1. Flowchart of research stages.

Caption: IG-Combined: combined intervention group, WMI: WM intervention group, WMP: Working Memory Program, NCP: Number Corner Program, WM: Working Memory.

(1) eight teachers completed the Portuguese version of the SNAP-IV (Mattos, Serra-Pinheiro, Rohde, & Pinto, 2006) for students who showed characteristics of inattention and hyperactivity-impulsivity according to the teachers' perception (128 students

were indicated, but 23 were excluded because they had less than 5 symptoms indicated on SNAP-IV by teachers; and 3 because their parents or guardians did not consent);

(2) arithmetic performance was evaluated using the arithmetic subtest of the School Achievement Test (SAT) (Stein, 1994). In this step was included as an exclusion criteria upper range of performance in the SAT (i.e. standard score >24).[1] 102 students were assessed;

(3) students' cognitive and intellectual level was assessed using Raven's Coloured Progressive Matrices Test (Angelini, Alves, Custódio, Duarte, & Duarte, 1999). In this step, the exclusion criteria was a result below 50%;[2]

(4) a psychiatric interview was conducted with the parents or guardians of students with possible ADHD for diagnostic purposes. The interview was conducted by a psychiatrist experienced in ADHD diagnosis using the Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (K-SADS-PL). A group of 82 students were evaluated (20 were not assessed because they missed more than one scheduled appointment and were excluded; and two students were excluded after psychiatric assessment because they had a diagnosis of autism, bipolar disorder, or ADHD with comorbid depression, which were exclusion criteria at this step). Finally,, 49 students were positively diagnosed with a probable ADHD based on the DSM-IV criteria (American Psychiatric Association, 2003) and were maintained at the sample (31students were excluded because they did not meet the diagnoses criteria for ADHD); and

(5) students' intellectual level was reassessed based on the vocabulary and block design subtests of the WISC-IV (Wechsler, 2013). In this step, the exclusion criteria was an estimated IQ below 70 (exclusion of three participants) to exclude students with possible intellectual deficit or borderline functioning and to keep the variable 'intellectual level' as homogeneous as possible. The final exclusion criteria proposed was the receipt of regular psychological support and/or any pedagogical support in mathematics other than that provided by the school. No students were excluded in this step.

After sample selection, students were randomised using a minimisation approach,[3] taking age and IQ as variables of interest (Tavis, 2010), and assigned to one of the two groups: Combined Intervention group (CI, N = 24), which received a combined intervention of WM and AR; and WM Intervention group (WMI, N = 22), which received a WM intervention alone. A detailed description of the sample is provided in Table 1. Before the start of the intervention, both groups completed WM measures and tasks to evaluate AR, as described in the next subsection. Four participants were lost at the deferred post-test (2 from each group; students changed schools or could not be contacted). The evaluation was performed by an experienced psychopedagogue who was blinded to both the intervention and condition of each student. Students in both groups were evaluated together to minimise between-group differences in assessment. The results were disclosed to the investigator only after the last evaluation.

Table 1. Sample characteristics.

Variables	CI (n = 24) N	CI (n = 24) %	WMI (n = 22) N	WMI (n = 22) %
Sex				
Male	14	58.3	9	40.9
Female	10	41.7	13	59.1
Education level				
3rd grade	9	37.5	12	54.5
4th grade	15	62.5	10	45.5
Age				
7 years	1	4.2	0	0
8 years	4	16.7	9	41.0
9 years	13	54.2	8	36.36
10 years	5	20.8	4	18.18
11 years	1	4.2	1	4.5
ADHD presentation				
ADHD-D	8	33.3	9	40.9
ADHD-HI	3	12.5	2	9.1
ADHD-C	13	54.2	11	50.0
Comorbidity				
No	11	45.8	10	45.45
ODD	6	25.0	10	45.45
CD	1	4.2	2	9.1
Anxiety disorders	3	12.5	6	27.27
Phobias	3	12.5	1	4.5
Encopresis	1	4.2	0	0
Panic	1	4.2	0	0
Tics	1	4.2	1	4.2
	M	SD	M	SD
IQ Brazilian version	100,50	13,32	98,90	10,19
IQ American version	92,73	12,26	92,71	10,30

Caption: ADHD-D is the predominantly inattentive presentation. ADHD-IH is the hyperactivity and impulsive presentation. ADHD-C is the combined presentation. ODD is Oppositional Defiant Disorder. CD is Conduct Disorder.

