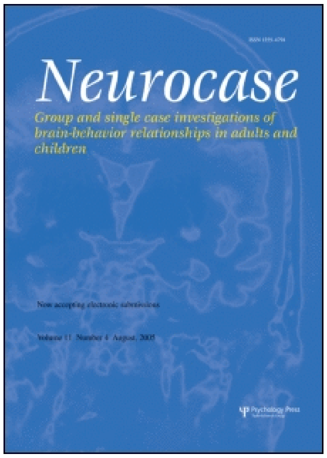

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Patterns of Developmental Dyscalculia With or Without Dyslexia

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This study has been conducted in order to investigate the extent to which some characteristics of dyscalculia may be common to dyslexia. Seven multiple single-cases were studied: two children with dyslexia only, two with dyscalculia only, and three more children with comorbidity of dyslexia and dyscalculia. Each participant was assessed with a standardized comprehensive battery of arithmetical, reading, and cognitive tests. We observed that a clinical impairment in mental and written calculations, arithmetical facts retrieval, number comparison, number alignment, and identification of arithmetical signs may appear with a normal reading capacity and independently of a short-term verbal memory deficit. These findings add convergent support to the evidence mainly obtained from group comparisons that the more distinctive characteristics of dyscalculia are functionally independent of dyslexia.

Keywords: Developmental dyscalculia, dyslexia, mental and written calculations, arithmetical facts

Introduction

This study aimed at investigating the specificity of dyscalculia with or without the presence of a concomitant dyslexia. Unlike most investigations on this topic, which employed a matched groups design, we chose a multiple single-case analysis design. Compared to the matched group designs, this methodological approach allows both a fine-grained analysis of single participants and a higher probability of discovering which characteristics of dyscalculia, if any, are independent of other cognitive and reading abilities. It is worth remembering that a statistically significant group difference does not preclude one or more participants of the experimental group from sharing the same characteristics of the control group. On the contrary, a cognitive neuropsychological approach based on single cases design makes a detailed investigation of the whole individual cognitive profile of subjects belonging to different clinical categories.

From a brief review of the literature on the subject it is clear that dyscalculia frequently co-occurs with a range of other disabilities, such as ADHD (Badian, 1983; Rosenberg, 1989; Shalev, Manor, & Gross-Tsur, 1997), poor hand-eye coordination (Siegel & Feldman, 1983), poor memory for non-verbal material (Fletcher, 1985), poor social skills (Rourke, 1989), developmental Gerstmann's syndrome (Grigsby, Kemper, & Hagerman, 1987), i.e., finger agnosia, dysgraphia and left-right discrimination difficulties, and spatial and psychomotor difficulties which would underlie a right-hemisphere dysfunction (Rourke, 1993). However, beyond a simple correlation, research has far from established whether these disabilities play a causal role in developmental dyscalculia (Landerl, Bevan, & Butterworth, 2004).

In particular, dyscalculia seems to be very common among dyslexics, as it is estimated that about 40% of dyslexics also have a math disability (Lewis, Hitch, & Walker, 1994). One of the most common ways of subtyping dyscalculic children is according to whether or not they have a comorbid reading disability. If different dyscalculia subtypes correspond to different underlying causes, there should be evidence of qualitatively different patterns of impairment across dyscalculia subtypes. This would allow us to understand what difference there is, if any, between dyscalculics who are also dyslexics and dyscalculics with a normal reading ability.

Relatively few studies have examined differences between math impaired children, and math and reading impaired ones on tasks involving numerical processing. For example, Landerl et al. (2004), Jordan, Hanich, and Kaplan (2003a, 2003b), and Shalev et al. (1997) found that the pattern of numerical impairment was the same for both groups. These studies found no evidence of a dissociation between the two groups in numerical processing, although children with comorbid math and reading difficulties were usually more impaired than children with specific math problems.

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Jordan and Montani (1997) compared a group of children with specific math disability with a group of children who had math disability in the contex of more general academic difficulties. The former were able to execute backup strategies in arithmetic, as well as perform at a normal level under untimed conditions, although their performance dropped under timed conditions. The latter struggled under both conditions. The authors suggest that children with specific math difficulties are able to compensate under untimed conditions thanks to their relatively good verbal or conceptual skills. However, although this study also indicates that children with general difficulties have quantitatively more difficulty than children with specific math disability, again there is no evidence that the pattern of numerical impairment is qualitatively different between the two groups.

