Dyscalculia Screener

by **Brian Butterworth**

Highlighting pupils with specific learning difficulties in maths

Age 6–14 years

BETT AWARDS 2004 WINNER

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Brian Butterworth

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What is dyscalculia?

1

Dyscalculia is sometimes called number blindness. It is the name given to the condition that affects our ability to acquire arithmetical skills.

Mathematics is a complex subject, involving language, space and quantity. Much research into the development of mathematical skills has focused upon counting or arithmetic, but even at early levels many complex abilities are involved in these skills, including:

- understanding number words (*one, two, … twelve, … twenty, …*), numerals (*1, 2, … 12, … 20, …*) and the relations between them;
- being able to carry out mental arithmetic using the four basic arithmetical operations – addition, subtraction, multiplication and division;
- being able to carry out written multi-digit arithmetic using the four basic operations;
- being able to solve 'missing operand problems' ($? + 4 = 6$);
- being able to solve 'word problems' which set arithmetical problems in realistic contexts, particularly using money and change.

The complexity of numerical processing has made defining what it means to have a specific mathematical learning disability (dyscalculia) difficult. Traditional definitions state that the pupil must substantially underachieve on a standardised test relative to the level expected given age, education and intelligence, and must experience disruption to academic achievement or daily living. Standardised achievement tests, however, generally test a range of skills, which may include spatial and verbal abilities, before collapsing the total into one global score of 'mathematics achievement'. In addition standardised tests are diverse, so what is meant by 'mathematics achievement' may vary substantially between tests. For this reason it has been hard for researchers to pinpoint the key deficits in dyscalculia, or to be sure how to define dyscalculics for study.

A range of terms for referring to developmental mathematics disability has emerged, including:

- 'developmental dyscalculia' or 'DC' (Shalev and Gross-Tsur, 1993; Temple, 1997);
- 'mathematical disability' (Geary, 1993);
- 'arithmetic learning disability': AD, ARITHD, or ALD (Geary and Hoard, 2001; Koontz and Berch, 1996; Shafrir and Siegel, 1994; Siegel and Ryan, 1989);
- 'number fact disorder' or NF (Temple and Sherwood, 2002);
- 'psychological difficulties in mathematics' (Allardice and Ginsburg, 1983).

As Geary (1993) and Geary and Hoard (2001) remark, these different classifications seem in most cases to describe the same condition. The term 'dyscalculia' will be used in this manual, but is intended to refer to all these groups.

The *Diagnostic and Statistical Manual of Mental Disorders*, fourth edition (*DSM-IV*), which is the standard US psychiatric handbook, gives the following diagnostic criteria for 'Mathematics Disorder':

> *Mathematical ability, as measured by individually administered standardised tests, is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education, which significantly interferes with academic achievement or activities of daily living that require mathematical ability.*
> (American Psychiatric Association, 1994, Section 315.1).

Since there are, as has been said, many reasons for being better or worse than your age group in mathematics (for example, if you had an exceptionally good or an exceptionally bad teacher), then these criteria are not going to pick out reliably the pupil (or adult) with a deficit in the capacity to learn maths.

A more helpful definition is given by the Department for Education and Skills (DfES, 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.*

Even this definition, though, does not explain why there should be a selective deficit of arithmetical abilities.

Definition of dyscalculia specific to this screener

This screener takes the more specific approach that dyscalculia is 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. Understanding numerosity means (Butterworth, 1999):

- understanding that collections of things have a numerosity and that some manipulations of these sets affect the numerosity – combining collections, taking subcollections away, and so on – and that one collection has the same numerosity as another, or a greater numerosity, or a smaller numerosity;
- understanding that the collections need not be of visible things; they can equally be audible things, tactile things, abstract things (like wishes);
- recognising small numerosities – collections of up to about four objects.

It is known that infants, probably from the first week of life, recognise when displays have the same numerosity – up to about four objects – and can detect a change of numerosity. As early as six months, they have arithmetical expectations about the effects on numerosity of adding an object to a collection or subtracting one from it. Infants also know which of two sets is numerically larger (Wynn, 1992). Similar capacities have been found in apes, monkeys and birds (Boysen, 1993; Boysen and Capaldi, 1993; Brannon and Terrace, 1998, 2000; Hauser, MacNeilage and Ware, 1996; Pepperberg, 1987; Washburn and Rumbaugh, 1991). This suggests that the understanding of numerosity is innate.

Numerosity concepts underlie arithmetic. Addition is usually understood as the change in numerosity resulting from combining collections; subtraction can be understood as removing a subcollection from a collection; and so on. The speed of retrieving addition facts (such as $5+3=8$) or multiplication facts (such as $5\times3=15$) is determined by the numerosity of the sum or product with larger sums and products taking longer. This suggests that arithmetical facts in memory are organised in terms of numerosity (Butterworth, Girelli, Zorzi, and Jonckheere, 2000).

Appendix 1 (p41) summarises the research that has led to this conclusion. It points to the existence of a 'number module' based in the parietal lobe of the brain (Butterworth, 1999) specialised for dealing with numerical representations. We propose that the underlying cause of dyscalculia is likely to be related to the dysfunction of this system.

This argument is not to suggest that verbal or memory abilities are not involved in numerical processing, particularly at higher levels; for example, language is necessary for counting. However, general problems with language or with memory might be expected to have a relatively broad impact on academic skills. Not only are maths disabilities specific to numbers, but within this specificity is a broad range of deficits. The evidence described above suggests that dyscalculic pupils may have problems with digit span, memory for number facts, speed of processing of numbers, counting, representing single-digit numbers, number matching, and executing calculation procedures. Conversely, there currently seems to be little reason to believe that they have problems with non-numerical tasks involving verbal or memory abilities. It is proposed here that the effects of this disability is best understood in terms of a specific *numerical* processing deficit.

Experiences of dyscalculia

Dyscalculic pupils themselves recognise that they fail to understand the basic concepts of number. Even the idea of numerosity is difficult for some pupils to grasp. Often, they fail to recognise small numerosities, and feel the need to count out sets as collections of two, three or four objects.

In focus groups, nine-year-old pupils repeatedly said that they didn't understand the concepts the teachers were presenting (quotes below are from Bevan and Butterworth, forthcoming):

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

One dyscalculic pupil, 'Josh' (not his real name), is an intelligent well-behaved boy, a good reader who does well at most school subjects. Even at nine he was unable to solve four plus one, even though he knew that four was the next number after three. He could recite the numbers up to 20 without difficulty, though he was abnormally slow at counting dots in array. Josh had a sense of the number sequence, but failed to understand the magnitude of numbers. That is, he was unable to grasp the numerosity of collections of objects. His problems with number magnitudes were clearly revealed when he was asked to select the larger of two numbers. This he found almost impossible.

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

In interviews, teachers stressed that the key problem was in understanding basic number concepts.

> *... when they're in the introduction for maths they're just sitting there basically.*
>
> *... for a pupil who hasn't got the basics, you almost feel like that instead of doing fractions and decimals, they just need to sit and be able to work out the value of numbers …*

There are also severe emotional side effects to dyscalculia. This is what some of the pupils said to us:

> *… 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.*

Diagnosing dyscalculia – why this screener is needed

2

If we accept the idea that dyscalculia is a specific disorder, it follows that a specific screener is needed, rather than more general tests of mathematical abilities.

The best available estimates put the prevalence of dyscalculia (as defined in *DSM-IV*, Section 315.1) at somewhere between 3.4 per cent and 10 per cent (Lewis, Hitch and Walker, 1994; Ostad, 1998).