Measures

Arithmetic Performance

Arithmetic performance was assessed by three measures:

- Arithmetic Skills Assessment Task (ASAT), adapted from Nunes (2009), which evaluated AR. The ASAT involves additive composition, additive reasoning, and multiplicative reasoning. The task consists of 20 applied problem-solving activities (orally presented problems in various contexts), as for example, there are 8 candies in the box; and we can see 3 candies outside the box. How many candies are there in total? (students receive a picture that illustrates this situation). Each student received a notebook with the illustrations of each problem. The students completed both tests in small groups of approximately 10 students each. In this study, the variable used as AR measure was the number of correct problems in the ASAT task (ASAT accuracy).
- Arithmetic subtest of the SAT (Stein, 1994) provided a measurement of arithmetic calculation. The SAT is a standardised psychometric instrument designed to assess basic school achievement skills in three areas: reading, writing, and arithmetic. The arithmetic subtest consists of oral and written questions involving arithmetic calculations with increasing degree of difficulty. The test score is based on the number of correct answers and it is applied with students from the 2nd to the 7th grades of

elementary school. In this study, SAT provides three different variables: the SAT accuracy (the number of right calculation), the SAT Conceptual Error (number of error committed by students because of a lack of conceptions), and SAT Procedural Error (number of Error committed by students in the calculation process).

- Teacher's Questionnaire was a questionnaire filled by the students' teachers, specifically designed for this study, aiming to investigate whether or not there was an improvement in mathematics performance, and to measure the intensity and quality of this improvement. One item was scored on a 4-point Likert scale as follows: performance decreased (−1), performance remained as before (0), significant performance improvement (1), and very significant performance improvement (2). In the other three items, teacher described the students' performance qualitatively and pointed which abilities they still needed to improve, and indicated if they required specialised help in the school context. The teacher completed the questionnaire only in the immediate post-test period.[4] At the time of the questionnaire completion, the teachers were unaware of which intervention each student had received. Only the first question was analysed in this paper.

Working Memory

The WM was assessed by three different measures:

- Backward Digit Span – DS Backwards(Wechsler, 2013): Digit Span task is commonly used in research (Figueiredo & Nascimento, 2007) to assess executive control over immediate retention of verbal information. This task consists of seven lists of digits formed by sets of two to eight numbers, spoken at an even pace by the evaluator that should be remembered in reverse order.
- Backwards Spatial Span – SS Backwards (Shiels et al., 2008): this task evaluates how recent visuospatial information is handled. Itis a computer task made available by Psychology Software Tools (Pittsburgh, PA, USA) in which an array of 10 white squares is presented on a black background. On each trial, a yellow smiley face appears within two to eight squares at a rate of one square per second. The participants must repeat the sequence by clicking on the corresponding squares initially in the reverse order. The task has 16 series, two in each level, from 2 to 8. However, when children make two consecutive errors the task is finished.
- Rey Auditory-Verbal Learning Test – RAVLT (Malloy-Diniz, Fuentes, Abrantes, Lasmar, & Salgado, 2010): It is a standardised test translated into Portuguese used internationally as a possible tool to evaluate phonological loop and episodic buffer (Martins & Ortiz, 2009; Teruya, Ortiz, & Minett, 2009). It consists of a list of 15 words (list A) read by the examiner at a 1-s interval. This procedure is repeated five consecutive times and each presentation is followed by the request to say out loud of the words recalled by the participant (A1, A2, A3, A4, and A5). After completion of the five tests, a second list of interference (list B) is read; participants are asked to enunciate the words from list B. Immediately after this distracting task, individuals are asked to say the words they recall from list A (A6). After 20 min, they are asked again to enunciate the words from list A (A7). The total score is determined by the number of words correctly memorised at each attempt. As a buffer episodic outcome, we use the A7 score.

ADHD Symptoms

Severity of ADHD symptoms was measured based on information provided by the teacher through the SNAP-IV.[5] The SNAP-IV (Mattos et al., 2006) is a public-domain questionnaire designed according to the DSM-IV diagnostic criteria for ADHD (American Psychiatric Association, 2003). The SNAP-IV was completed by the teacher in the pre and immediately post-test.

Intervention Process

Interventions occurred in the schools' computer laboratories. The principal investigator and two research assistants carried out this process. Both groups received, initially, an intervention for general WM ability with the use of the Working Memory Programme (WMP), which was developed by a group of researchers at the University of Oxford (Nunes et al., 2011). The training was conducted in groups of 7–14 children each and lasted approximately a month and a half, with two to three 1-h weekly sessions, for a total of 11 sessions. Immediately after finishing the WMP,[6] CI students received training in AR with the use of the Numeracy Corner Programme (NCP), also developed by the group of researchers at the University of Oxford (Nunes, 2009). Each session of the programme was conducted in two moments. First, children completed tasks involving additive composition, additive reasoning, and multiplicative reasoning. Second, children played web-based games involving the same AR abilities. The training lasted approximately a month and a half, with two 1-h weekly sessions, for a total of 11 sessions. We chose the AR intervention because there is evidence of the existence of a correlation between logical abilities and mathematical performance (Nunes et al., 2007).