Landerl et al. (2004) have specifically compared 8–9-year-old children selected on the basis of rigorous criteria for dyscalculia (a cutoff of –3 standard deviations to ensure a low incidence of false positives). In addition, all children categorized as dyscalculic had been declared as having learning difficulties, reading difficulties, or both, by their teacher. All participants were tested on a range of basic number processing tasks. These included elementary skills of transcoding between verbal and Arabic number codes or vice versa (number reading and writing), understanding numerosities up to 9, simple number sequencing, and dot counting. Both response speed and accuracy were measured for each of the tasks, as deficits in dyscalculic children are not always detected in untimed tasks (Jordan & Montani, 1997). In addition, the authors also carried out a number of non-numeric tasks for which they did not expect specific deficits in dyscalculia, such as speed of processing, articulation and access to semantic memory (color naming), phonological short-term and working memory (WISC-III digit span forward and backward), vocabulary (British Picture Vocabulary Scale), and executive and visual motor skills (WISC-III Mazes subtest). Children with only reading disability performed similarly to controls on numerical tasks. They were slower than controls in reciting number sequences (although less than dyscalculic children), and showed non-significant trends towards slowness in number naming. However, unlike the two dyscalculic groups, their number naming trend disappeared once general naming ability was controlled. Dyslexic children were also identical to controls on non-verbal (or non-phonological) tasks, such as Arabic number writing and number comparison. This pattern of results suggests that children with reading difficulties only do not have number processing deficits, although difficulties with verbal or phonological aspects of some of these tasks may affect their performance. Dyscalculic children without reading disability were normal, or above average, when performing tasks involving phonological working memory, non-verbal intelligence, linguistic and psychomotor abilities, and in accessing non-numerical verbal information. Furthermore, patterns of performance of the two dyscalculic groups were very similar on numerical tasks. This study found no evidence of a qualitative difference in the numerical abilities of dyscalculic children with or without reading disabilities. In many tasks the double deficit group's performance was slower or more prone to error than the dyscalculic group, suggesting that their difficulties may be more severe, consistently with the findings of Jordan and Montani (1997) and Shalev et al. (1997). The pattern of impairment was the same for both groups: each appeared to struggle with every aspect of numerical processing tested in the study, suggesting that the double reading deficit or language difficulties had no particular effects on their number disability pattern. These results argue against theories that put forward different cognitive causes at the root of diverse dyscalculia subtypes. Instead, they help to better define dyscalculia as a deficit in the representation or processing of specifically numerical information.

Convergent evidence of the independence of reading from numerical processing derives from neuroimaging studies. From these studies it emerges that numerical abilities, including arithmetic, are mediated bilaterally by areas in the parietal lobe (Dehaene, Dehaene-Lambertz, & Cohen, 1998), and that the ability to understand numbers and to calculate is dissociable from language (Cohen, Dehaene, Cochon, Lehericy, & Naccache, 2000), from semantic memory of non numerical information (Cappelletti, Butterworth, & Kopelman, 2001), and from working memory (Butterworth, Cipolotti, & Warrington, 1996). Recent investigations suggest that the brain areas necessary to develop normal arithmetical skills are localized in the horizontal segment of the bilateral intraparietal sulcus (HIPS) (Dehaene, Molko, Cohen, & Wilson, 2004), a brain area with no role in reading.

In our study, we aim to further investigate if a condition of pure developmental dyslexia can be associated with some aspect of numerical processing, which is qualitatively different from a condition of pure developmental dyscalculia, by observing the performance of each single participant on a wide battery of number processing tasks. The expected qualitative differences are clearly in the numerical processing tasks which require a phonological or a naming component. If these components are common to dyslexia and dyscalculia, purely dyslexic children, but not purely dyscalculic children, should demonstrate an impaired performance in accuracy or in speed in some numerical tasks such as naming forwards and backwards, writing numbers by dictation, reading numbers and numerical facts retrieval.

In this multiple single cases study we also added some participants with a diagnosis of both dyslexia and dyscalculia. If we assume that dyslexia entails some numeric processing difficulties which are qualitatively different from those deriving from a condition of pure dyscalculia, these participants should demonstrate both type of difficulties.

To better control how the different numerical processing abilities are associated with the condition of dyslexia and dyscalculia, our tests battery also included some tasks aimed at assessing some cognitive abilities often tested in these kind of investigations, namely, verbal and visual–spatial short-term memory and visual–motor integration ability.

Method

Participants

Seven children (six males, one female) were selected consecutively amongst those patients with learning difficulties referred by their schoolteachers to a public Neuropsychiatric Clinic located in the north-east of Italy. They were chosen to participate in the study after meeting the criteria for a diagnosis of developmental dyslexia only (RD), dyslexia plus dyscalculia (RD+MD), and dyscalculia only (MD) according to the DSM-IV guidelines (APA, 1994). The only further criteria for their inclusion were that their chronological age be as similar as possible and that they attended the final grades of primary school to reduce the possible condition of an insufficient school experience. As expected, the condition of pure dyslexia and pure dyscalculia were more difficult to observe, unlike the condition of comorbidity of dyslexia and dyscalculia that represents the more common condition amongst the children referred for learning disabilities.