This means that between 2 million and 5.8 million people in the UK suffer from a problem that interferes with daily living and academic achievement.

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 standardised maths test.

Here is an example of the kind of test item currently used, based on *WISC-III*^{UK} (Wechsler, 1992):

> *If you buy 3 dozen pencils at 30 pence a dozen, how much change should you get back from £1?*

A nine-year-old pupil is allowed 45 seconds to solve this. The problem with this approach is that there are many reasons for being bad at school-type arithmetic. Inappropriate teaching, behavioural and health problems may affect particularly those curriculum areas where each concept is built on the one before (mathematics being a prime 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 pupils who solve the problem confidently in two seconds, from those who take the whole 45 seconds to solve it on their fingers. So we may diagnose as dyscalculic many pupils who are bad at mathematics for other reasons, and miss many dyscalculic pupils who manage to scrape by through dogged determination using strategies inappropriate for their age.

Other widely-used assessments, such as *BAS II* (Elliot, Smith and McCulloch 1997), also rely solely on tests of arithmetical attainment. These include the kinds of arithmetical problems taught and practised in schools, such as multi-digit addition, long multiplication, fractions and decimals. These standardised tests satisfy the *DSM-IV* criteria, but while dyscalculic pupils will perform poorly on these tasks, many other pupils will also manifest poor attainment. (Of course it is important to remember that these types of test are valid for overall achievement – they are simply not designed to specifically diagnose dyscalculia.)

Good numeracy skills are important for being an effective member of a modern numerate society. Bad numeracy skills are known to be even more of a handicap than poor literacy skills to getting a job, keeping a job and being promoted within employment (Bynner and Parsons, 1997).

There are contributing factors to good numeracy attainment – a well-structured curriculum, good teaching matched to the pupil's current level of understanding, an attentive pupil, and so on. Similarly, there will be many reasons for failing to acquire good numeracy skills, just as there are many reasons for low levels of attainment in other school subjects. These include the attitude of the pupil, inappropriate teaching methods, time off school, and so on. In fact, learning arithmetic seems to be more sensitive to these disruptive factors than other subjects.

However, there seems to be a group of pupils (and indeed adults) whose poor attainment in arithmetic cannot be ascribed to these problems. They seem to have been born with a deficit that makes acquiring numeracy skills particularly difficult. These pupils are sometimes called 'dyscalculic'. Unfortunately, dyscalculia is not nearly as widely recognised as its literacy counterpart, dyslexia. As with dyslexia 20 years ago, poor performance is taken as a sign of low general cognitive ability. This has been one of the problems in getting recognition for this condition. Another is that poor mathematics attainment frequently co-occurs with dyslexia, and is widely thought to be another symptom of that condition. In interviews that we conducted, many teachers claim that a pupil must be bad at mathematics because he or she is dyslexic; conversely, because a pupil has great difficulty learning simple arithmetic, many teachers assume that the pupil must be dyslexic, or more often, must be of low cognitive ability (Bevan and Butterworth, forthcoming).

It has been known for more than a decade that arithmetical learning difficulties often co-occur not only with dyslexia, but also with other problems. For example, something like 40 per cent of dyslexics have maths problems; attention deficit hyperactivity disorder (ADHD), autism, dyspraxia, and specific language impairment also appear to show a higher incidence than normal of arithmetical learning difficulties, though incidence statistics are not available. Since these problems are better known than dyscalculia, there will be a temptation to expect any pupil with dyslexia, dyspraxia, ADHD, or autism also to be poor at arithmetic. However, the unusually high proportion of dyscalculics with dyslexia or these other conditions still leaves the majority of sufferers with no problems with mathematics, and indeed some may be exceptionally good at mathematics.

As mentioned in Chapter 1, however, the DfES does now acknowledge the existence of dyscalculia as a special problem (DfES, 2001).

One of the main problems with gaining recognition for dyscalculia is that there has been no simple test for identifying dyscalculia. We have therefore developed the *Dyscalculia Screener*, which aims to provide a quick and reliable way of identifying dyscalculia, and to separate it from the other causes of poor numeracy attainment. This new approach involves using item-timed tests of the capacity for numerosity. The approach minimises 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, for example, the finger counters from the fluent performers.

How the *Dyscalculia Screener* works

3

How the screener was developed

The idea behind the *Dyscalculia Screener* is that pupils are normally born with specific capacities for simple numerical tasks. In particular, they are born with an understanding of 'numerosity' – that a set of things has a number – and will quickly develop a sense of particular small numerosities and also an understanding that numerosities are ordered by size – four is bigger than three, for example. These capacities will not depend on the learning experience of the pupil, but both capacities will support learning the basic numerical skills of counting and understanding the numerals – 1, 2, 3, 4, 5, 6, 7, 8, 9. There has been much recent evidence in support of the role of these specific capacities in learning arithmetic.

We took this idea as the starting point for developing a test of basic numerical capacities. In research studies, we have evaluated a variety of ways of testing the understanding of numerosities across a range of age groups from six-year-old pupils to adults. We have also carried out detailed case studies of individual pupils and adults with maths learning difficulties, and we have found that those with limited capacities as measured by performance on tasks of number comparison and dot counting almost invariably have had profound difficulties at school in learning mathematics.

We tested these hypotheses in a detailed study of eight-year-old pupils in one Local Education Authority, funded by the DfES (Butterworth, Bevan and Landerl, forthcoming). Our results confirm that pupils who are slow for their age at basic numerosity tasks are those who show the lowest levels of arithmetical attainment and are also those most unhappy in the Numeracy Hour.

For the *Dyscalculia Screener*, we have selected the tests that have been most effective in discriminating dyscalculics from other pupils.

These involve comparing numbers and counting dots. In our research study, we asked pupils to name the number of dots and name the larger number. Since the critical element of these tests was the time taken to respond accurately, the research study required a microphone, a voice key connected to the computer, a quiet room, and for the experimenter to note down the pupil's response for subsequent analysis. We felt that this would be difficult and time-consuming for a screener.

Instead, we opted for a test where the pupil simply has to press a button or a touch-screen connected to the computer, which can then record the response and time taken accurately, and could even analyse the results while you wait. To test this version, we created tests of number comparison, dot counting and simple arithmetic that could be self-administered provided one could read the instructions. We installed this in a science museum in Bristol, and, to date, over 15,000 people of all ages have done this test. Each participant is told where his or her results fit into the pattern for age and sex. It was very encouraging to see that the patterns of results obtained in our careful research studies were replicated in the Bristol experiment.

The *Dyscalculia Screener* builds on the Bristol experience. It uses button-press responses, which are automatically analysed by the computer. The screener is an easy-to-use test of a pupil's capacity for simple arithmetic. It focuses on whether the pupil understands the concept of numerosity, and whether the pupil is able to identify and use small numerosities. These capacities are the basis of all subsequent arithmetic.

We do not expect this test to identify pupils who will be excellent mathematicians. Insofar as we know what it takes to be an excellent mathematician, it is likely to be factors that are known to produce excellence in other fields of endeavour, such as music. These will include the quality of teaching, the enthusiasm of the pupil, and willingness to work hard over several years (Butterworth, 1999).

The *Dyscalculia Screener* will not identify capacities for other branches of mathematics that are not so dependent on numerosities, and therefore cannot be used to predict a pupil's attainments on, for example, geometry, algebra, or topology, or whether the pupil can follow procedures for using a calculator or a computer to carry out data analysis and statistical tests.

