Screening for Dyscalculia: A New Approach
SEN Presentation Summary
Mathematical Difficulties: Psychology, Neuroscience and Interventions.
Professor Brian Butterworth
Oxford, September 2002.

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The Diagnostic and Statistical Manual of Mental Disorders, fourth Edition, gives the following diagnostic criteria for "Mathematics Disorder" (DSM-IV, Section 315.1) is a "Mathematical ability, as measured by individually administered standardized tests, is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education" which can significantly interferes with academic achievement or activities of daily living that require mathematical ability.

The best available estimates put the prevalence of dyscalculia at somewhere around 5%. This is a lot of people in the UK with a problem that interferes with daily living and academic achievement (3m people).

Most current diagnostic methods use the DSM-IV approach to defining dyscalculia (or mathematical disorder – the terms are interchangeable): a discrepancy between what is expected on the basis of measured intelligence (or performance on other school subjects) and performance on a standardized maths test.

Here is an example of the kind of test item current used, from perhaps the most widely-used test, the WISC-IIIUK:

> If you buy 2 dozen pencils at 45 pence a dozen, how much change should you get back from £1?
>
> A nine-year old child is allowed 45s to solve this.

The problem with this approach is that there are many reasons for being bad at school-type arithmetic, including inappropriate teaching, behavioural and health problems, all of which may affect particularly curriculum areas where each concept is built on the one before, maths being a paradigm example, rather than those which comprise a variety of topics loosely-connected with a developing set of skills, such as history or literature.

At the same time, this test does not distinguish between children who solve the problem confidently in two seconds, from those who take the whole 45s to solve it on their fingers. So we may diagnose as dyscalculic many children who are bad at maths for other reasons, and miss many dyscalculic children who manage to scrape by through dogged determination using age-inappropriate strategies.

Dyscalculia appears to be a persistent congenital condition. Twin studies suggest that it is inherited, though little is known about which genes are involved. Any capacity specified in the genome is likely to be for simple concepts. The best candidate is for the concept of numerosity itself – that is, for a sense of the number of things in a collection. It is known that infants are able to detect changes of numerosity, and as early as six months, have arithmetical expectations about the effects on numerosity of adding an object to a collection of subtracting one from it. Infants also know which of two sets is numerically larger. Similar capacities have been found in apes, monkeys and birds.

Dyscalculic children themselves recognise that they fail to understand the basic concepts of number. In focus groups, nine year olds told us:

> *Child 1: "Sometimes she says stuff fast, and then I just forget it.*
> *Moderator: "Right."*
>
> *Child 2: "I don't forget it, I don't even know what she's saying."*

This is echoed by what their teachers told us:

There are also severe emotional sequelae to dyscalculia. This what some of the children said to us:

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" … when I don't know something, I wish that I was like a clever person and I blame it on myself…"

"I would cry and I wish I was at home with my mum and it would be...I won't have to do any maths and come out...come back when it was the end of maths"

"... I'm not good, and I don't like it when my mum says that - that's why I don't like times tables at all."

Our new approach to dyscalculia is to use item-timed tests of the capacity for numerosity. This minimizes the effect of educational experience, and therefore of educational achievement, and focuses on this basic capacity. Our main tests are counting dots and selecting the larger of two numbers. We also use item-timed calculation, which allows us to discriminate the finger counters from the fluent performers.

One dyscalculic child, "Josh" (not his real name) is an intelligent well-behaved boy, a good reader who does well at most school subjects. Even at 9;7 he was unable to solve 4+1. He was abnormally slow on dot counting and number comparison.

These difficulties persist into adulthood. "Charles", like Josh, was abnormally slow on dot counting and number comparison, and even at 31 years with a degree in psychology, was unable to multiply two one-digit numbers, or to add or subtract two digit numbers on paper.

We have carried out a DfES-funded pilot study of this approach in the London Borough of Harrow. One additional issue we addressed in this study was the relationship between dyscalculia and dyslexia, since many dyslexics are also dyscalculic. Could dyscalculia be a form of dyslexia, or indeed a consequence of it?

We tested over 100 children between the ages of 8 and 9. Out of these, we selected 10 children with dyscalculia (MD), 11 with dyscalculia and dyslexia (MD/RD), 10 with dyslexia (RD) and 18 matched controls.

The study asked the following questions

MD (Maths Disability) just a matter of low IQ? *We equated groups for IQ*

MD due to poor Short-term Memory? *We used span tests to compare the groups*

MD due to poor language abilities? *We had colour naming and reciting tests*

MD a consequence of RD (reading disability - dyslexia)? *We compared MD/RD with RD on numerical tests*

MD due to a deficit in basic numerical abilities? *Tests of enumeration and number comparison*

Our basic finding were these: the MD and MD/RD groups performed far worse than Controls and RD on dot counting, number comparison, and timed arithmetic. If we had looked only at arithmetical accuracy, the groups would not have differed significantly.

MD had similar short-term memory span, reading and language abilities to the Controls, and better than RD and MD/RD. We also found that the groups did not differ significantly on tests of spatial ability - for example, they did not differ in their ability to compare the sizes of rectangles.

So,

MD a matter of low IQ? *No, because groups equated for IQ*

MD due to poor STM? *No, because MD = Controls (RD worse than Controls)*

MD due to poor language abilities? *No, because same colour naming performance*

MD a consequence of slow reading? *RD normal on maths tests accuracy and speed*

MD a consequence of RD? *No, because MD pattern of maths performance same as MD/RD*

MD due to a deficit in basic numerical abilities?

Yes, MD and MD/RD worse on enumeration and number comparison

This was a research study using a wide a variety of tests, whose diagnostic value was being assessed. The outcome of this study and several other lines of evidence, has been distilled into the Dyscalculia Screener.

This comprises three computer-controlled, item-timed tests.

Number comparison

Dot counting

Item-timed arithmetic

We also take into whether a person is simply a slow responder, by including a fourth test of Simple reaction time, which we use to adjust the child's reaction times.

It will be available as software for your PC. The results are given as standard scores (average 100, standard deviation 15). These are automatically calculated by computer in a printable form

On the basis of our standardization study of a stratified random sample of 546 children, the lowest 10% on all tests are classified as dyscalculic. Where there is low performance on arithmetic but not on the other tests, we can now attribute this to poor learning or teaching. This helps us to eliminate Type 1 errors. Because the test is item-timed, it will pick up those children who can manage to get an average number of answers correct, but who solve them in an abnormal and an abnormally-slow manner.

Unlike other tests, the Screener is focussed on diagnosing dyscalculia, and is not a general test of mathematical achievement (for which the BAS is much better suited). It has the advantage for the user in that it is not necessary to record the raw scores, translate them into standard scores by looking them up in a table, and then categorise the outcome. This is all done by the computer.