Their demographic and IQ characteristics are presented in Table 1.

Their reading and arithmetical abilities were evaluated using standardized Italian tests (see description below). The performance on both cognitive and achievement tasks was considered clinically abnormal when the scores obtained were significantly different in statistical terms from the norms of the sample, using the SINGLIMS™ software (Crawford & Garthwaite, 2002; Crawford & Howell, 1998). This software allows us to compare the patient's score to the norms derived even from a small sample when a mean and a standard deviation (not percentiles) are available. The algorithm treats the statistics of the normative or control sample as statistics rather than as population parameters. In addition, this software uses the t-distribution (with $N - 1$ degrees of freedom), rather than the standard normal distribution, to estimate the abnormality of the individual's scores. Essentially, this method is a modified independent samples t-test in which the individual is treated as a sample of $M=1$, and therefore does not contribute to the within group variance estimate. Simulation studies have shown that Crawford and Howell's method is surprisingly robust even when confronted with very severe skew and/or leptokurtosis.[1] This new method it is deemed to be superior to the conventional method of choosing a cutoff of –2 or –3 standard deviation below the norms as a clinical criterion, or a performance below the 10th or 5th percentile.

Table 1. Chronological and general cognitive characteristics of participants

Group	ID	Age	Grade	VIQ	PIQ	FSIQ
RD	S.C.	9;1	III	112	103	108
	A.	10;10	V	109	126	119
MD	S.R.	10;11	V	100	98	99
	N.	9;5	IV	97	118	108
RD+MD	S.T.	10;9	V	91	110	100
	G.	9;11	IV	100	120	110
	D.	10;6	V	91	104	96

VIQ, Verbal IQ; PIQ, Performance IQ; FSIQ, Full Scale IQ.

In the literature there are different criteria to define the presence of dyscalculia. For example, some authors refer to arithmetic facts (Jordan et al., 2003b; Temple & Sherwood, 2002), while others refer to difficulties in numbers comparison (Butterworth, 2005) or in written arithmetic calculation (APA, 1994). We chose the criteria that both written and mental arithmetic calculation should be statistically significant in these two subtests from our standardized ABCA test (Lucangeli, Tressoldi, & Fiore, 1998) using the SINGLIMS™ software.

To be classified as dyslexics, participants should obtain a statistically significant difference in speed or accuracy performance in reading words and non-words on our standardized BDD test (Sartori, Job, & Tressoldi, 1995), in addition to a performance within the normal range in speed and accuracy on both ABCA written and mental arithmetic calculation subtests.

To qualify for a condition of comorbidity a participant had to meet the criteria for both dyslexia and dyscalculia.

According to the above-defined criteria, two participants, S.C. and A. were diagnosed as pure dyslexics (RD); two, S.R. and N. as pure dyscalculics (MD); and three, S.T., G., and D, as double deficits (RD+MD).

None of the participants suffered from a primary perceptual, neurological, or psychiatric disorders.

Tasks and procedure

Each participant was tested individually in five sessions of 60 min. Cognitive tests were always administered beforehand, followed by the randomized presentation of the achievement tests.

Cognitive tests

WISC-R (Wechsler, 1994; Orsini, 1993)

All participants were given the full Wechsler Intelligence Scale for Children-R (The Italian version of WISC-III was not available at the time of this study). For the purposes of our study, we took into account only three measurements: full scale IQ (FSIQ), verbal IQ (VIQ), and performance IQ (PIQ).

Digit Span (Orsini et al., 1987)

The forward auditory Digit Span from the WISC-R subtest (Wechsler, 1974) was used as a standard measure of phonological short-term memory. Norms are available in percentiles.

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[1] Further information and the software may be found at the following website: http://www.abdn.ac.uk/~psy086/dept/SingleCaseMethodsComputerPrograms.htm

Corsi Span (Milner, 1971; Orsini et al., 1987)

The Corsi blocks task was administered to measure spatial span. The apparatus for this task comprises a set of identical blocks glued to random positions on a board. On each trial the participant observes the experimenter tapping a sequence of blocks, and then attempts to reproduce the sequence. Trials start with a sequence of length 2 and continue with an incremental procedure. The span corresponds to the longest sequence correctly remembered by the subject in three of five attempts. Norms are available in percentiles.

Visual motor integration test (Beery, 1989)

This is a well-known test of visual–motor praxia. The child is requested to copy geometric shapes of increasing complexity. The score is obtained by summing up the partial scores obtained according to the degree of accuracy of each shape copied. Norms are available in percentiles.