The screener comprises three computer-controlled, item-timed tests. Since speed of response to numerical questions is the measure used in the *Dyscalculia Screener*, we also take into account whether a person responds slowly to these questions, or is simply a slow responder. We do this by including a fourth test of Simple Reaction Time. The computer programme will adjust the pupil's reaction times as a function of the Simple Reaction Time, therefore this is the first test the pupils see.

1. Simple Reaction Time

Tests of Capacity:

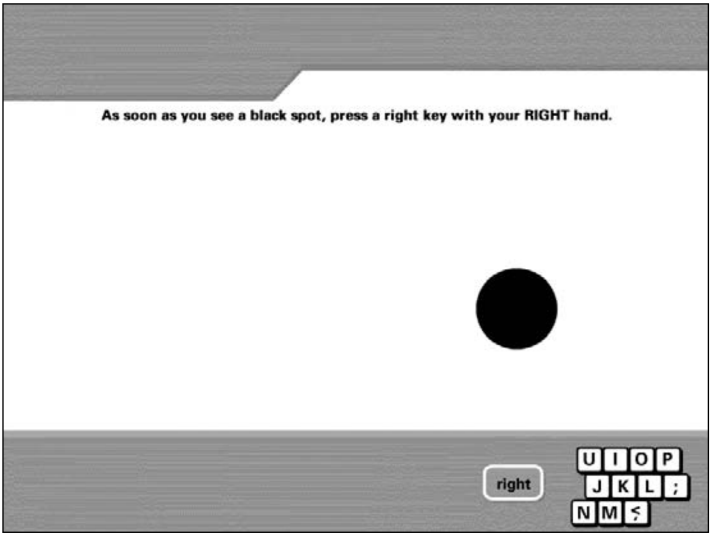
2. Dot Enumeration
3. Number Comparison (also referred to as Numerical Stroop)

Test of Achievement:

4. Arithmetic Achievement test (addition and multiplication)

Individual subtests: rationale/virtues

Simple Reaction Time

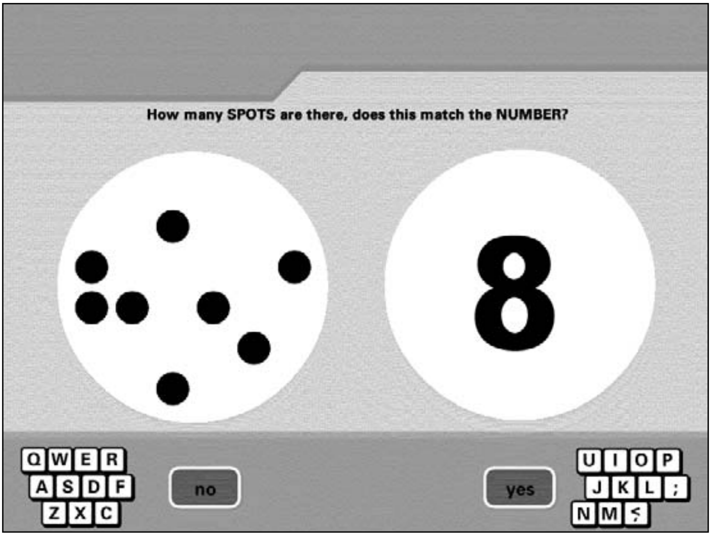


We recognise that some pupils will be relatively slow at pressing buttons in response to any stimulus. Our Simple Reaction Time test is designed to evaluate this. The scores on this test do not form a separate element in the report on the pupil. Instead, the reaction times on the following three tests are adjusted to take this measure into account.

Dot Enumeration

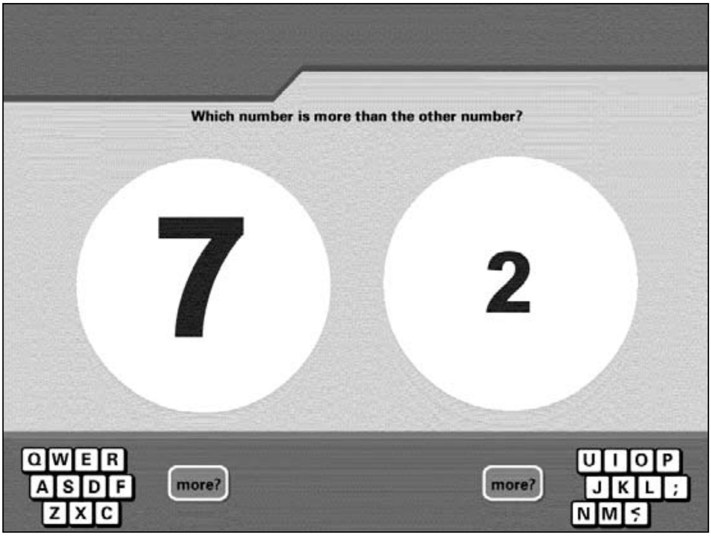
In this task, we ask the pupil to compare the number of dots on half of the screen with the numeral on the other half of the screen, and to press a key according to whether the two numbers match.

The pupil has to judge the number of dots in a visual array of up to nine dots. To do this, the pupil will need the capacity for enumerating the set of dots, either by seeing immediately that there are one, two, three or four dots in the set without needing to count them (this is called 'subitising'), or by counting the larger sets of dots. The capacity for estimating small numbers is critical in learning to count, since it enables the learner to check the outcome of the count (Fuson, 1988). It is thought that this capacity is innate, and a deficit could contribute to dyscalculia.



The pupil will also have needed to learn the meaning of the numerals 1 to 9; that is, they will need to know what numerosity each numeral denotes. We ask the pupil to do this task as quickly as possible and record reaction time, to the millisecond, for each array of dots presented. Accurate timing is important. This is a very easy task, and we expect all the pupils to get most of the answers right. This means that accuracy, the normal measure of performance on standardised mathematics tests, will not discriminate the pupils who have difficulties learning from those that do not. Reaction times will, however, separate those pupils who have had problems learning to count because of a deficient capacity for identifying numerosities. There is extensive research relating the time taken to enumerate collections of dots to numerosity capability.

Number Comparison (Numerical Stroop)

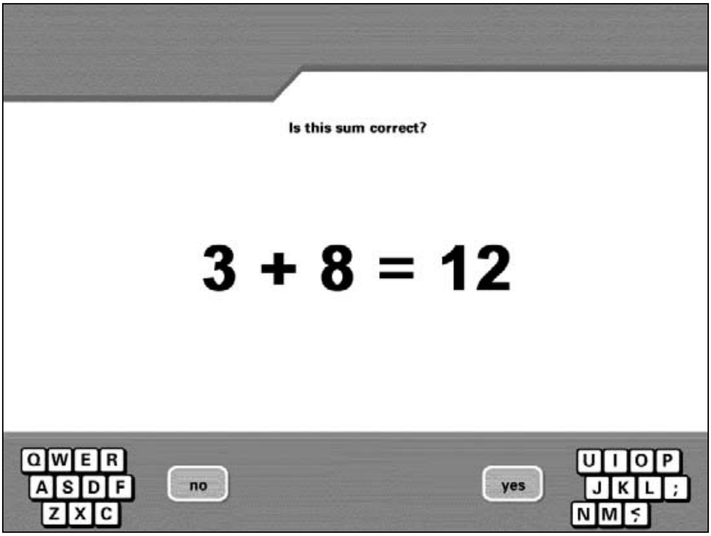


The next basic task asks the pupil to select the larger of two numbers. This is a test of the capacity to order numerosities by their size. The task also requires a fluent understanding of the numerals. Pupils with deficits in the capacity to recognise and understand numerosities may have failed to form efficient connections between numerals and their meanings. Being able to order numerosities by magnitude is a key to understanding numbers. Again, this capacity is thought to be innate, so a deficit could contribute to dyscalculia.