WMI students received, in turn, more 11 sessions that consisted in using three alternative games adapted by the principal investigator (The Alternative Colours Game, The Alternative Words Game, and The Alternative Missing Digits Game), which were similar to those administered initially, and to web-based games that train the same WM components. Therefore, they spent more time training the WM. These alternative games were included in the WMP intervention as a resource to have more tasks to train WM components. As with the CI group, the sessions were composed of two moments. First, they completed a game, writing their answers in a book. Second children played web-based games. All students received 22 intervention sessions.[7] Before initiating the intervention process in both groups, a meeting was held with the students and their parents or guardians to explain the process and introduce the work team.

Students' performance was measured immediately after the interventions and 3 months after the end of the interventions (delayed post-test), and pre- and post-test performance was compared for each student. Overall performance in each measure was compared between groups. The time between de pre-test and the immediately post-test was approximately 3 months.

Working Memory Programme

The intervention programme consists of computer games designed by a mediator[8] and web-based games. In the games designed by a mediator, children are taught rehearsal strategies that combine linguistic and visual-spatial encoding. There are three games: The Colours Game, The Words Game,[9] and The Missing Digits Game. In the first game, students need to remember sequences of colours in the direct and reverse order that appeared on a screen. They needed to remember the colour and the place that they appear in a specific space of a grade. This game trains the central executive and visual-spatial WM. In the second game, students needed to pay attention to a sequence of phrases and images that appear on a screen.[10] After watching the sequence, they need to repeat the final word of each sentence in direct or reversing order and judge with the sentence and the image combined (truth with combined and false with did not combine). This game trains the episodic buffer by processing a combination of multimodal information (words and images to remember) with information retrieved from long-term memory (judge if the sentence was true or false). In the last game, students need to remember the final digits of a sequence of numbers in the direct and reverse order. This game trains the phonological and central executive components. Basically, in all games, children need to remember items (verbal, visual or both) in the same order that they appeared or reversing the order. The number of items that children need to remember increases at each level until level 7 in all games. In web-based games, children play without a tutor. There are three web-based games (Animals, Number and Letters) available at http://www.education.ox.ac.uk/research/child-learning/resources-2/. In all games, the children needed to remember numbers or letters in the same order that they appear or reversing the order. Immediately after children enter the answer, the computer provides feedback (more details in Nunes et al., 2014).

The alternative games are one resource of the WMP that was used only with the students in the WMI in this study. This resource is composed of three games: The Alternative Colours Game, The Alternative Words Game, and The Alternative Missing Digits Game. These games have the same structure as the games used in the first step of the intervention. For more information, see http://www.education.ox.ac.uk/ndcs/ndcs_resources.php.

Numeracy Corner Programme

The intervention programme includes 11 booklets (books with problems presented to children, one per session) and 30 computer games. The booklets application needs a tutor to read the problems to children (booklets with figures only). The problems involved additive composition, additive reasoning, and multiplicative reasoning with the same proportion of questions in each category. To solve these problems, children have some resources, such as figures, fake coins and counting counters. The computer games involve the same categories of problems, but children do not have other resources than the ones provided by the computer. When playing the games, children have feedback immediately after they enter the answer. For more information, see www.education.ox.ac.uk/ndcs/maths_corner.php.

Ethical Aspects

The study was approved by the Research Ethics Committee of the Hospital de Clínicas de Porto Alegre. Participants and their parents or guardians were informed in advance of the nature of the study and possible discomfort resulting from participation, and written consent was obtained for participation in the study. After the end of the study, the results were disclosed to the students, parents, and schools. The Attention Deficit/

Hyperactivity Programme of the Hospital de Clínicas de Porto Alegre (ProDAH/HCPA) referred the participants for further clinical evaluation to determine the need for continuity of care.

Analysis

The intervention results were analysed using generalised estimating equations (GEE) based on the theory of generalised linear models, which allowed for intragroup and intergroup comparisons of the following variables: mathematics performance (ASAT accuracy, SAT accuracy, SAT Conceptual Errors and SAT Procedural Errors), WM performance, and ADHD severity (measure by SNAP-IV). These variables worked as dependent variables, while time and group as independent variables. Robust estimation covariance matrix was used and an unstructured working correlation matrix was adopted. Variables are with outcomes based on counting and were analysed using a Poisson distribution with log link function. The Bonferroni post hoc test was used for significant factors. The intervention effect size for the measures was determined using the Cohen's d.