Reading tests

MT reading test for the primary school—2 (Cornoldi & Colpo, 1998)

This is a standardized test of accuracy and fluency of a series of different passages for each grade. Norms are based on a sample of 8000 children selected from the first to the eighth grade. Reliability (test–retest coefficient) and validity measures (discriminant and convergent) are within the range of conventional psychometric standards (all coefficients are above .80).

BDD—Battery for the assessment of developmental dyslexia and disorthographia (Sartori et al., 1995)

This is a standardized test. Norms have been drawn from a total sample of 1200 children selected from the second to the eighth grade. Reliability (test–retest) and validity measures (discriminant and convergent) fall within the range of the conventional psychometric standards (all coefficients are above .80). We used only those two subtests which required the reading of a list of single real and nonsensical words respectively. Both subtests yield accuracy and speed measures.

Arithmetic test

Arithmetic ability was assessed using the *ABCA battery* (Lucangeli et al., 1998). This standardized battery is modeled on the McCloskey, Caramazza, and Basili (1985) neuropsychological modular model of calculation and numeric processing. Each subtest yields a measure of accuracy and speed. Norms are based on a total sample of 350 children selected from the third to the fifth grades. Reliability (test–retest) and validity measures (convergent and discriminant) are within the range of the conventional psychometric standards (all coefficients are above .80).

This battery is divided in three parts: arithmetic calculation, number comprehension, and number production.

The *Calculation part* includes mental (i.e., 43+6, 43 – 7, 18 × 2, 66 : 2) and written calculations (i.e., 47+15, 80−26, 492 × 7, 7056 : 9). During the execution of these calculations, children are observed in order to understand the procedure they are using. Both mental and written calculations comprise three additions, three subtractions, three multiplications, and three divisions.

The *Number Comprehension* part comprises the following subtests:

> *Naming and using arithmetic signs:* The child is asked to name each of the basic arithmetic symbols (i.e.: "+", "–", "×", ":", "<", ">"), and to give one example of how they may be used, for example writing 4+6 or 5×7.
>
> *Ordering numbers:* The child is asked to arrange six series of four numbers respectively in ascending and decreasing numerical size. Items are presented in a pseudo-random order (e.g., 111, 11, 101, 1011; 45, 54, 5, 154).
>
> *Magnitude judgments:* The child is asked to point out which number of a pair is larger in magnitude. Six items are visually presented on cards, while a further six are presented auditorily, one pair at a time. Numbers range from two to four digits (e.g., 83–88). Half of the times the first number is larger than the second, and vice versa.
>
> *Positional value recognition:* The child is asked to write the number corresponding to a given amount of units, tens, hundreds, and thousands written for instance as follows: zero tens, five units, one hundred (response=105). This subtest comprises 24 items.

The *Number Production* part includes:

> *Counting backwards:* The child is asked to count backwards from 100 to 50.
>
> *Number writing:* The child is asked to write from dictation eight numbers in Arabic form on a piece of paper. Numbers range from two to four digits.
>
> *Dot counting:* The child is asked to enumerate groups of randomly arranged dots on eight consecutive cards. For each card, dots range from 13 to 34.
>
> *Numbers alignment:* The child is asked to align vertically according to the number's positional value, eight series of numbers, ranging from one to four digits, presented horizontally on a sheet of paper.
>
> *Arithmetic facts:* The child is asked to solve 12 simple calculations verbally. The items comprise multiplication Tables (i.e., 7×4; 8×3), and additions and subtractions whose results are a multiples of ten (e.g., 87+13, 93−13).

Results

As shown in Table 1, all participants scored within the normal range (91–126) on the full scale, Verbal and Performance IQs of the WISC-R.

Table 2. Raw data and corresponding normative values obtained by participants at the cognitive tests. Values in bold correspond to a deficit

Group	ID	Digit span raw score	Percentile	Corsi span raw score	Percentile	VMI raw score	Percentile
RD	S.C.	**3**	**0.8**	4	22.7	17	24
	A.	5	40.6	6	95.6	18	25
MD	S.R.	**4**	**5.9**	**3**	**1.3**	**16**	**12**
	N.	6	88.5	5	76.6	**14**	**6**
RD+MD	S.T.	**4**	**5.9**	7	100	23	68
	G.	5	57.0	7	100	16	20
	D.	5	40.6	**4**	**12.7**	18	20

Being as it concerns the performance on the Digit and Corsi span measures, identifying a group whose members showed a specific impairment has not been possible. At least one participant emerged with a normal performance in both the Digit and Corsi span tests from among all the three groups.

The picture is different for the performance on the VMI. In this case, only the members of the dyscalculic group showed an impairment, suggesting an underlying visual–spatial difficulty (Badian, 1983; Rourke & Strang, 1983) of these two children (see Table 2).