Screening for dyscalculia: a new approach.

Brian Butterworth

Institute of Cognitive Neuroscience

ICN Numeracy Group

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Collaborators

Luisa Girelli (U. Milan-Bicocca), Nick Nelson, Cres Fernandes (NFER-Nelson)

www.mathematicalbrain.com

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Prevalence estimates of maths disabilities

STUDY location	ESTIMATE OF LEARNING DISABILITY	CRITERION	PERCENTAGE LITERACY DISORDER
OSTAD (1998) Norway *Log. Phon. Vocal., 23, 145-154*	10.9% "Maths disabled"	Registered for special long-term help	51% Spelling disorder
LEWIS et al (1994) England *J. Child Psychol. Psychiat., 35, 283-292*	3.6% "specific arithmetic difficulties"	<85 on arithmetic test, >90 on NVIQ	64% Reading difficulties
GROSS-TUR et al (1996) Israel *Dev. Medicine Child Neurol., 38, 25-33*	6.4% "dyscalculic"	Two grades below Chronological Age	17% Reading disorder

Definitions of "dyscalculia", mathematics disorder, mathematics disability

(I use all these terms interchangeably)

- *The Diagnostic and Statistical Manual of Mental Disorders*, fourth Edition, gives the following diagnostic criteria for "Mathematics Disorder" (DSM-IV, Section 315.1)
  - A. Mathematical ability, as measured by individually administeredstandardized tests, is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education.
  - B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living that require mathematical ability.
  - C. If a sensory deficit is present, the difficulties in mathematical ability are in excess of those usually associated with it.
- DfES in *Guidance to support pupils with dyslexia and dyscalculia* (0512/2001)
  - " A condition that affects the ability to acquire arithmetical skills. Dyscalculic learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers, and have problems learning number facts and procedures. Even if they produce a correct answer or use a correct method, they may do so mechanically and without confidence."

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What MD children say about trying to cope cognitively with the Numeracy Hour

"...in the mornings we do mental maths, so she's like saying that - saying the questions and she goes really fast, and then I - then I start doing it and then I'm left behind."

Child 1: "Sometimes she says stuff fast, and then I just forget it.
Moderator: "Right."
Child 2: "I don't forget it, I don't even know what she's saying."

"I was paying attention to the question...and then I don't get it and then…uh...the person next to me gets it and then I don't even ask him...and then I just like get confused and I get most of my answers wrong…"

Verbatim unedited transcripts of 8-9 year olds in 5-child focus groups: low achieving group (Bevan & Butterworth, in prep)..

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Emotional consequences of dyscalculia

" I feel like screaming and saying 'why are you doing this, why are you doing this?' and I feel like punching the teachers…"

" …when I don't know something, I wish that I was like a clever person and I blame it on myself…"

"... I'm not good, and I don't like it when my mum says that - that's why I don't like times tables at all."

Verbatim unedited transcripts of 8-9 year olds in 5-child focus groups: low achieving group (Bevan & Butterworth, in prep).

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Emotional consequences

Low ability children about what it's like for them

Moderator: *How does it make people feel in a maths lesson when they lose track?*
Child 1: *Horrible.*
Moderator: *Horrible? Why's that?*
Child 1: *I don't know.*
Child 3 (whispers): *He does know.*
Moderator: *Just a guess.*
Child 1: *You feel stupid.*

****

When I 't something, I wish I was like a clever person, and I blame it on myself.

****

he just comes up to us and says "ha ha - you don't know anything - you are so dumb" and then he asks me, like, questions like "thousand times thousand" which he knows and I don 't know ...which is very hard for us

Other children notice

Yeah, and then she goes hide in the corner - nobody knows where she is and she's crying there

Problems with the traditional methods for identifying of dyscalculic children

- Many reasons for failing standardized maths tests
  - Inappropriate teaching
  - Emotional or behavioural problems
  - Poor reading or writing skills (”It’s dyslexia”)
  - Anxiety about arithmetic tasks
  - And so on
  - Risk of Type 1 misdiagnosis
- Reason for doing well
  - Dogged application of rote-learned or age-inappropriate procedure - like finger counting for multiplication
  - Risk of Type 2 misdiagnosis

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Existing test 1: WISC-III^{UK}

Arithmetic sub-test

- A girl had 12 newspapers and sold 5. How many newspapers did she have left?
  - 30s - if all correct up to here, scaled score of 5 for 9 yr olds
- If you buy 2 dozen pencils at 45 pence a dozen, how much change should you get back from £1?
  - 45s - if all correct up to here, scaled score of 13 for 9 yr olds

Diagnosis of dyscalculia depends on a discrepancy between the Arithmetic Sub-test and overall IQ

Test performance depends a lot of learning in school,

so high risk of Type 1 error - diagnosing as dyscalculics those bad at the test for other reasons

Test performance not timed,

so high risk of Type 2 error - missing dyscalculics who are fairly accurate but abnormally slow

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Existing tests 2: Woodcock-Johnson III

- Cognitive abilities:
  - Comprehension-knowledge Gc, Long-term retrieval Glr, Visual-spatial thinking Gv, Auditory processing Ga, Fluid reasoning Gf, Processing speed Gs, Short-term memory Gsm
- Maths is part of the Achievement scale

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Test 5 Calculation

A. $\square$	B. $\square$	1. $2 + 2 = \square$	2. $1 + 1 = \square$	3. $2 + 1 = \square$
4. $6 + 1 = \square$	5. $2 + 4 = \square$	6. $3 - 2$	7. $5 - 2$	8. $3 - 1 = \square$
9. $5 - 1 = \square$	10. $9 + 7$	11. $17 - 9$	12. $89 - 18$	13. 5×3
14. $476 + 61 + 2{,}611$	15. $2\overline{)8}$	16. 8×5	17. 13×7	
18. $48 - 19$	19. 14×6	20. $\frac{2}{3} - \frac{1}{3}$	21. $42\overline{)126}$	
22. $48\overline{)288}$	23. $\frac{7}{8} - \frac{2}{8}$	24. $25\overline{)3250}$	25. $2\frac{3}{4} + 4\frac{1}{8}$	

Go to the next page →

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Problems with Woodcock-Johnson III

- Diagnosis of dyscalculia depends on a discrepancy between Number Skills Test and Cognitive Ability
- Test performance depends a lot of learning in school,
  - so high risk of Type 1 error
- Test performance not timed,
  - so high risk of Type 2 error