Students' mathematics performance, as reported by the teacher in the post-test Teachers' Questionnaire, was compared between the two groups using the non-parametric Mann–Whitney test, based on total score. Descriptive analysis was conducted to make explicit the improvement of students results by percentage. Descriptive statistics were used to describe students' performance in both groups. All analyses were performed using SPSS, version 18.0 (SPSS, 2009).

Results

The results indicated a significant group × time interaction (Waldχ^2 = 6.414; gl = 2; p = 0.04) in AR problem-solving performance (ASAT accuracy), the main outcome of this study. CI students showed significantly better performance in the ASAT than WMI students immediately after intervention (Bonferroni p [p_B] = 0.042). Table 2 shows the results of the statistical analysis for the ASAT measures (total accuracy). The intervention had a large effect size for CI (Cohen's d = 1.14) and a moderate effect size for WMI (Cohen's d = 0.41) from the pre to immediate post-test. Although CI students had a slight reduction in their scores at the deferred post-test, the increase in relation to the pre-test remained significant (p_B<0.001), but the difference between groups did not remain significant.

A secondary arithmetic measure assessed was mathematical calculations. Calculation accuracy was analysed based on total accuracy in the arithmetic subtest of the SAT (SAT accuracy) and on categories with conceptual and procedural errors (SAT Conceptual Errors and SAT Procedural Error). The results are shown in Table 2. There was no group × time interaction in this measure. However, an effect of time was observed on SAT accuracy in the post-test (Wald χ^2 = 48.305; gl = 2; p < 0.001). Both groups showed a slight decline in their scores at the deferred post-test, especially WMI students, but in both groups performance remained significantly higher (p_B<0.001) than that in the pre-test. The intervention had a large effect size for both groups from pre-test to immediate post-test (Cohen's d = 0.89 for CI and Cohen's d = 1.09 for WMI).

The number of conceptual errors made by the students in the arithmetic subtest was analysed. There was an effect of time on this measure (Wald χ^2 = 9.126; gl = 2; p = 0.01).

Table 2. GEE results for the variables related to arithmetic reasoning and calculation performance.

		Mean score										
		CI			WMI							
Variables	Time	Mean		SE	Mean		SE		P_{Group}	P_{Time}	$P_{Interaction}$	Differences
ASAT accuracy	1	10.54	Aa	0.82	11.09	Aa	0.77		0.436	<0.001	**0.040**	CI T1 ≠ CI T2
	2	14.50	Bb	0.58	12.55	Ab	0.77					CI T1 ≠ CI T3
	3	14.07	Ab	0.58	12.98	Ab	0.79					WMI T1 ≠ WMI T2
												WMI T1 ≠ WMI T3
												WMI T1 ≠ WMI T2
SAT accuracy	1	11.0		0.6	9.2		0.7	α	**0.048**	**<0.001**	0.439	T1 ≠ T2
	2	13.5		0.626	12.5		0.5	β				T1 ≠ T3
	3	13.4		0.627	11.6		0.7	β				CI ≠ WMI
		*			#							
SAT conceptual errors	1	4.4		0.6	4.6		0.8	α	0.430	**0.010**	0.752	T1 ≠ T3
												T2 ≠ T3
	2	3.2		0.631	3.5		0.6	α				
	3	2.5		0.469	3.5		1.1	β				
SAT procedural errors	1	2.5	Aa	0.44	3.64	Aa	0.52		0.752	0.005	**0.043**	WMI T1 ≠ WMI T2
												WMI T1 ≠ WMI T3
	2	2.2	Aa	0.26	1.77	Ab	0.26					
	3	2.8	Aa	0.40	2.07	Ab	0.32					

Caption: Different uppercase letters indicate means and proportions statistically different in relation to the groups fixing time. Different lowercase letters indicate statistically different means or proportions of fixing groups. # and * symbols indicate means statistically different comparing groups. α and βletters indicate means statistically different comparing time. CI is combined intervention. WMI is working memory intervention. SE is standard error. T1 is the pre-test, T2 is the immediately post-test, and T3 is the deferred post-test. ≠ is significant difference.

Both groups showed a reduction in the number of conceptual errors in the immediate post-test that remained at the deferred post-test (Cohen's d = 0.65 for CI from pre-test to deferred post-test; and Cohen's d = 0.35 for WMI from pre-test to immediate post-test). Although both groups had a reduced number of errors, CI had a slightly greater reduction in the number of conceptual errors than WMI. In relation to procedural errors, a group × time interaction was identified (Wald χ^2 = 6.306; gl = 2; p = 0.043): WMI students had a statistically significant reduction from pre-test to post-test, and this reduction was maintained at the deferred post-test (Cohen's d = 0.97).