The data presented in Table 3 are consistent with our subject's classification scheme. The reading measures of the dyscalculic group were all within the normal range, with the only exception of N's accuracy deficit when reading non-words. In contrast, all the dyslexic and double deficit participants' performance attained the statistically significant criteria in these tests.

Table 4 presents the data more relevant to the aim of this investigation. To help the reader analyze the results, only the presence of an accuracy or speed deficit has been reported. As for the other tests, the deficit corresponds to a statistically significant difference from the normative data using the SIN-GLIMS™ software. For those readers interested in the *z* scores obtained by each participant in each subtest, the data are presented in the Appendix.

Table 3. Raw data (words per min and percentage of errors)

		Passage		Words		Nonwords	
Group	ID	Speed wpm	Errors %	Speed wpm	Errors %	Speed wpm	Errors %
RD	S.C.	30*	10*	21*	16*	15*	37*
	A.	53*	2	30*	6	27*	43*
MD	S.R.	86	2	83	0	52	8
	N.	60	2	69	2	43	27*
RD+MD	S.T.	22*	4*	20*	6	13*	23*
	G.	32*	5*	42*	5	27*	25*
	D.	38*	10*	29*	11*	20*	31*

*Performance at a clinical level corresponding to $p < .05$ using the SIN-GLIMS software.

In the two children with pure dyslexia, no subtest was found to be impaired in both. The presence of isolated deficits in some subtests, i.e., number writing in participant A. or a speed deficit in counting backward in participant S.C. suggest that they are independent of their dyslexia.

If we look at the performance of the other two groups, apart from the impairment in the mental and written calculation that was used for the diagnosis of dyscalculia, all children show an impairment in only two subtests, number alignment and number facts retrieval. No other subtest of our battery showed impairment in all children.

Discussion

Comparing children with dyslexia only to dyscalculic children with or without co-occurring dyslexia, selected according to stringent clinical criteria and assessed with a comprehensive standardized arithmetic battery in a variety of numerical processing tasks, we aimed to see which of these may be a consequence of the deficit that causes dyslexia and which, on the other hand, are specific to dyscalculia.

The analysis of the data presented in Table 4 shows that the patterns of performance on the numerical subtests of the dyscalculic only group are very similar to those of the double deficit group.

Besides impairment in written and mental calculations, the common features of dyscalculia with or without dyslexia observed in our subjects are the difficulties in number alignment and in the arithmetic facts retrieval. In addition, these participants showed different, but inconsistent deficits in number processing such as naming and using the arithmetic signs, writing numbers by dictation, an ability that requires visual motor skills, knowledge of the digits positional value and the ability to make judgments on the magnitude of numbers.

It is interesting to observe that two out of three double deficit children showed a normal performance on counting backwards, as observed in the dyscalculic children group, adding further proof that dyslexia does not affect this ability.

Table 4. Data obtained at the ABCA battery

		Numbers comprehension				Mental calcul.	Numbers production					Written calculations				
												Procedural knowledge				Total
Group	ID	Naming and using arithmetic signs	Ordering numbers	Magnitude judgments	Positional value	Total	Counting backwards	Number writing	Dot counting	Number alignment	Number facts	+	–	×	:	
RD	S.C.				**A**		**S**					Yes	Yes	Yes	Yes	
	A.							**A+S**				Yes	Yes	Yes	Yes	
MD	S.R.	**A**		**S**	**S**	**A+S**		**S**	**A+S**	**S**	**S**	Yes	Yes	Yes	**No**	**A+S**
	N.	**A**	**A**			**A**				**A**	**A+S**	Yes	**No**	**No**	**No**	**A**
RD+MD	S.T.	**A**		**S**		**S**	**S**	**A+S**		**S**	**S**	Yes	Yes	Yes	Yes	**S**
	G.			**A**		**S**		**S**		**S**	**A+S**	Yes	Yes	Yes	Yes	**S**
	D.	**A**				**A**		**S**		**A**	**A+S**	Yes	Yes	**No**	**No**	**A+S**

A, accuracy deficit; S, speed deficit; cut-off: $p < .05$ using the SINGLIMS software.
Yes = correct.

Butterworth (2005) suggests that the key deficit in developmental dyscalculia is a failure to represent and process numerosity, the ability to recognize and manipulate quantities in a normal way, a condition observed, for example, in a group of adults diagnosed as having developmental dyscalculia by Rubinsten and Henik (2005).