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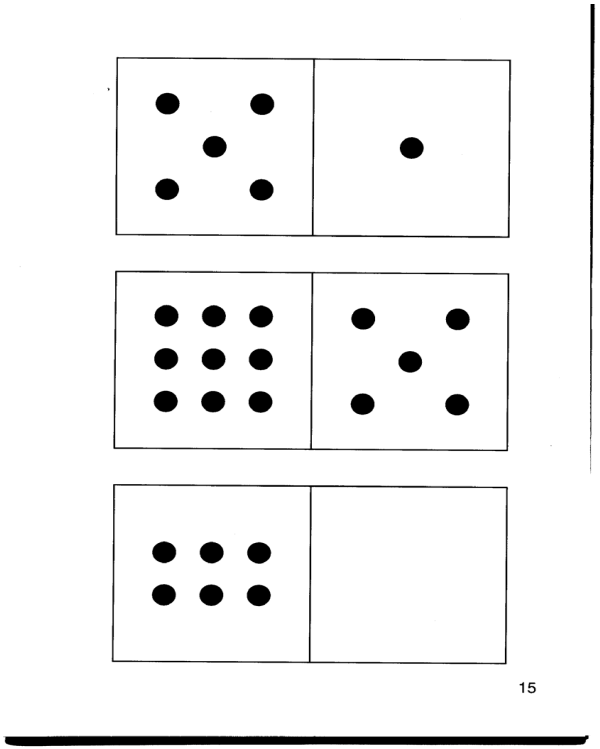
Existing tests 3 - British Ability Scale

Quantitative reasoning

Contribute to General Cognitive Ability

For 9yr olds, 8 questions.



Problems with BAS

- "Scores may reflect the child's
  - Inductive reasoning, including identification of rules governing numerical relationships, and formulation and testing of hypotheses about these rules
  - Analytical ability, involving the process of separating a problem into its components
  - Retrieval of information from long-term memory
  - Knowledge of numerals, basic number facts and simple arithmetical operations
  - Use of verbal mediation strategies
- Low scores may reflect
  - Poor understanding of verbal instructions
  - Impulsivity (responding too rapidly)
  - Inflexibility in choosing solution strategies”

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Lot's of reasons for being bad at maths, but

- Is there a congenital condition, dyscalculia, that is not the consequence of deficits in other "more basic" cognitive capacities?
  - E.g. Intelligence, STM, language, reading
- Recent research suggests that there are number-specific innate capacities
- Which may have a specific neuroanatomical locus.
- These innate capacities will be very simple, and a screener must test for these capacities
  - Tests of attainment will confound all the different causes of poor mathematics
- They are likely to involve the core concept of number - numerosity
  - General: concept of collection and its numerosity, effects of operations on collections
  - Specific numerosities: twoness, threeness, …

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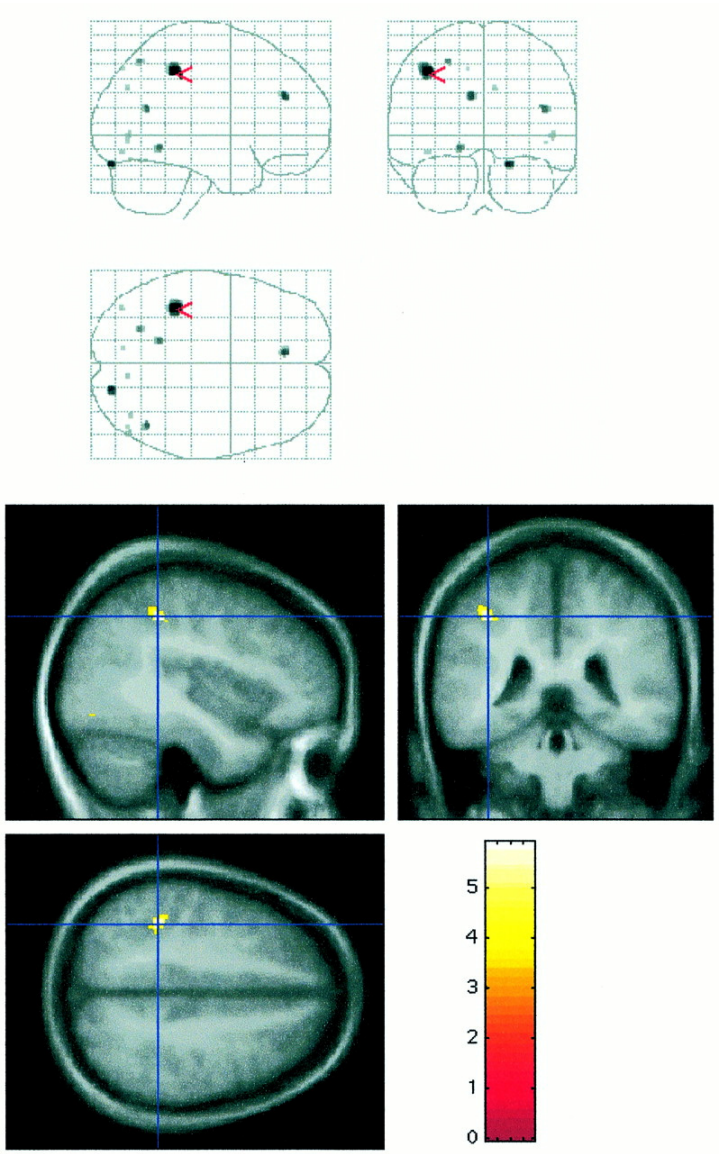
Reduced grey matter in VLBW adolescents poor on simple number tests



From Isaacs et al, *Brain,* 2001

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Tests of basic numerical capacities: the idea of numerosity

Capacity	Tests
Numerosity as a property of sets	Enumeration (counting), conservation, matching
Estimated numerosities	Estimation
Sense of ordered numerosities (magnitudes)	Number comparison
Acquiring cultural tools for numbers	Counting

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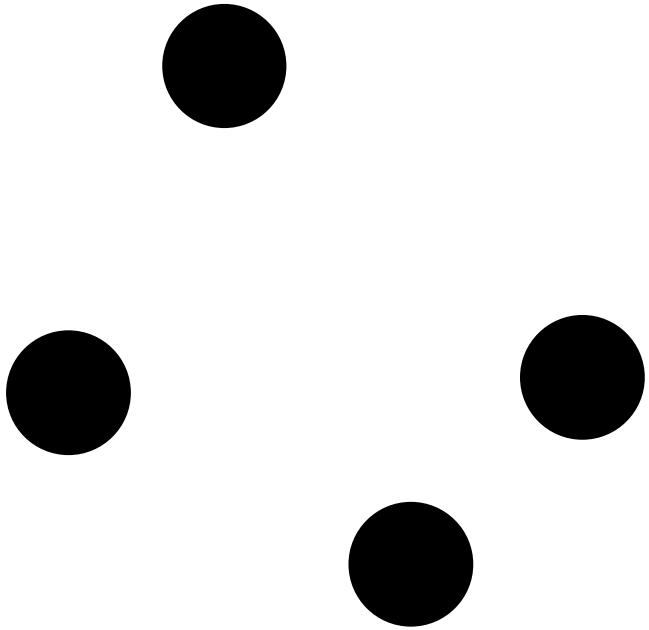