As with Dot Enumeration, this is a very easy task, and we would expect most pupils to get all or almost all the questions right, so that accuracy alone will not discriminate dyscalculic pupils from the others. There is extensive research on the time taken to make the decision. Our research shows that pupils (and adults) who are slow at the task are likely to be dyscalculic.

There is a useful variation in the Number Comparison tasks which exploits the fact that the physical size of the numerals – how tall they are – can also be varied. We know that when the taller number is numerically smaller – e.g. 5 3 – then skilled adults show a slowed time to select the larger, relative to when the two numbers are the same height. This is called the incongruity effect, or interference, because the physical dimension interferes with the numerical judgment. Conversely, when the taller number is numerically larger – 5 3 – decision times are faster than when the two numbers are the same height. This is called the congruity effect, or facilitation, because the physical dimensions facilitate the numerical decision. These effects are called 'Stroop' effects after the scientist who first discovered that task-irrelevant features (in this case the height of the numerals) can influence task performance (Girelli, Lucangeli and Butterworth, 2000).

Arithmetic Achievement test (addition and multiplication)



For younger pupils, this task consists only of addition; for older pupils there is also multiplication. If a pupil is aged 10 or over then he or she will see the multiplication subtest. The problems are presented on the screen with an answer – e.g. 3+5=8. The pupil has to judge as quickly as possible whether 8 is the correct answer. Most pupils will get the majority of these answers correct. Again the critical factor is how long they need for each problem. There is an important difference between the pupil who has already learned that 3+5=8 and can retrieve this fact from memory, as compared with a pupil who still has to calculate the answer using fingers, for example. Reaction times enable us to distinguish the first type of pupil from the second.

The results are given as standard scores, which are further explained in Chapter 5. These scores are automatically calculated and displayed by computer in a printable form.

The standardisation sample comprised a stratified random sample of 549 pupils (see Appendix 2). On the basis of the standardisation study, if a pupil performs low on the two capacity tests, he or she is classified as showing dyscalculic tendencies. Where there is low performance on the achievement test but *not* on the capacity tests, we can now attribute this to poor learning or teaching. Because the test is item-timed, it will identify those pupils who, despite an average number of answers correct, solve the problems in an abnormally slow manner.

These tests have to be taken together. If the pupil performs low on all the tests, this is a cause for concern. However, often a pupil will not be attending equally to all the tests; therefore, poor performance on only one of the tests should not be considered diagnostic of dyscalculia; see Chapter 5 for more detail.

Unlike other tests, the *Dyscalculia Screener* is focused on diagnosing dyscalculic tendencies, and is not a general test of mathematical achievement. 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.

Using the *Dyscalculia Screener* 4

When and why to use

The *Dyscalculia Screener* can be used with any pupil or group of pupils aged from 6 to 14 years. However, pupils in their first year of school show much greater variability than older pupils. It will be more reliable for pupils aged seven years and above.

The test can be used to screen a whole group of pupils to assess the number with dyscalculic tendencies. This could be useful for resource planning.

It can also be used with a single pupil believed to be at risk of dyscalculia. This can be valuable for determining an individualised educational plan for the pupil. It can also be used in a request to the Local Education Authority for a statement of special needs.

We also see the *Dyscalculia Screener* as a research tool for use in studies of mathematical abilities and disabilities. We provide instructions for retrieving data files from the computer for those who need them; see Appendix 3.

The test will take between 15 and 30 minutes to administer depending on the age and ability of the pupil being tested.

The *Dyscalculia Screener* can be used in conjunction with standardised tests of arithmetical attainment, to establish whether a pupil has low attainment because of a dyscalculic deficit. It will also help to establish that a pupil is perfectly capable of good arithmetical attainment, but that some other factor is preventing this. In our standardisation we used results of the nferNelson *Mental Mathematics* series to establish arithmetic attainment; see Appendix 2.

Pupils should be tested individually in a quiet room.

Getting started

Conventions

These instructions assume a basic understanding of computing terms and of the Windows operating system. However, we have provided more information in the comprehensive glossary of terms at the end of this chapter.

Please read all of the instructions carefully before using the program. If you have any further technical queries, please call (+44) 0161 827 2778.

System requirements

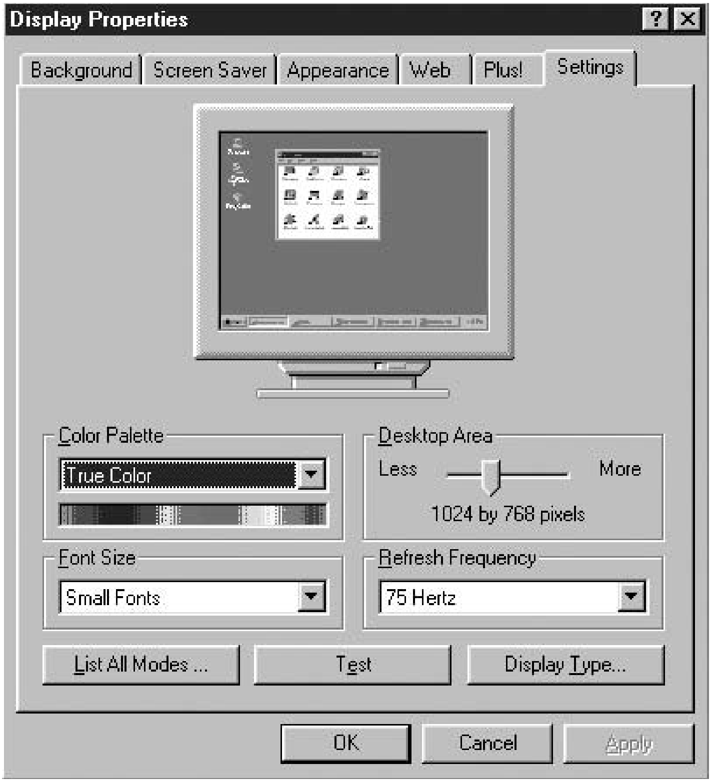
Before installing the *Dyscalculia Screener*, you should make sure that the computer on which you wish to run the software conforms to the following basic specification:

- A Pentium® class system with at least 32 mb of RAM (64mb is recommended). 100mb of free hard drive space. Windows® 98, 98se, ME, NT4 or 2000.
- In addition, your system will require a properly configured sound card so that users will have access to the spoken instructions.
- In order to guarantee that the tests are standardised, the *Dyscalculia Screener* will always run at a resolution of 800 x 600. On computer displays that are set to this resolution, the program will be maximised; it will fill the entire screen. On displays that have been configured to run at higher settings, the *Dyscalculia Screener* window will appear in the centre of the display with the Windows desktop visible around the periphery. This may, in some circumstances, represent a distraction to pupils when they are undertaking a test. It is therefore recommended that the screen resolution of your monitor is set at the recommended figure of 800 x 600 before any assessments are undertaken, see instructions below.
- As the screener requires accurate timing it is unadvisable to run the screener on a network. It should be installed individually on a computer's hard drive.