The results for WM performance were investigated in an attempt to help explain the results for mathematics performance. It was necessary to determine whether students improved WM capacity in order to explain a possible increase in their scores on mathematics performance in relation to improved WM capacity. The results indicate a significant effect of time in both groups (Table 3). WM performance improved from pre-test to immediate post-test in the measures RAVLT (Wald χ^2 = 12.246; gl = 2; p = 0.002; Cohen's d = 0.72 for CI and Cohen's d = 0.39 for WMI), DS Backwards (Waldχ^2 = 15.544; gl = 2; p < 0.001; Cohen's d = 0.36 for CI and Cohen's d = 0.68 for WMI), and SS Backwards (Wald χ^2 = 9.447; gl = 2; p = 0.009; Cohen's d = 0.17 for CI and Cohen's d = 0.25 for WMI). There was no significant group × time interaction or significant effect of group on WM components.

Transfer effects in relation to the severity of ADHD symptoms were investigated using the SNAP-IV. There was no group × time interaction (p = 0.970) or significant effect of group (p = 0.687). However, there was an effect of time on this parameter (Waldχ^2 = 8.680; gl = 1; p = 0.003; pre-test: mean = 1.57, SD = 0.70 for CI and mean = 1.55, SD 1.55 for WMI; immediate post-test: mean = 1.28, SD = 0.68 for CI and mean = 1.4, SD = 0.63). Approximately 37% (n = 17) of the students had a reduction of 20% or more in the severity of symptoms.

Among CI students, the intervention also influenced mathematics performance in the classroom, as reported by the teachers in the Teachers' Questionnaire. Performance improvement was significantly higher in CI than in WMI (U = 173; p < 0.05; median = 1, [0;1] for CI; median = 0, [0;1] for WMI), and approximately 70% of CI students had a significant improvement or very significant improvement in mathematics performance

Table 3. GEE results for the variables related to WM performance.

		Mean score								
		CI		WMI						
Components	Time	Mean	SE	Mean	SE		P_{Group}	P_{Time}	$P_{Interaction}$	Differences
Phonological loop	1	8.75	0.56	8.18	0.50	α	0.448	**<0.001**	0.628	T1 ≠ T2
	2	9.75	0.58	9.73	0.47	β				
	3	8.75	0.45	9.10	0.50	αβ				
Visuospatial sketchpad	1	3.21	0.35	3.14	0.36	α	0.887	**0.009**	0.461	T1 ≠ T2
	2	3.42	0.32	4.18	0.25	β				T1 ≠ T3
	3	4.07	0.16	4.02	0.17	β				
Episodic buffer	1	7.79	0.55	7.82	0.64	α	0.975	**0.002**	0.680	T1 ≠ T2
	2	10.08	0.73	8.95	0.63	β				T1 ≠ T3
	3	9.76	0.58	8.81	0.61	β				

Caption: αand βletters indicate means statistically different comparing time. CI is combined intervention. WMI is working memory intervention. SE is standard error. T1 is the pre-test, T2 is the immediately post-test, and T3 is the deferred post-test. ≠ is significant difference.

after the intervention against 40% of WMI students, considering that numbers 1 and 2 on likert scale represented improvement on performance.

Discussion

This is the first study aimed to compare the effects of a combined intervention of WM and AR *vs* WM intervention alone on the arithmetic reasoning of students with ADHD. It was hypothesised that the combined WM/AR intervention would result in greater benefits for ADHD students' arithmetic reasoning than a WM intervention alone, and this hypothesis was partially confirmed.

The analysis of AR performance indicated a significant interaction between intervention condition and time. Both groups showed an improvement in performance from pre-test to immediate post-test, but the improvement was significantly higher in CI than in WMI, with no major differences in baseline parameters. This difference was not maintained in the deferred post-test, 3 months after intervention. During this time, students were on school vacation, which could have influenced this result. Anyway the significant difference found between the two groups on immediate post-test helped to confirm the need, already pointed out in previous studies (Melby-Lervåg & Hulme, 2013; Rapport et al., 2013), for developing specific intervention programmes targeting the learning skills intended to be improved rather than developing interventions focusing only on domain-general skills (such as WM) to obtain better performance.

CI showed an increase of approximately two points. This increase is clinically relevant if we consider, based on evidence from the literature, that students with ADHD are slower in developing mathematical knowledge than students without the disorder (Costa et al., 2015).