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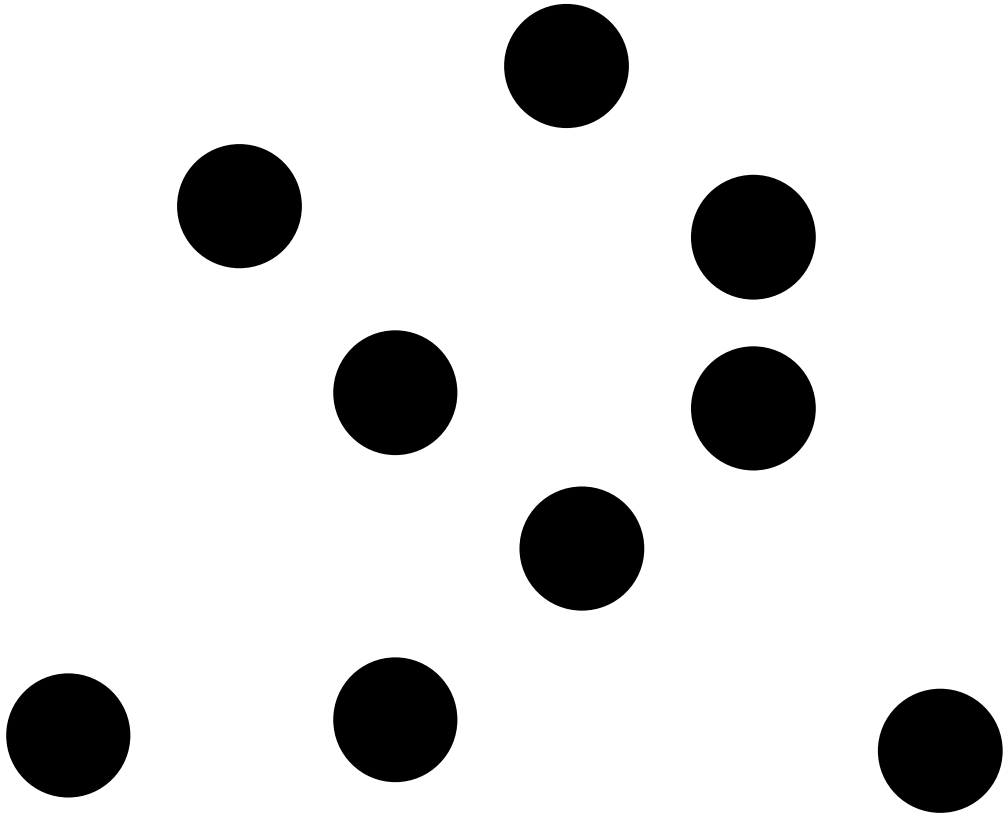

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6 5

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2 9

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8 7

Stroop conditions

	Congruent	Incongruent	Neutral
Numerical task	3 6	3 6	3 6
Physical task	3 6	3 6	3 3

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Case CW ("Charles")

- CW
  - 30 yr old RH male. No clinical history
  - Degree in psychology; postgraduate qualifications
  - always very bad at maths at school; finds shopping extraordinarily difficult.
  - Takes 4-5 times as long as normals adding single digits; cannot subtract two digit numbers.
  - Always calculates on his fingers (which makes multiplication hard).
  - Compensated dyslexic