Changing the screen resolution

The recommended shortcut for changing screen resolution on all Windows operating systems is:

1. Right-click on the Windows desktop.
2. Choose 'Properties' from the menu that appears by clicking it.
3. Click 'Settings' on the dialog box that has appeared.



The settings dialog will vary slightly depending on which version of Windows you are running. Simply drag the 'Desktop Area' scrollbar until it shows 800 x 600 and then click 'OK'. Your desktop will be resized and the display may go blank for a moment. When Windows asks whether you would like to keep the new screen size, click 'OK'.

Installation

1. Place the *Dyscalculia Screener* disk into the CD-ROM drive of your computer. After a few moments, the installation will begin automatically.

   On slower machines there can sometimes be a considerable pause between placing a disk in the drive and the autorun routine beginning. If nothing happens after a minute or so, or you know that the autorun routine has been disabled on your machine, you can either:

   ◆ Open 'My Computer' by double-clicking the icon on the Windows desktop or accessing it from the 'Start' menu. Double-click the icon for your CD-ROM drive, and then double-click 'Setup.exe', to begin the installation

   [or]

   ◆ Click 'Run' from the Windows 'Start' menu, and then type the full path name of 'Setup.exe' into the text field.

2. Follow the instructions that appear on screen.

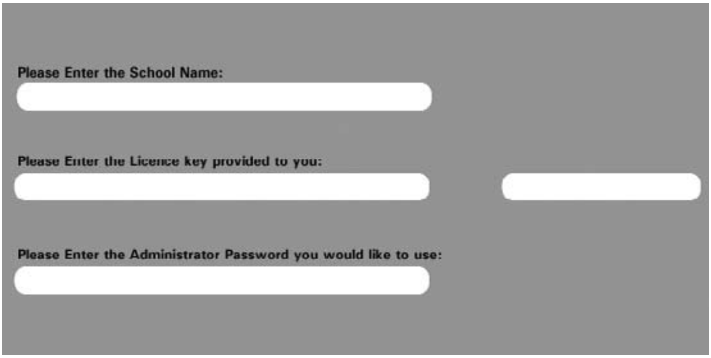
Starting *Dyscalculia Screener*

The program is installed to the nferNelson program group on the hard drive of your computer. To start it:

1. Click 'Start' in the bottom left-hand corner of the screen to launch the 'Start' menu.
2. Hover the mouse pointer over the Programs icon.
3. Look for the nferNelson program group and hover the mouse pointer over it.
4. Click the *Dyscalculia Screener* icon to launch the program.

Unlocking the program

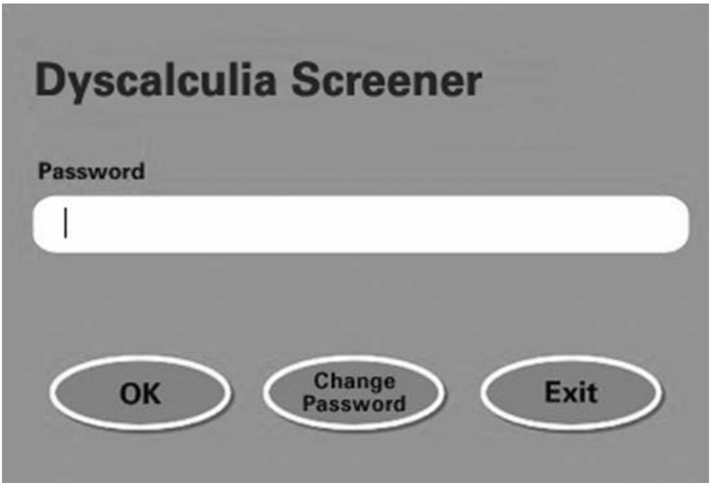
In order to begin using the *Dyscalculia Screener*, you must enter the licence information that has been supplied along with your copy of the software. The following screen will appear:



The administrator password allows one user to act as the administrator for the program; to set up users and log their results, for example.

In future, when you start the *Dyscalculia Screener* from the Windows 'Start' menu, you will be required to enter the administration password before proceeding, in the window shown below.

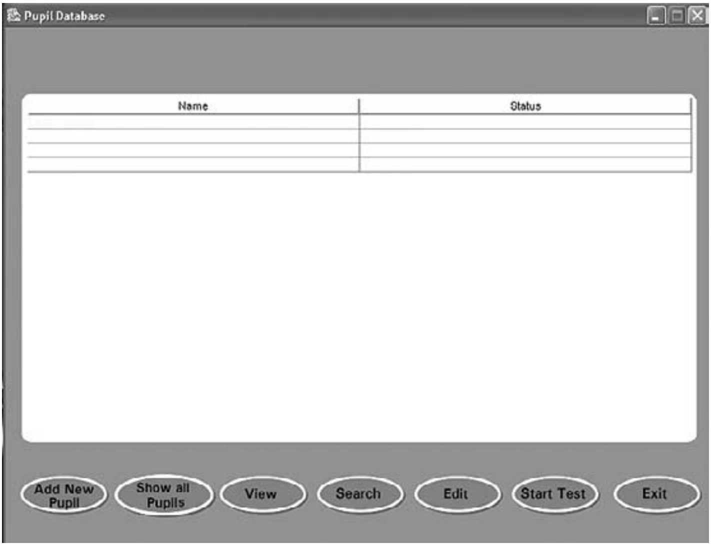
Before you enter the *Dyscalculia Screener* an epilepsy warning appears. Due to the nature of the Simple Reaction Time test it may cause flashing images on screen. Please read the warning carefully before using the test.



Adding pupils to the database

Before someone can be assessed by the software he or she must be added to the Pupil Database. This is the screen you will see after entering your password and clicking 'OK'.

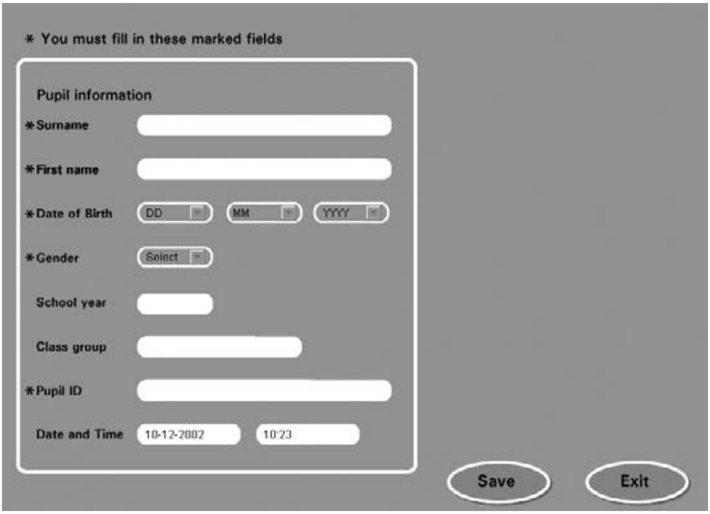
The first time you use the program the Pupil Database will be empty, as shown below.



Creating a new user

1. Click 'Add New Pupil'.
2. The screen that appears is essentially a form that you have to complete. Each of the required fields is indicated by an asterisk. You will not be able to proceed further until you have entered some information in these fields. Complete the form by typing into the text fields and making choices from the drop-down lists.

   Tip: You can use the 'tab' key on your keyboard to cycle through the elements of the form in sequence.