It is important to note, however, that the improvement in arithmetic reasoning performance could not be explained by WM capacity alone. The results indicated a significant improvement in WM performance in both groups from pre-test to immediate post-test in all WM measurements, but the CI students had a greater increase in their arithmetic reasoning than the WMI students. The improvement in two tasks, one with influence of the phonological component and another with the visuospatial component, indicates increased performance in the central executive component. Despite these positive results in WM capacity, it is not possible to confirm that they are the result of the intervention, because this study did not have a control group. And it is also important to consider the effect of practice, since the same tasks were applied to the three assessment time points.

Several studies have considered WM capacity an important cognitive resource for learning mathematics (Kyttälä, 2008; Passolunghi et al., 2007). However, interventions in WM alone have not been enough to improve the school performance significantly (Melby-Lervåg & Hulme, 2013; Rapport et al., 2013). The results presented here corroborate this evidence. Students in the WMI group showed a significant reduction in the number of procedural errors made during the problem-solving test (arithmetic subtest), but this result cannot be attributed to an increase in WM capacity in this study. Both groups showed a significant increase in arithmetic calculation mean scores from pre-test to immediate post-test, and this increase remained at the deferred post-test. Both groups also showed a significant reduction in the number of conceptual errors in the immediate post-test, which also remained significant at the deferred post-test. Given that the students completed the same tasks in the three assessment moments, a test effect may be responsible for these positive results.

Transfer effects were reported by the teachers in relation to the severity of ADHD symptoms and to mathematics performance in the classroom. Both groups showed a significant reduction in the severity of ADHD symptoms from pre-test to immediate post-test. Another important result, perhaps the most relevant in a school setting, was the transfer of effects from the combined intervention to regular classroom activities, which resulted in significantly greater improvement in mathematics performance for the students who participated in the CI compared to the ones in the WMI. Although both groups increased in mathematical calculation measure (SAT), CI group presented a higher increase in AR than WMI on post-test. So, increased mathematics performance in the classroom, in tasks that were not the target of the intervention, could be explained by the fact that AR is an essential skill for the development of mathematical knowledge (Passolunghi et al., 2007). Thus, impairment in this ability can compromise mathematics performance in other areas.

These findings should be interpreted in the context of some limitations. First, our relatively small sample may not be able to detect the difference after intervention. Second, our study lacked an AR intervention alone to verify if the effects on arithmetic performance would be different from the combined intervention. Third, there is a lack of a control group to distinguish the effects of each intervention condition from those of formal education and of cognitive development itself. The following could also be considered limitations: the interventions were conducted by the researcher rather than a teacher; the interventions were not blinded; the same tests were applied in the three testing times, which could produce a practice effect; and the instrument used to assess the episodic buffer does not provide a real measure, but rather influences this component.

Despite these limitations, the present findings are sufficiently relevant to be considered for application in schools as well as in clinical psychopedagogy. They provide a model of intervention that may help students with both ADHD and impaired arithmetic performance, especially in elementary education, given the positive results demonstrated in mathematics performance obtained using an intervention applied collectively in a school environment.

In summary, the findings in this study partially confirm the hypothesis that a combined intervention of WM and AR is more effective at improving arithmetic reasoning than a WM intervention alone. The AR performance of CI and WMI was only significantly different on the immediate post-test. There were no significant differences in the deferred post-test after 3 months. In addition, the intervention results seem to be transferable to the school setting, leading to possible improvements in mathematics performance in the classroom. The WM intervention had positive effects on calculation and reduction of procedural errors, but it was not as effective at improving arithmetical reasoning as the combined intervention. Further studies could evaluate separately each intervention programme used in this study, in order to clarify the effect of each one separately, and also extrapolate these findings to other aspects of mathematics performance.

Notes

1. No student was excluded at this step.
2. No student was excluded at this step.
3. Students' assignment to the different interventions was carried out using QMinim software (http://qminim.sourceforge.net/demo/).
4. The questionnaire was completed only in the immediate post-test period because the instrument aimed to investigate the intensity of improvement resulting from the intervention (if any). The questionnaire was not completed in the late post-test period because it coincided with the beginning of the school year and the teachers did not have enough information about the students. Moreover, it would require a grade adjustment of the scale.
5. The SNAP-IV was not completed by the teachers at the deferred post-test because it coincided with the beginning of the school year and the teachers responsible for the students participating in the study did not have enough information for this evaluation. The same teacher provided the information at the two assessment time points.
6. There were not repeated measures between the intervention programmes application.
7. The session was rescheduled when students missed it. The principal investigator or a research assistant conducted the rescheduled session.
8. In this study, Terezinha Nunes and Oxford University research group designed the games.
9. The Words Game was adapted to Portuguese after a careful analysis of each translated word and picture. Some words and pictures have been modified because they are not common in the Brazilian culture. Efforts were made to keep the same structure in the modified sentences.
10. The phrases were read aloud to the students.