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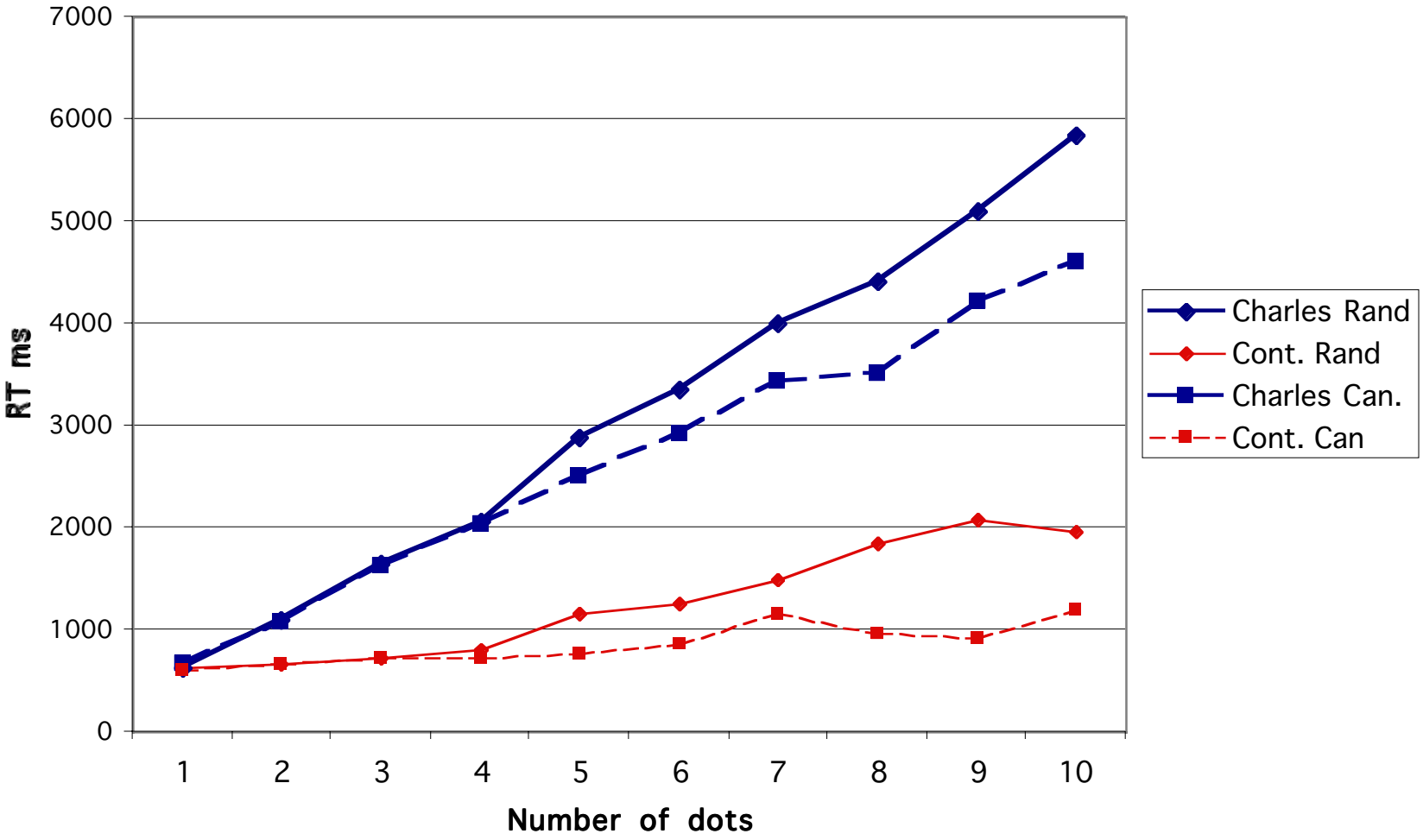
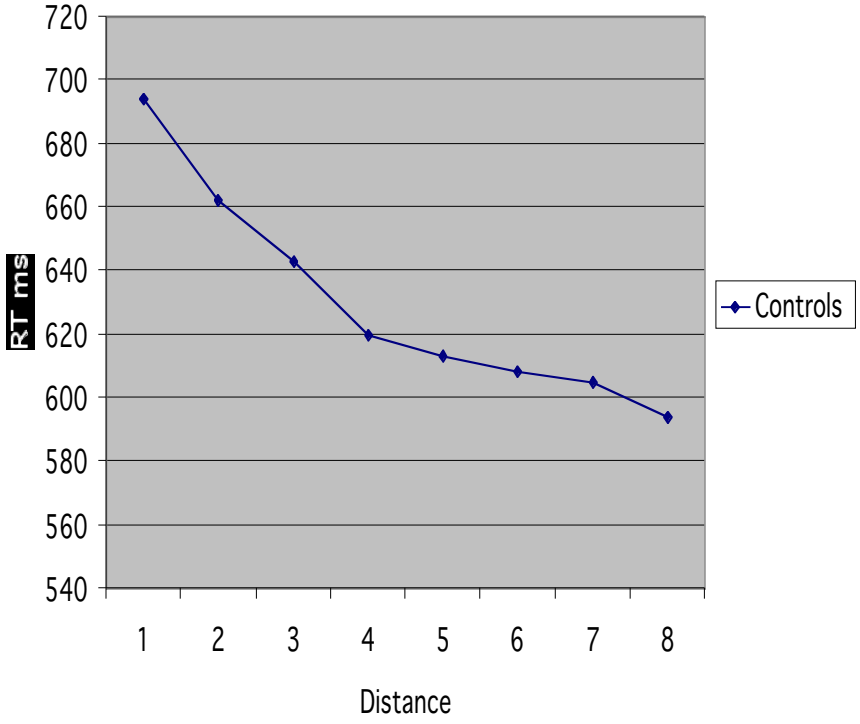
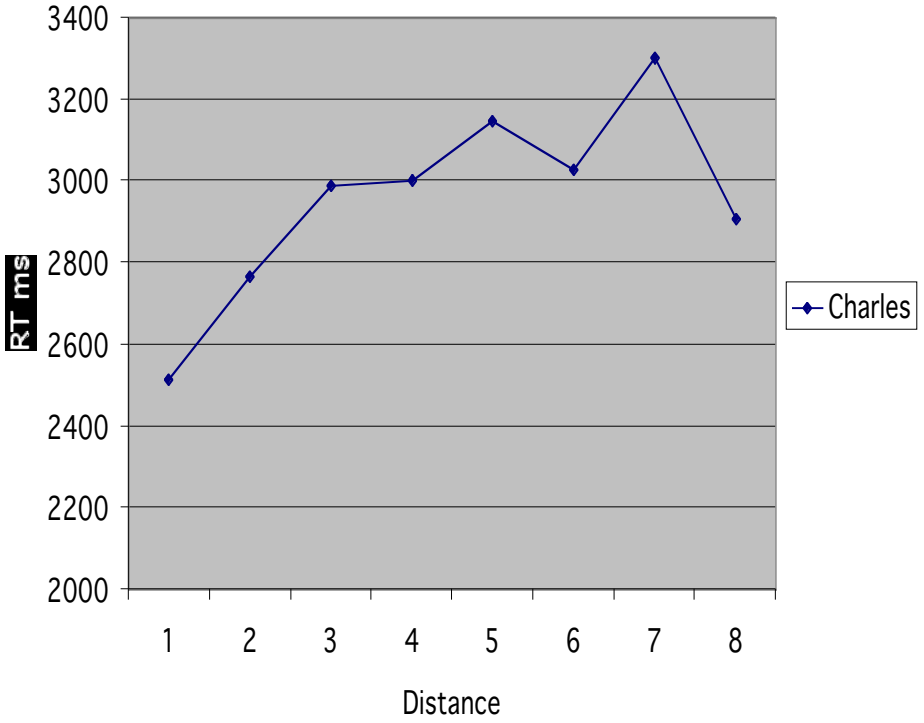
Charles vs controls: dot enumeration