3. When the form is complete, click ‘Save’ to add the new user to the Pupil Database.

Editing user details

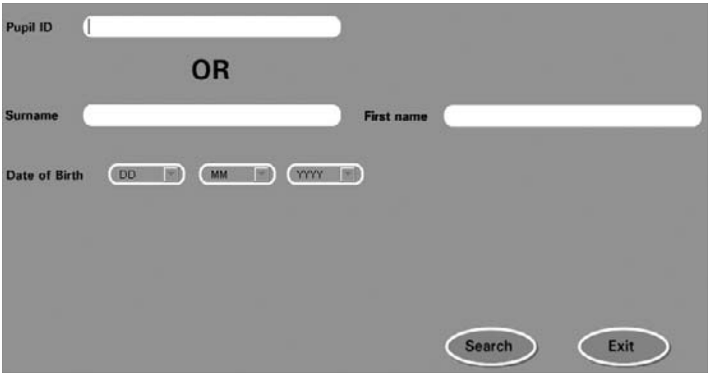
If you wish to change any details at a later date:

1. Highlight the name of the pupil in the Pupil Database whose details you wish to edit by clicking on it. Depending on the sensitivity of your computer you may have to double-click.
2. Click ‘Edit’.
3. Change the details as necessary.
4. Click ‘Save’ to confirm the changes.

Searching for pupils

When the Pupil Database contains many records, you may find it easier to search for a specific user rather than scrolling through a long list of names.

1. Click ‘Search’.
2. The next screen will offer you a choice of different search criteria.



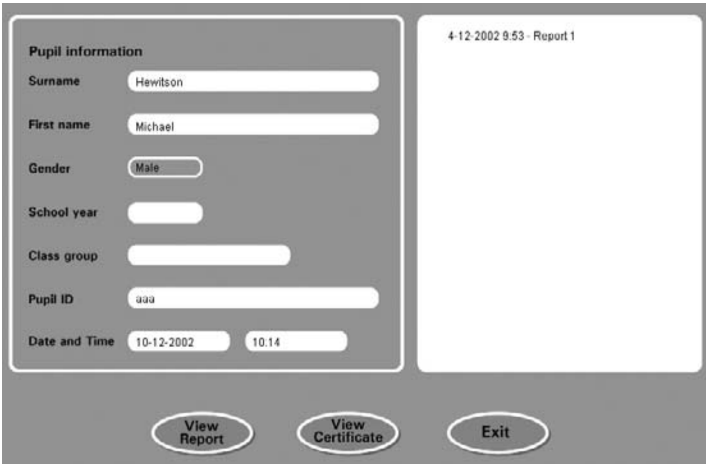
Tip: Searches are case sensitive, which means that you must remember to capitalise words in the search fields exactly as they are in the Pupil Database.

3. Type a search term in to the relevant field, or choose from the drop-down lists if you are searching on date of birth.
4. Click ‘Search’. If the search is successful the Pupil Database will now contain the records that match the search criteria that you specified; otherwise you will see the following message:

Tip: Return the Pupil Database to its default setting by clicking ‘Show all Pupils’.

Viewing pupil details and reports

1. Highlight the name of the pupil in the Pupil Database by clicking on it.
2. Click ‘View’. The individual pupil record is launched. If the pupil has taken the test the details will be displayed on the right-hand side of the screen.

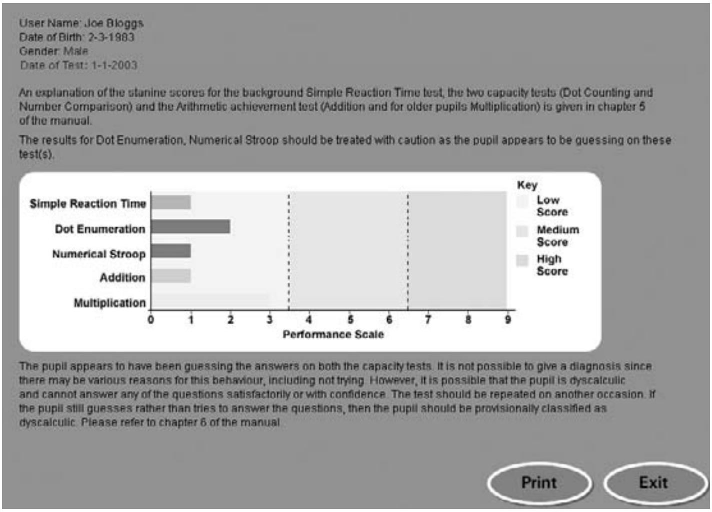


You will notice that there are three options at the foot of the record.

View report

Selecting this option will load the report that was generated when the pupil took the test. You may need to highlight the information on the right before you click on ‘View Report’. An example is shown overleaf.

If you wish to have a hard copy of the report, click ‘Print’ to launch the usual options for the printer that is connected to your computer.



View certificate

Click this button to view the certificate that was generated by the system after the test was assessed. Click 'Print' to print a copy for the pupil to keep.

Exit

Return to the Pupil Database.

Sitting the test

When a pupil has been added to the database, he or she can be tested.

Starting at the Pupil Database:

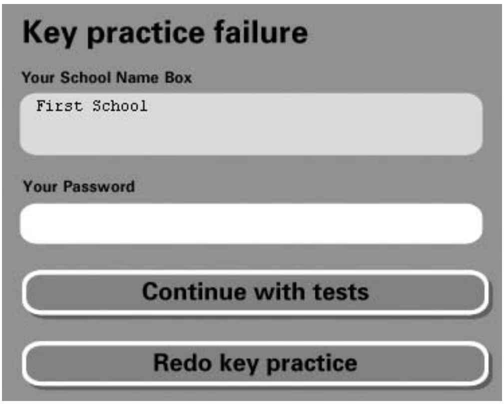
1. Click the name of the pupil to be tested.
2. Click 'Start Test'.

After viewing the welcome screen the pupil is given both written and audio instructions and will be led into a practice session.

The practice session is used to configure the system by nominating a selection of keys at the left-hand and the right-hand sides of the keyboards to represent the yes and no answers. One of the screens involved is shown below.

The pupil should continue to work through all the practice screens.

If he or she should fail to get all of the questions correct, the program will be 'locked' until the teacher – or the nominated administrator – unlocks it by entering the administration password.



Clear this dialog box by typing the administration password into the 'Your Password' field and clicking one of the options.

When Key practice has been successfully completed, or you have decided to allow the pupil to continue, he or she will be invited to begin the assessment by clicking a left or a right button.

Once into the actual test, each subtest also has practice sections that will lock if a pupil gets all the answers wrong. Again you can unlock it as described above.

When a pupil has completed the test another password box will be shown. You can then either leave the test or click back to revisit the Pupil Database immediately.

If you are in the middle of a test and wish to exit, you can push the 'Ctrl' and 'Q' keys on your keyboard to exit.

Glossary of terms

Click

Click always refers to a single click with the left mouse button. Double-click means to click rapidly twice in succession with the left mouse button. Clicking with the right mouse button will often reveal a hidden menu.

Desktop

The Windows desktop is the visual 'front end' of the operating system. Double-clicking the icons on the desktop will open the programs for which they represent shortcuts. Right-clicking on the desktop will reveal hidden menus. For example see 'Changing the screen resolution' section.

Directory

A directory is essentially a folder that contains items grouped together for convenience. The *Dyscalculia Screener* is installed to the nferNelson directory on the hard drive; any other nferNelson software would be installed to the same location.

Disk drive

The disk drive on your computer is the physical location in which the operating system and all the software that you have installed is stored. Disk space is measured in megabytes (mb). Each of the applications that you install will have particular space requirements and you should make sure that you have enough free space before installing them.