Even if a deficit like this one may be present in dyscalculic children, as demonstrated for example by our participants S.R., S.G. and G in the magnitude comparison task, we favor the opinion that considers dyscalculia not as the expression of a single deficit, but as a variable constellation of deficits that impair mental and particularly written calculations in different ways (Temple, 1991; von Aster, 2000). The performance of all our dyscalculic participants in the different numerical tasks are a demonstration of this hypothesis. Even if all of them demonstrated a deficit in the number alignment and in the recovery of numerical facts tasks, we prefer to wait before suggesting that these two deficits may represent the landmark of developmental dyscalculia until further single cases investigations can confirm this as true.

The role of a verbal or visual–spatial short-term memory deficit as being the cause of dyslexia or dyscalculia seems to be equally unsupported by our findings. In fact, while one child with pure dyscalculia, S.R., showed an impaired performance both on the digit and Corsi span, the other child, N., displayed a performance above average on both these tests. Furthermore, in the RD+MD group, while, on the one hand S.T. showed a deficit on the digit, but not on the Corsi span measure, D. presented the opposite pattern, and a third member, G., displayed a normal range performance on both tests.

The irrelevance played by the digit span in explaining some features of dyscalculia is reinforced by the lack of a consistent association between this form of memory and the arithmetic facts performance, often considered a consequence of a verbal short-term memory impairment (Geary, 1993), a datum which corresponds with what Temple and Sherwood (2002) reported.

The observed association with a visual motor integration deficit in the two pure dyscalculic children, but not in the three with comorbidity, lends little support to the suggestions that dyscalculia may depend more on visual–spatial than on verbal cognitive difficulties, as proposed by Rourke (1993) and other authors (Badian, 1983).

Our findings may be considered to be a further support to the suggestion that dyscalculia features are independent from verbal and spatial short-memory span, from general verbal cognitive skills, and from dyslexia, adding convergent support to the results obtained from group studies (Jordan et al., 2003a, 2003b; Landerl et al. 2004; Shalev et al., 1997; Temple & Sherwood, 2002).

It is clear that the methodology of single-cases study adopted in this study has both strengths and limitations that have been the subject of heated debated in the field of cognitive neuropsychology in the last 20 years (see for example Caramazza, 1986; Shallice, 1979; Vallar, 2004). It is not our intention to continue the debate here. What is important, however, is to consider the questions this methodology can answer as being different from those that could be posed by the methodology of groups comparison.

In our case, the methodology of single cases can provide some answers to the question if a child with a clinical diagnosis of dyslexia has some specific difficulties in number processing, for example, in tasks requiring naming or verbal memory, or if there is a unique profile of impairments in a condition of dyscalculia. These are quite different questions from the one regarding, for example, whether dyscalculic children have more impairments than dyslexic children in numerical processing tasks requiring magnitude comparison than in recovering number facts.

The answers that emerge from our data show that even if a child with a condition of dyslexia shows difficulties in some aspects of numerical processing, these difficulties appear to be independent from dyslexia and further demonstrate that there are different individual dyscalculic profiles dependent on the number processing abilities which turn out to be inefficient.

If this interpretation is correct, the more parsimonious interpretation of the comorbidity of dyslexia and dyscalculia is that there are two complex independent functional cognitive systems that do not function properly.

In conclusion, this study reinforces the suggestion that dyscalculia is the consequence of a specific neurofunctional disability and shares almost nothing with the neurofunctional substrate that causes dyslexia.

The practical implications of these findings are that any rehabilitative approach that aims to improve the impaired cognitive components (i.e., number alignment, number facts retrieval, etc.) observed in a child with dyscalculia, should be specific and, above all, tailored to the child's specific characteristics and should not draw on the contents of rehabilitative techniques used to improve reading accuracy or speed such as training to improve phonological awareness, verbal memory or rapid recovery of verbal information.

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References

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.

Badian, N. A. (1983). Arithmetic and nonverbal learning. In H. R. Myklebust (Ed.), *Progress in learning disabilities* (Vol. 5, pp. 235–264). New York: Grune and Stratton.

Beery, K. (1989). *Developmental test of visual motor integration*. Cleveland, OH: Modern Curriculum Press.

Butterworth, B. (2005). The development of arithmetical abilities. *Journal of Child Psychology and Psychiatry*, *46*, 3–18.

Butterworth, B., Cipolotti, L., & Warrington, E. K. (1996). Short-term memory impairments and arithmetical ability. *Quarterly Journal of Experimental Psychology, 49A*, 251–262.

Cappelletti, M., Butterworth, B., & Kopelman, M. D. (2001). Spared numerical abilities in a case of semantic dementia. *Neuropsychologia*, *39*, 1224–1239.

Caramazza, A. (1986). On drawing inferences about the structure of normal cognitive systems from the analysis of patterns of impaired performance: The case for single-patient studies. *Brain and Cognition*, *5*, 41–66.