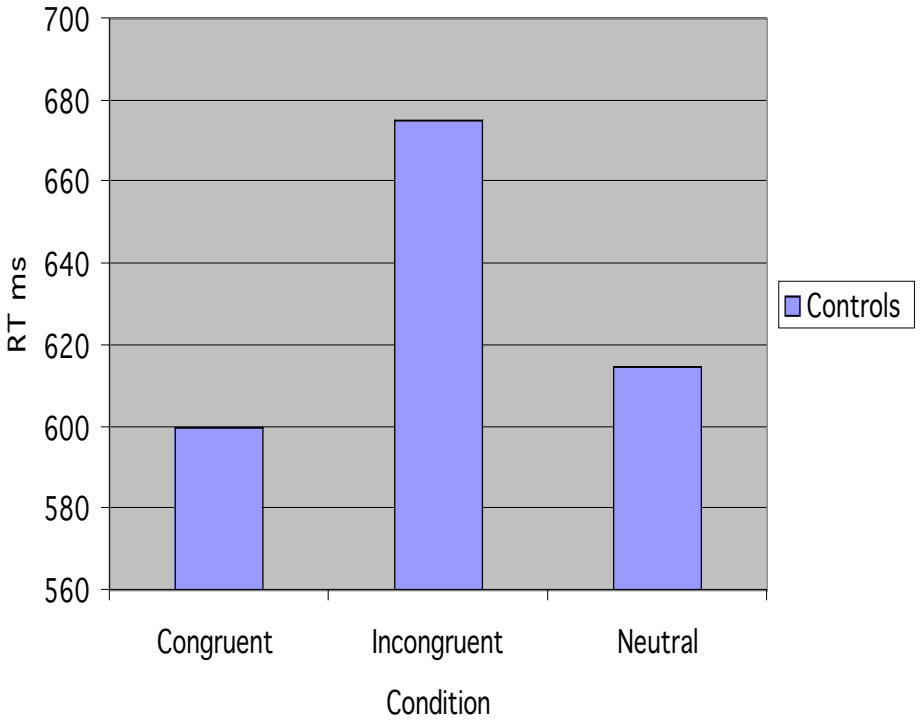


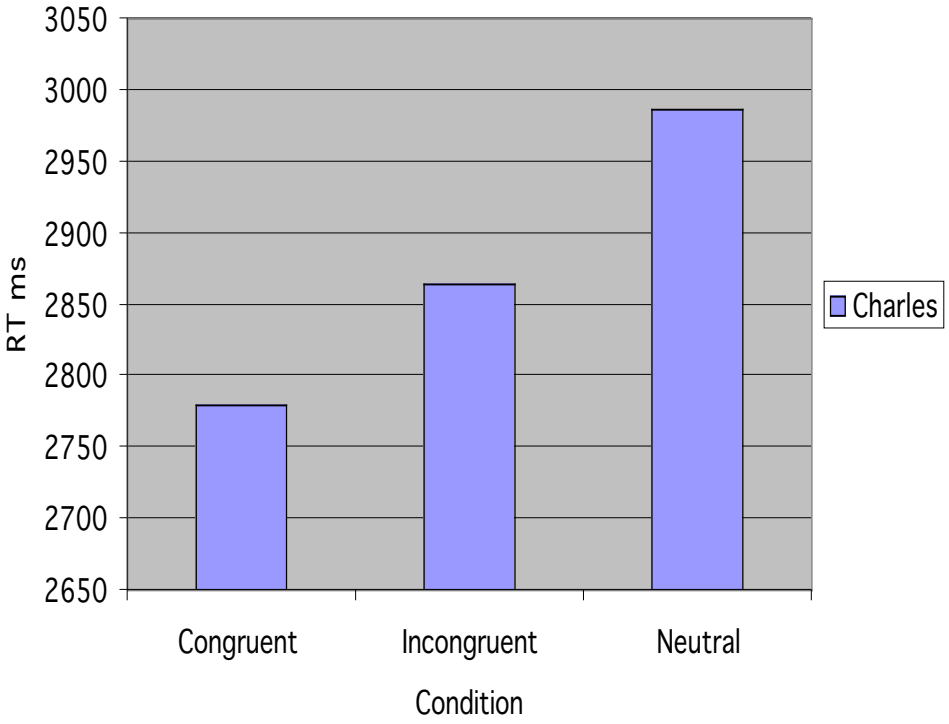
Charles vs controls: number comparison





Number stroop. Charles vs controls





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Case JB

- 9;7 year old, RH male. Normal in all school subjects except maths, which he finds impossible. Not dyslexic. Counts up 20 slowly. Can read and write numbers up to 3 digits.
- Failed SBAS arithmetic questions
- Knows that 4 is the next number after 3.
- Believes that 3+1 is 5
- Dot enumeration: 1-3 accurate. Guesses larger numbers
- Cannot do the number comparison task
- Cannot do the number Stroop task
- Approximate magnitudes

Line 1-10			Line 1-100			Line 1-250	
2	9	7	25	57	83	72	215
1.9	**4.4**	7.1	**92.3**	54.4	**71.8**	**179.5**	215.4

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DfES study: questions

- MD (Maths Disabled) a matter of low IQ?
  - Control for IQ
- MD due to poor STM?
  - Span tests
- MD due to poor language abilities?
  - Naming and reciting tests
- MD a consequence of slow reading?
  - Control for reading
- MD a consequence of RD (reading disability - dyslexia)?
  - MD pattern different when a consequence of RD
- MD due to a deficit in basic numerical abilities?
  - Tests of enumeration and number comparison

(Butterworth, Bevan & Landerl, in prep)

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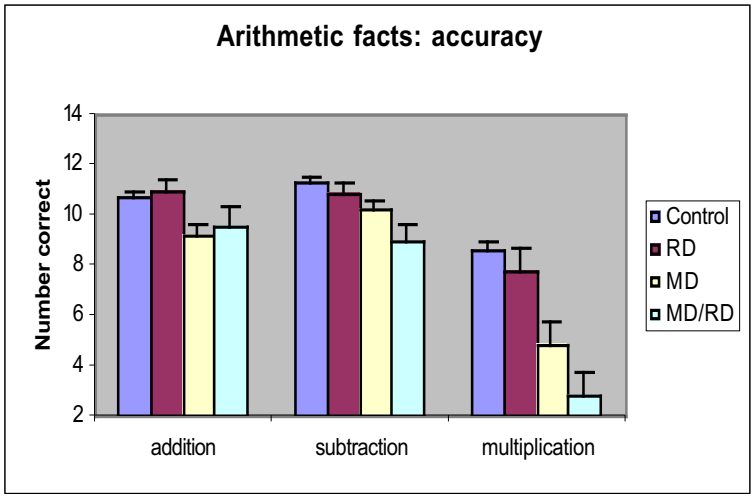
DfES study: participants

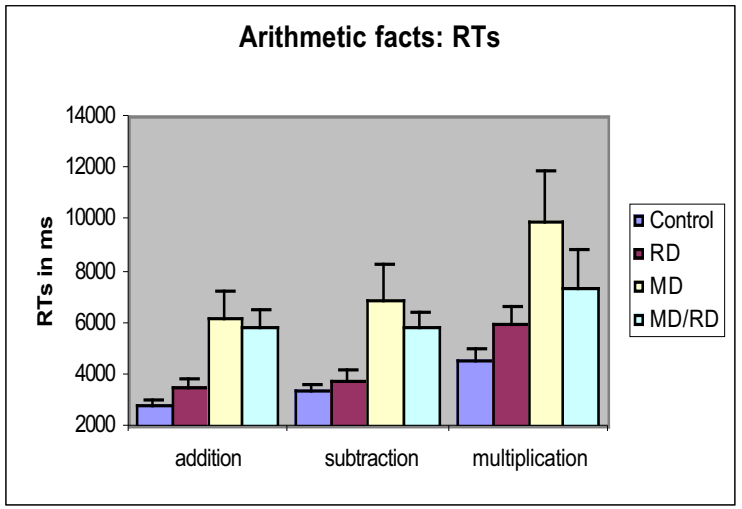
	Control[2] N=18	RD[1] N=10	MD[1] N=10	MD/RD[1] N=11
Age in mths	108.7	110.1	103.7	103.9
IQ (percentile)	50th - 75th	75th	75th – 90th	75th
BAS reading RA-CA in mths	-0.94	-19.90	-6.30	-19.73
BAS numeracy NA-CA in mths	5.72	0.90	-8.20	-7.18
Digit span standard score	10.24	8.60	10.80	8.22
Mazes standard score	9.88	10.60	12.10	10.11