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References

Alderson, R., Kasper, L., Patros, C., Hudec, K., Tarle, S., & Lea, S. (2015). Working memory deficits in boys with attention deficit/hyperactivity disorder (ADHD): An examination of orthographic coding and episodic buffer processes. *Child Neuropsychology*, *21*(4), 509–530.

American Psychiatric Association. (2003). *DSM-IV-TR: Manual diagnóstico eestatístico de transtornos mentais* [Diagnostic and statisticalmanual of mental disorders] (4th ed., text revision. Porto Alegre, RS: Artes Médicas.

Angelini, A., Alves, I., Custódio, E., Duarte, W., & Duarte, J. (1999). *Matrizes Progressivas Coloridas de Raven: Escala Especial. Manual*. São Paulo, SP: CETEPP.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual review of psychology*, *63*, 1–29.

Bolic, V., Lidström, H., Thelin, K., Kjellberg, A., & Hemmingsson, H. (2013). Computer use in educational activities by students with ADHD. *Scandinavian Journal of Occupational Therapy*, *20*(5), 357–364.

Chacko, A., Bedard, A. C., Marks, D. J., Feirsen, N., Uderman, J. Z., Chimiklis, A., . . . Ramon, M. (2014). A randomized clinical trial of cogmed working memory training in school-age children with ADHD:

A replication in a diverse sample using a control condition. *Journal of Child Psychology and Psychiatry*, *55*(3), 247–255.

Corso, L. V., & Dorneles, B. V. (2012). Qual o Papel que a Memória de Trabalho Exerce na Aprendizagem da Matemática?[What role does the working memory play in mathematics learning?]. *Bolema*, *26*(42B), 627–647.

Costa, A., Rohde, L., & Dorneles, B. (2015). Teaching facts in addition to brazilian children with attention-deficit/hyperactivity disorder. *Educational Research and Reviews*, *10*(6), 751–760.

Dorneles, B., Corso, L., Costa, A. P., Pisacco, N. M. T., Sperafico, Y., & Rohde, L. (2014). Impacto do DSM-5 no Diagnóstico de Transtornos de Aprendizagem em Crianças e Adolescentes com TDAH: Um estudo de prevalência [the impact of dsm-5 on the diagnosis of learning disorder in ADHD children and adolescents: A prevalence study]. *Psicologia: Reflexão E Crítica (UFRGS. Impresso)*, *27*(4), 759–767.

Figueiredo, V. L. M., & Nascimento, E. D. (2007). Desempenhos nas duas tarefas do subteste dígitos do WISC-III e do WAIS-III [Performances in the forward and backward digit span in the WISC-III and WAIS-III]. *Psicologia: Teoria E Pesquisa*, *23*(3), 313–318.

Fortes, I. S., Paula, C. S., Oliveira, M. C., Bordin, I. A., de Jesus, J., & Rohde, L. A. (2016). A cross-sectional study to assess the prevalence of DSM-5 specific learning disorders in representative school samples from the second to sixth grade in Brazil. *European Child & Adolescent Psychiatry*, *25*(2), 195–207.

González-Castro, P., Rodríguez, C., Cueli, M., Cabeza, L., & Álvarez, L. (2014). Math competence and executive control skills in students with attention deficit/hyperactivity disorder and mathematics learning disabilities. *Revista De Psicodidáctica*, *19*(1), 1–30.

Holmes, J., Gathercole, S., Place, M., Dunning, D., Hilton, K., & Elliott, J. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology*, *24*, 827–836.

Kyttälä, M. (2008). Visuospatial working memory in adolescents with poor performance in. *Educational Psychology*, *28*(3), 273–289.

Malloy-Diniz, L. F., Fuentes, D., Abrantes, S. S., Lasmar, V. A., & Salgado, J. V. (2010). Teste de aprendizagem auditivo-verbal de Rey (RAVLT). In L. F. Malloy-Diniz, D. Fuentes, O. Mattos, & N. Abreu (Eds.), *Avaliação Neuropsicológica* (pp. 337–343). Porto Alegre, RS: Artmed.

Martins, F. C., & Ortiz, K. Z. (2009). The relationship between working memory and apraxia of speech. *Arquivos De Neuro-psiquiatria*, *67*(3B), 843–848.