Cohen, L., Dehaene, S., Cochon, F., Lehericy, S., & Nacchache, L. (2000). Language and calculation within the parietal lobe: A combined cognitive, anatomical and fMRI study. *Neuropsychologia*, *38*, 1426–1440.

Cornoldi, C., & Colpo, M. (1988). *Prove di lettura MT per la Scuola Elementare* [MT Reading Test for the primary school–2], Firenze: O. S.

Crawford, J. R., & Garthwaite, P. H. (2002). Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*, *40*, 1196–1208.

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist*, *12*, 482–486.

Dehaene, Dehaene-Lambertz, & Cohen, L. (1998). Abstract representations of numbers in the animal and human brain. *Trends in Neuroscience*, *21*, 355–361.

Dehaene, S., Molko, N., Cohen, L., & Wilson, A. J. (2004). Arithmetic and the brain. *Current Opinion in Neurobiology*, *14*, 218–224.

Fletcher, J. F. (1985). Memory for verbal and nonverbal stimuli in learning disabled subgroups: Analysis by selective reminding. *Journal of Experimental Child Psychology*, *40*, 244–259.

Geary, D. C. (1993). Mathematical disabilities. Cognitive, neuropsychological, and genetic components. *Psychological Bulletin*, *114*, 345–362.

Grigsby, J. P., Kemper, M. B., & Hagerman, R. J . (1987). Developmental Gerstmann syndrome without aphasia in Fragile X syndrome. *Neuropsychologia*, *25*, 881–891.

Jordan, N., & Montani, T. O. (1997). Cognitive arithmetic and problem solving. A comparison of children with specific and general mathematics difficulties. *Journal of Learning Disabilities*, *30,* 624–634.

Jordan, N., Hanich, L. B., & Kaplan, D. (2003a). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with co-morbid mathematics and reading difficulties. *Child Development*, *74*, 834–850.

Jordan, N., Hanich, L. B., & Kaplan, D. (2003b). Arithmetic fact mastery in young children: A longitudinal investigation. *Journal of Experimental Child Psychology*, *85*, 103–119.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8–9-year-old students. *Cognition*, *93*, 99–125.

Lewis, C., Hitch, G., & Walker, P. (1994). The prevalence of specific arithmetic difficulties and specific reading difficulties in 9- and 10-year old boys and girls. *Journal of Child Psychology and Psychiatry*, *35*, 283–292.

Lucangeli, D., Tressoldi, P. E., & Fiore, C. (1998). *ABCA/Test delle abilità di calcolo matematico* [ABCA/Test of calculation skills] Trento: Erickson.

McCloskey, M., Caramazza, A., & Basili, A. G. (1985). Cognitive mechanisms in number processing and calculation: Evidence from discalculia. *Brain and Cognition*, *4*, 171–196.

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, *27*, 272–277.

Orsini, A. (1993). *WISC-R. Contributo alla taratura italiana* [WISC-R Italian norms], Firenze: O.S.

Orsini, A., Grossi, D., Capitani, E., Laiacona, M., Papagno, C., & Vallar, G. (1987). Verbal and spatial immediate memory span: Normative data from 1355 adults and 1112 children. *Italian Journal of Neurological Science*, *8*, 539–548.

Rosenberg, P. B. (1989). Perceptual-motor and attentional correlates of developmental dyscalculia. *Annals of Neurology*, *26*, 216–220.

Rourke, B. P. (1989). *Nonverbal learning disabilities. The syndrome and the model*. New York: Guilford Press.

Rourke, B. P. (1993). Arithmetic disabilities, specific and otherwise: A neuropsychological perspective. *Journal of Learning Disabilities*, *26*, 214–226.

Rourke, B. P., & Strang, J. D. (1983). Concept-formation and non verbal reasoning abilities of children who exhibit specific academic problems with arithmetic. *Journal of Clinical Child Psychology*, *12,* 33–39.

Rubinsten, O., & Henik, A. (2005). Automatic activation of internal magnitudes: A study of developmental dyscalculia. *Neuropsychology*, *19*, 641–648.

Sartori, G., Job, R., & Tressoldi, P. E. (1995). *Batteria per la valutazione della dislessia e della disortografia in età evolutiva* [Battery for the assessment of developmental dyslexia and dysorthographia], Firenze: O. S.

Shalev, R. S., Manor, O., & Gross-Tsur, V. (1997). Neuropsychological aspects of developmental dyscalculia. *Mathematical Cognition*, *3*, 105–120.

Shallice, T. (1979). Case study approach in neuropsychological research. *Journal of Clinical Neuropsychology*, *1*, 183–211.

Siegel, L. S., & Feldman, W. (1983). Non-dyslexic children with combined writing and arithmetic difficulties. *Clinical Pediatrics*, *22*, 241–244.