1.Identified by teacher as MD or RD; PLUS MD children: 3sd below age equivalent on timed arithmetic, and above 25 percentile on BAS word-reading; RD below 25 percentile on BAS word-reading., and within -1sd/+2sd on timed arithmetic. All children 25-90 percentile on Coloured Progressive Matrices (IQ).
2. Controls identified by teachers as 'average', PLUS matched overall for reading and maths; RA-CA<12 mths. Equivalent numbers of boys and girls.

MD not due to low IQ or poor STM

Item-timed arithmetic

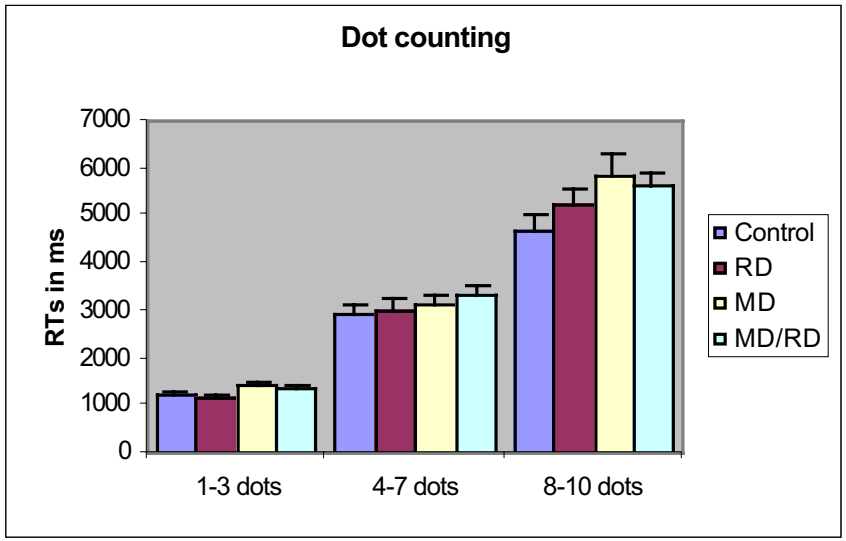


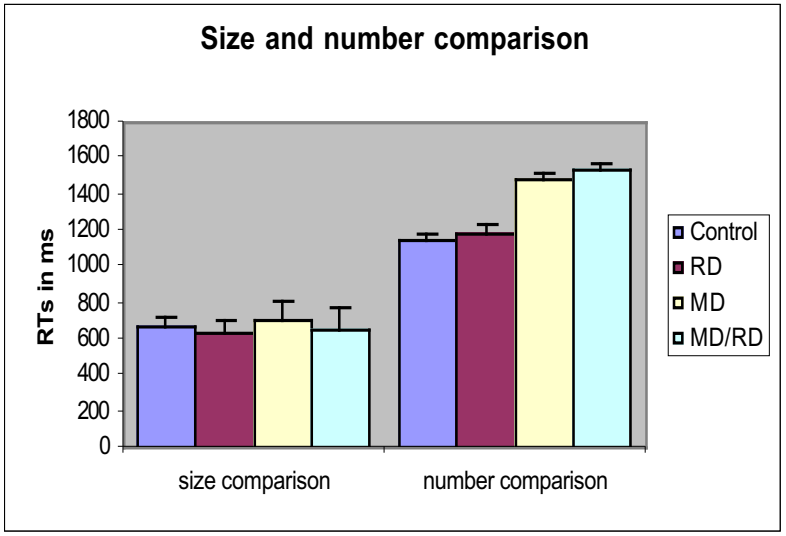


Control = RD < MD and MD/RD

Control = RD < MD and MD/RD

Performance on tests of basic numerical capacities



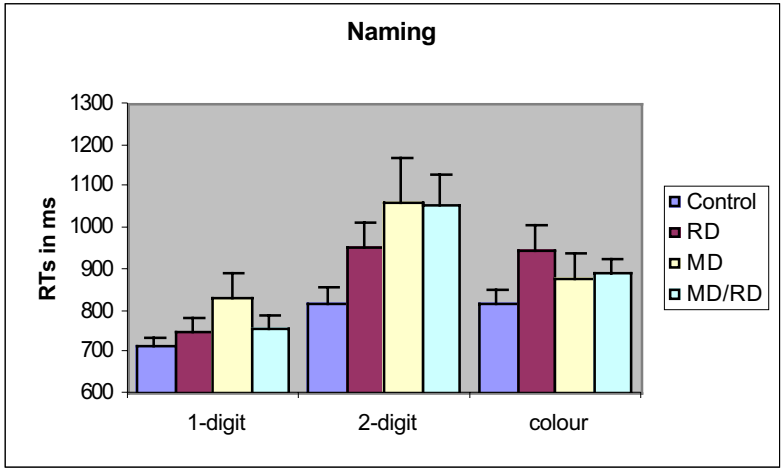


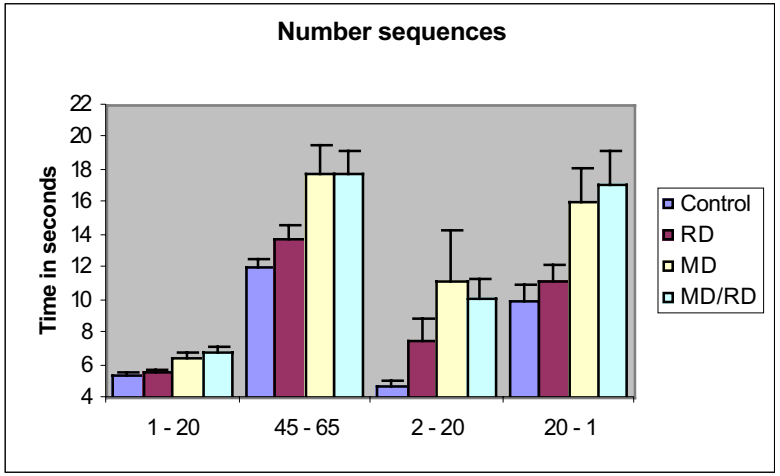
8-10: Control = RD < MD and MD/RD

Number comparison:
Control = RD < MD and MD/RD
Size comparison n.d.