> **Tip:** You can check the amount of free space on your hard disk drive by double-clicking the 'My Computer' icon on the Windows desktop, right-clicking the icon for the disk drive (typically 'Drive C:'), and selecting 'Properties'.

Hardware

Hardware refers to the physical components of the computer system: the computer itself, monitor, keyboard, mouse and printer. Any peripherals that you later add, such as a scanner, also come under this heading.

Keyboard

Computer keyboards are essentially the same as typewriter keyboards with some additional special function keys. References to particular keys assume an identical layout.

Megabyte

The amount of space available on computer hard drives, CD-ROMs and other storage media is expressed in megabytes (MB).

Memory

This is shorthand for 'Random Access Memory'; chips installed on a computer where tasks are accomplished and information is 'turned around'. Memory, like disk space, is expressed in megabytes. All computer applications have memory requirements below which they cannot be guaranteed to work effectively.

Network

A number of computers linked together that are able to access shared resources such as hard drives and printers.

Operating system

The operating system is the software that manages a computer's resources. The operating system 'hosts' the software that is installed on the computer. Software is developed to run under a particular operating system, most commonly Microsoft Windows.

Screen resolution

The screen resolution of a computer display (monitor) is expressed as the number of dots per inch of screen (dpi); this refers to individual dots of colour. The higher the screen resolution, the more detail and clarity in the display. Some applications, the *Dyscalculia Screener* being one of them, are designed to run at a particular resolution. On the whole, applications will adapt themselves to the screen resolution that has been set for your monitor.

> **Tip:** Older and 'budget' type monitors may not be designed to run at high resolutions. Whenever you change the monitor settings, Windows gives you the option to test the new settings before accepting them and you should always accept this option.

Software

Software is the umbrella term for everything that you install to the computer hard drive. It refers to applications such as the *Dyscalculia Screener*, and to 'drivers', such as the code that controls items like the graphical display and the way sound is produced and output by the machine.

Scores and how to use them

5

Each pupil will receive a standardised score for each of the subtests within the *Dyscalculia Screener*. The way these scores are computed is as follows: on each subtest, the median reaction time of correct answers is calculated, it is then adjusted by the median simple reaction time; finally, it is divided by the proportion of correct answers to yield an 'efficiency measure'. The efficiency measures for an age group constitute the norms for that age group. These are initially converted into age-adjusted standardised scores. The program will tell you the ranking of the pupil on each of the tests in terms of stanines – where the distribution of scores is divided into nine segments.

Standardised scores and stanines enable you to compare your own pupils with a large, nationally representative sample of pupils who have taken the test prior to publication. Each pupil is also compared directly against other pupils of the same age in years and months.

The test has been standardised so that the average nationally standardised score automatically comes out as 100, irrespective of the difficulty of the test, and so it is easy to see whether a pupil is above or below the national average.

The measure of the spread of scores is called the 'standard deviation', and this is usually set to 15 for educational attainment and ability tests. This means that, for example, irrespective of the difficulty of the test, about 68 per cent of the pupils in the national sample will have a standardised score within 15 points of the average (between 85 and 115) and about 95 per cent will have a standardised score within two standard deviations (30 points) of the average (between 70 and 130). These examples come from a frequency distribution known as 'the normal distribution', which is shown in Figure 1.

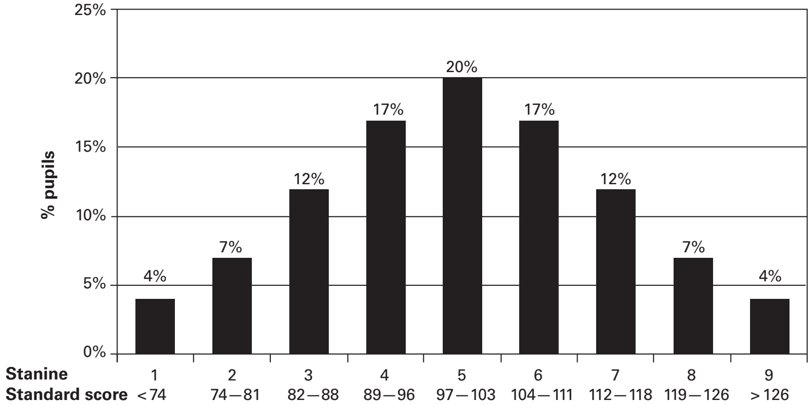
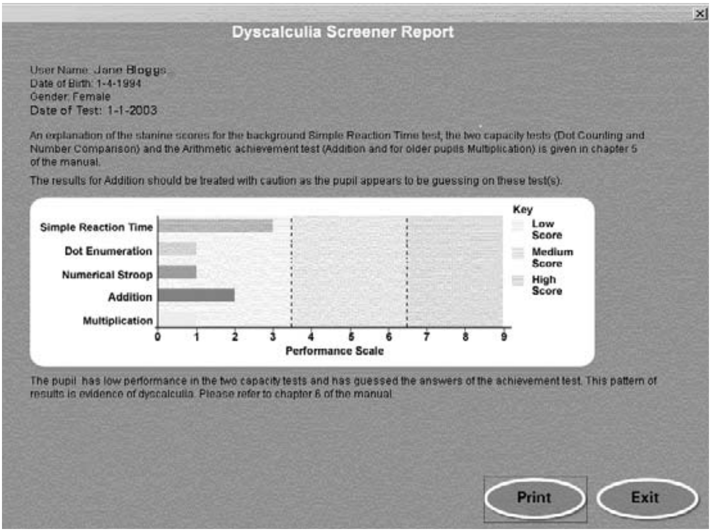


***Figure 1**: The normal score distribution showing the relationship between stanines and standardised scores*

The top stanine is equivalent to roughly the top 4 per cent of the age group. For example, the test might tell you that the pupil is in the top stanine for addition, but in the seventh stanine for Numerical Stroop.

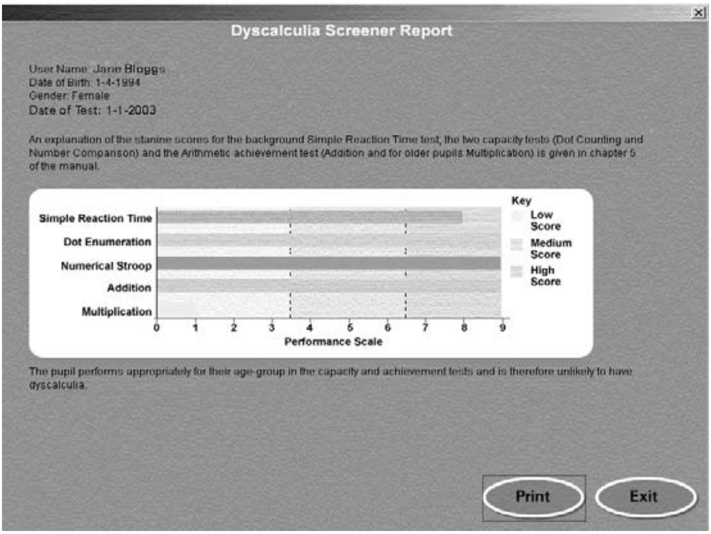
There will also be a composite score for all the tests consisting of the mean of the standard scores for each test. You do not see this score but a narrative interpretation of the main outcome patterns is provided by the software. Here are three examples of the diagnoses you could see on the computer screen.