Temple, C. M. (1991). Procedural dyscalculia and number fact dyscalculia. Double dissociation in developmental dyscalculia. *Cognitive Neuropsychology*, *8*, 155–176.

Temple, M. C., & Sherwood, S. (2002). Representation and retrieval of arithmetic facts: Developmental difficulties. *Quarterly Journal of Experimental Psychology*, *55A*, 733–752.

Vallar, G. (2004). The 2003 status of cognitive neuropsychology. *Cognitive Neuropsychology, 21*, 45–49.

Von Aster, M. (2000). Developmental cognitive neuropsychology of number processing and calculation: varieties of developmental dyscalculia. *European Child & Adolescent Psychiatry*, *9*, 41–57.

Wechsler, D. (1994). *WISC-R/Scala di intelligenza Wechsler per bambini-Riveduta* [Scale for children intelligence assessment], Firenze: O. S.

Appendix

Appendix 1. *Z* scores related to reading tests. Values in bold correspond to a deficit

Group	ID	Passage speed	Passage accuracy	Words speed	Words accuracy	Nonwords speed	Nonwords accuracy
RD	S.C.	**–2.7**	**–4.8**	**–4.50**	**–3.07**	**–4.16**	**–2.95**
	A.	**–2**	–1.4	**–6.40**	–1.30	**–3.00**	**–3.80**
MD	S.R.	.08	–1.2	0.06	0.70	0.06	0.20
	N.	–1.8	.74	–0.15	–0.14	–0.07	**–2.20**
RD+MD	S.T.	**–3.1**	**–2.2**	**–11.40**	–1.27	**–9.79**	–1.45
	G.	**–2.7**	**–4**	**–2.61**	–1.21	**–1.83**	**–1.91**
	D.	**–2.4**	**–6**	**–6.60**	**–3.09**	**–5.44**	**–2.40**

Appendix 2. *z* scores related to the ABCA subtests. Values in bold correspond to a deficit

			Numbers comprehension				Mental calculations	Numbers production					Written calculations				
													Procedural knowledge				
Group	ID		Naming and using arithmetic signs	Ordering numbers	Magnitude judgments	Positional value	Total	Counting backwards	Number writing	Dot counting	Number alignment	Number facts	+	−	×	:	Total
		Acc.	1.41	0.53	0.88	**−2.26**	0.01	−0.46	0.48	−0.62	0.58	−1.35					0.53
	S.C.	Speed		1.41	0.36	−0.03	−0.04	**−2.27**	0.13	−0.7	−1.57	−1.44	Yes	Yes	Yes	Yes	−0.44
		Acc.	0.53	0.01	0.61	0.46	1.04	0.76	**−4.5**	0.37	−0.6	−0.32					0.25
RD	A.	Speed		2.1	−0.56	−0.83	−1.57	−1.24	**−3.61**	−1.5	−1.08	−0.7	Yes	Yes	Yes	Yes	−1.51
		Acc.	**−5.61**	0	−0.15	.46	**−2.04**	0.77	0.5	**−2.12**	−0.6	−0.72					**−2.25**
	S.R.	Speed		0.51	**−3.22**	**−1.84**	**−2.89**	−1.55	**−6.11**	**−6.56**	**−5.27**	**−2.83**	Yes	Yes	Yes	**No**	**−3.39**
		Acc.	**−2.87**	**−1.93**	−0.09	−1.42	**−2.08**	0.25	0.2	0.3	**−9.76**	**−3.45**					**−2.70**
MD	N.	Speed		0.67	0.22	−0.81	−0.75	−0.13	−1.53	0.36	−0.8	**−2.63**	Yes	**No**	**No**	**No**	−0.59
		Acc.	**−2.53**	0	−0.92	0.46	−0.11	0.1	**−4.5**	0.37	0.4	0.72					0.25
	S.T.	Speed		2.03	**−5.12**	−0.01	**−5.05**	**−1.74**	**−7.95**	−0.74	**−2.52**	**−8.4**	Yes	Yes	Yes	Yes	**−6.46**
		Acc.	−1	−1.26	**−2.81**	0.35	0.08	0.25	0.2	0.92	0.23	**−1.95**					−0.20
	G.	Speed		.95	.57	1.59	**−4.51**	−1.13	**−5.19**	−0.3	**−4.22**	**−3.81**	Yes	Yes	Yes	Yes	**−2.71**
		Acc.	**−2.53**	0	.61	0.46	**−2.8**	0.43	0.5	−1.5	**−5.6**	**−2.32**					**−1.75**
RD+MD	D.	Speed		.51	.82	−0.61	−1.48	−0.55	**−2.78**	−0.56	−0.83	**−3.4**	Yes	Yes	**No**	**No**	**−3.04**