Mattos, P., Serra-Pinheiro, M. A., Rohde, L. A., & Pinto, D. (2006). Apresentação de uma versão em português para uso no Brasil do instrumento MTA-SNAP-IV de avaliação de sintomas de transtorno de déficit de atenção/hiperatividade e sintomas de transtorno desafiador e de oposição [A Brazilian version of the MTA-SNAP-IV for evaluation of symptoms of attention-deficit/hyperactivity disorder and oppositional-defiant disorder]. *Revista De Psiquiatria Do Rio Grande Do Sul*, *28*(3), 290–297.

Mautore, J., DuPaul, G., & Jitendra, A. (2005). The effects of computer-assisted instruction on the mathematics performance and classroom behavior of children with ADHD. *Journal of Attention Disorders*, *9*(301), 300–312.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *49*(2), 270–291.

Nunes, T. (2009). *Teacher notes*. Retrieved from: Department of Education - University of Oxford: http://www.education.ox.ac.uk/research/child-learning/resources-2/#lm

Nunes, T., Barros, R., Evans, D., & Burman, D. (2014). Improving deaf children's working memory through training. *International Journal of Speech & Language Pathology and Audiology*, *2*(2), 51–66.

Nunes, T., Bryant, P., Evans, D., Bell, D., Gardner, S., Gardner, A., & Carraher, J. (2007). The contribution of logical reasoning to the learning of mathematics in primary school. *British Journal of Developmental Psychology*, *25*, 147–166.

Nunes, T., Evans, D., Barros, R., & Burman, D. (2011). *Can deaf children's working memory span be increased?* Retrieved from http://www.education.ox.ac.uk/wordpress/wp-content/uploads/2011/04/research-briefing-on-the-WM-intervention.pdf

Passolunghi, M. C., Vercelloni, B., & Schadee, H. (2007). The precursors of mathematics learning: Working memory, phonological ability and numerical competence. *CognitiveDevelopment*, *22*(2), 165–184.

Rapport, M., Orban, S., Kofler, M., & Friedman, L. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, *33*(8), 1237–1252.

Shiels, K., Hawk, L. W., JR., Lysczek, C. L., Tannock, R., Pelham, J. W., & Spencer, S. W. (2008). The effects of incentives on visual-spatial working memory in children with attention-deficit/hyperactivity disorder. *Journal of Abnormal Child Psychology*, *36*(6), 903–913.

SPSS. (2009). *PASW statistics for windows, version 18.0*. Chicago: Author.

Stein, L. M. (1994). *TDE: Teste de Desempenho Escolar: Manual para a aplicação e Interpretação* [School Achievement Test: Application and Interpretation Manual]. São Paulo, SP: Casa do Psicólogo.

Steiner, N., Frenette, E., Rene, K., Brennan, R., & Perrin, E. (2011). Computer-based attention training in the schools for children with attention deficit/hyperactivity disorder: A preliminary trial. *Clinical Pediatrics*, *50*(7), 615–622.

Swanson, H. L., Moran, A., Lussier, C., & Fung, W. (2013). The effect of explicit and direct generative strategy training and working memory on word problem-solving accuracy in children at risk for math difficulties. *Learning Disability Quarterly*, *37*(2), 111–123.

Tavis, D. R. (2010). The use of minimization in clinical trials. *Contemporary Clinical Trials*, *31*(2), 180–184.

Teruya, L. C., Ortiz, K. Z., & Minett, T. S. C. (2009). Performance of normal adults on rey auditory learning test: A pilot study. *Arquivos De Neuro-psiquiatria*, *67*(2a), 224–228.

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*, *13*(1), 1–14.

Wang, D., Dong, X., Ren, Y., Wang, S., Yang, S., Tu, W. . . . & Jiang, K. H. (2013). Mathematical cognitive function in children with attention deficit hyperactivity disorder: A behavior and event-related potential study. *Zhonghua Yi Xue Za Zhi*, *90*(20), 1555–1558.

Wechsler, D. (2013). *WISC-IV: Escala de Inteligência Wechsler para Crianças: Manual* [Wechsler Intelligence Scale for Children: Manual] (4th ed.). São Palo: Casa do Psicólogo.

Witt, M. (2011). School based working memory training: Preliminary finding of improvement in children's mathematical performance. *Advances in Cognitive Psychology*, *7*, 7–15.

Wu, S., & Gau, S. (2013). Correlates for academic performance and school functioning among youths with and without persistent attention-deficit/hyperactivity disorder. *Research in Developmental Disabilities*, *34*, 505–515.

Zental, S. (2007). Math performance of students with ADHD: Cognitive and behavioral contributors and interventions. In D. Berch & M. Mazzocco (Eds.), *Why is math so hard for some children?* (pp. 219–243). Baltimore, MD: Paul H Brookes Publishing.