MD and RD/MD worse on basic numerical abilities

Language abilities performance





Control = RD < MD and MD/RD

Control = RD < MD and MD/RD

Language difficulties not a sufficient explanation

DfES study: answers

- MD (Maths Disabled) a matter of low IQ?
  - No, because groups equated for IQ
- MD due to poor STM?
  - No, because MD = Controls (RD worse than Controls)
- MD due to poor language abilities?
  - No, because same colour naming latency
- MD a consequence of slow reading?
  - RD normal on maths tests accuracy and RT
- MD a consequence of RD (reading disability - dyslexia)?
  - No, because MD pattern same as MD/RD
- MD due to a deficit in basic numerical abilities?
  - Yes, MD and MD/RD worse on enumeration and number comparison

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Dyscalculia Screener

A distillation of our previous research

- Three tests
  - Number Stroop
  - Dot counting
  - Item-timed arithmetic
  - (Simple reaction time)
- Software for your PC
- Results given as standard scores and automatically calculated by computer in a printable form
- Critical Diagnoses:
  - Lowest 10% on all tests: dyscalculic (an empirical cut-off)
  - Low performance on arithmetic but not on the other tests: poor learning/teaching

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Standardization methods

- Population: 546 children, representative sampling, 6-14 yrs
- Performance: efficiency measure
  - Median adjusted RT / %correct
  - Converted to age-based standard scores
    - Mean =100 SD = 15

- Standardization by Nick Nelson and Cres Fernandes for NFER-Nelson

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Implications for practice: Diagnosis

- All children at risk should be diagnosed
  - *"Bored… stupid … bored"*
  - *"I would cry and I wish I was at home with my mum and it would be…I won't have to do any maths and come out…come back when it was the end of maths"*
- Recognition of dyscalculia diagnosis
  - By schools, by LEAs, by DfES

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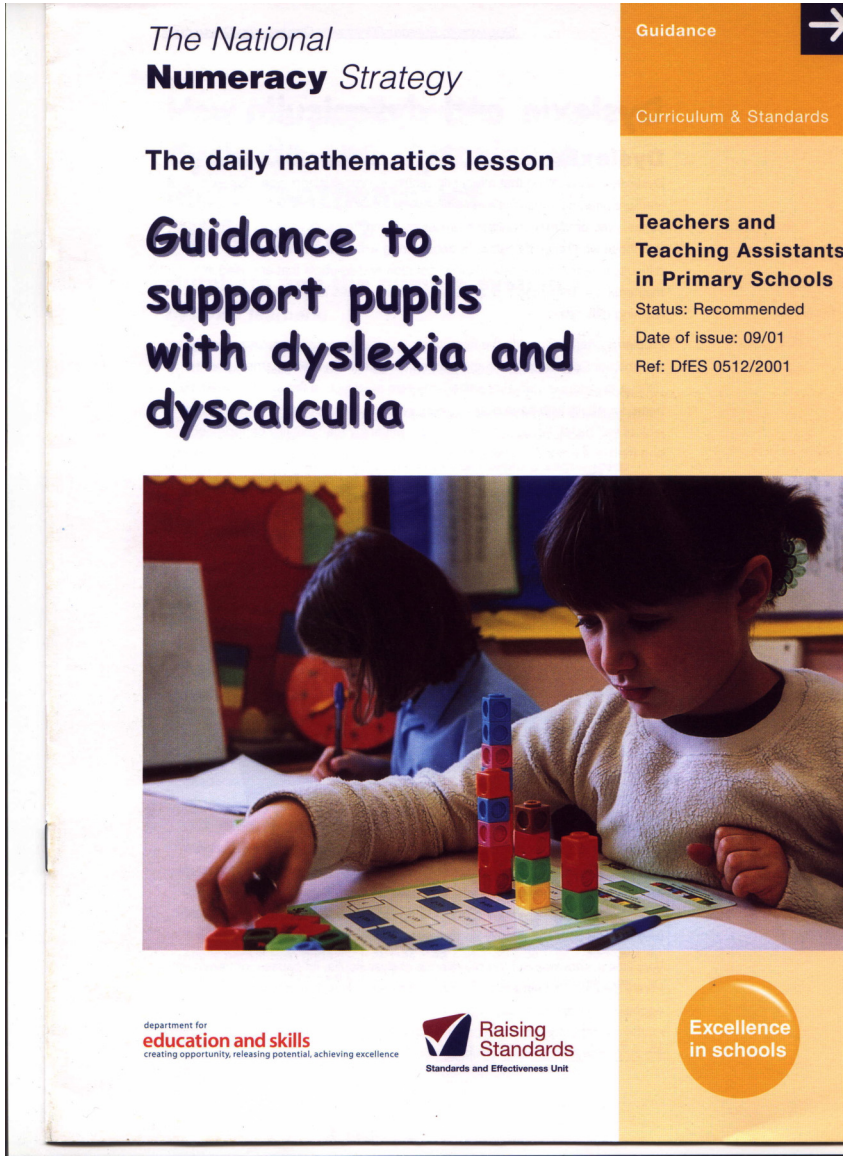

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Implications for practice: Support

- Remove MD children from the Numeracy Hour so they can learn separately
  - They won't get humiliated
    - *I would cry and I wish I was at home with my mum and it would be...I won't have to do anymaths and come out...come back when it was the end of maths*
  - Or spend their time on avoidance activities like sharpening pencils, going to the toilet, looking for rubbers, all of which interferes with other learners
    - *..when they're in the introduction for maths they're not - they're just sitting there basically*.
  - High ability children get bored at the teachers repeating material they understand
  - Teachers have an impossible job
    - *In a class of thirty I've got six. You've got a lot of problems. And when I'm on my own, I don't - I feel very guilty that I'm not giving them the attention they need*
    - ... hard *it's like being stretched between the two really, if I could just focus on them that would be fine. And if I could focus on the others that would be fine as well, but trying to split - be split between the two is quite hard*
- Provide Additional Numeracy Support staff
  - To help the children outside the Numeracy Hour
    - *the gap will get bigger and bigger unless they give them a chance to catch up, and there's not - So I think for them, I would prefer them not to have the Numeracy Hour, but just to focus on those basic skills*.

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Implications for practice: Intervention

- Develop methods for helping MD children grasp basic number concepts
  - Estimation, matching and manipulating sets and numerosities, recognising numerosities
  - No point in rote learning of number bonds or tables if the child doesn't understand basic number concepts
- E-learning
  - Children like computer games
  - But all games need to be evaluated
  - DfES has new e-learning Strategy Unit

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