Dyscalculia



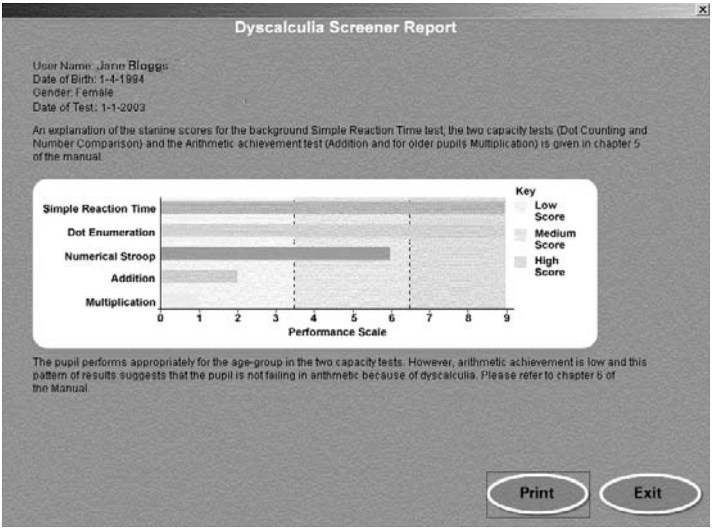
The pupil has low performance in the two capacity tests and the achievement test. This pattern of results is evidence of dyscalculia.

Normal performance



The pupil performs appropriately for their age-group in the capacity and achievement tests and is therefore unlikely to have dyscalculia.

Poor arithmetic without dyscalculia



The pupil performs appropriately for the age-group in the two capacity tests. However, arithmetic achievement is low and this pattern of results suggests that the pupil is not failing in arithmetic because of dyscalculia.

Next steps

6

What to do if the *Dyscalculia Screener* produces a diagnosis of dyscalculic tendencies

- Dyscalculic pupils are often anxious or distressed about mathematics, both within and outside school. Try to reduce anxiety. It is *not* helpful to stress the importance of mathematics in daily life or in academic advancement. The pupil already knows this. Stressing the fact will only increase anxiety and distress. Learning is more effective when it is enjoyable and relaxed.
- You should consult the special needs coordinator (SENCO) in the pupil's school about what additional support is available. If the pupil is in primary school, the Numeracy Hour may be frustrating or even distressing. Pupils may need special support, either outside the Numeracy Hour class or in an appropriate set or stream, if the school follows this practice.
- There are some organisations outside school that offer courses for dyscalculic pupils, and for teachers and parents (see Appendix 4).
- Self-study materials presented in book form or as software exist that may be helpful for the pupil (Appendix 4). However, none of the materials have yet been properly evaluated, so it is unclear how effective they are or whether they work for all kinds of dyscalculic pupils.
- In very severe or distressing cases, it could be worth considering a special school. There are no special schools for dyscalculia, but some schools for dyslexia or other special learning needs may have made provision for dyscalculic pupils (see Appendix 4).

- The pupil's underlying problem is likely to be in understanding numerosities. Interventions should stress this very basic aspect of arithmetic. Use sets of objects for manipulation and counting.
- It will not help a pupil in primary school to practise number bonds and tables until the numerosity concept is firmly established. Attempting to induce rote learning of number bonds and tables could lead to frustration and avoidance. Even if the pupil can successfully repeat the bonds and table facts, this does not necessarily mean that they are understood or can be used appropriately.
- In our experience, it is sometimes best for all concerned – pupil, teacher and parent – to try to find ways around the difficulties rather than confront them head-on. A useful analogy is with colour-blindness: no known training regime will enable you to see the difference between red and green, but society demands that you stop at red lights and go on green. This means you have to find another way of determining which is which. In the case of traffic lights position is a sufficient cue.

  With arithmetic, our suggestion is that the pupil should focus on trying to master the calculator. This does require understanding, but not calculation skills. Often even severe dyscalculics may be successful with more abstract aspects of mathematics, such as algebra, which can help with using calculators.

What to do if the *Dyscalculia Screener* produces a diagnosis of dyscalculic tendencies with compensatory aspects

- Pupils who find mathematics particularly difficult – whether they are dyscalculic or not – are often anxious or distressed about mathematics. It is *not* helpful to stress the importance of mathematics in daily life or in academic advancement as the pupil already knows this. Stressing the fact will only increase anxiety and distress. Learning is more effective when it is enjoyable and relaxed.

- If the pupil appears to be managing well despite relatively limited numerical capacities, he or she may nevertheless be struggling with some aspects of the curriculum. The pupil's maths teacher and head of year should be consulted about problems that may have arisen in specific curriculum topics.
- If the pupil is performing poorly in school maths, you should consult the special needs coordinator (SENCO) in the pupil's school about what additional support is available.
- There are some organisations outside school that offer courses for dyscalculic pupils and for teachers and parents (see Appendix 4).
- Self-study materials in book form or as software that may be helpful for the pupil exist (Appendix 4). However, none of the materials have yet been properly evaluated, so it is unclear how effective they are or whether they work for all kinds of dyscalculic pupils.
- If the pupil appears to be managing reasonably well with school arithmetic, it could be helpful to attempt more abstract mathematics – such as algebra – which could turn out to be much easier since they make fewer demands on the weak areas of number knowledge and number manipulation.
- Alternative methods of calculation – using slide rules, calculators and computers – should be encouraged.
- Rote rehearsal of number bonds and tables may not be helpful. The use of sets of objects for counting and manipulation may help to ground concepts of numerosity.

What to do if the *Dyscalculia Screener* produces a diagnosis of low achievement

- Pupils struggling with mathematics are often anxious or distressed about mathematics both within and outside school. It is *not* helpful to stress the importance of mathematics in daily life or in academic advancement. Try to reduce anxiety. Learning is more effective when it is enjoyable and relaxed.
- There are many causes of low mathematical achievement in addition to dyscalculia. The first task is to discover why the pupil had a low score on the Arithmetic Achievement test. The pupil may not have been trying on this occasion. This can be established by asking the pupil to re-take the test. Alternatively, another test of achievement can be used, such as the appropriate test from nferNelson's *Mathematics 5–14* series.
- If the pupil's achievement is low on the re-test or on *Mathematics 5–14* series, then something in the learning situation will have been responsible. Possible causes should be investigated, such as (this list is not exhaustive):
  - absence from mathematics classes;
  - anxiety about mathematics;
  - inappropriate teaching – e.g. wrong level for the pupil.
- Pupils who fall behind, for whatever reason, may find it very hard to catch up. The gap between what is expected of them in class and what they are competent to do will grow wider and wider unless steps are taken to help the pupil make up lost ground.
- Discuss the situation with the pupil's mathematics teacher and head of year – additional help may be available within the school – or if you are the pupil's teacher then discuss it with their parents.

Appendix 1

Summary of research leading to the definition of dyscalculia specific to this screener

Background

This chapter provides a summary of research leading to the definition of dyscalculia which is specific to the *Dyscalculia Screener*, expanding on the information already provided in Chapter 1.

Research conducted with infants (see Chapter 1, pages 2 to 3) suggests that numerosity is innate. If this is the case, the human genome codes for building a specialised brain system for understanding and recognising numerosities. There may therefore be individuals with a genomic variation such that the brain system fails to develop normally. Seeing the world in colour is a useful analogy. The genome codes for building a specialised neural system (including the receptors in the retina) for seeing the world in colour, and most of us have this capacity. However, a small minority have a variation in the genetic code that causes colour-blindness. Similarly, the dyscalculic minority appears to suffer a kind of congenital number blindness.

The effects of this can be far-reaching, though they may not necessarily encompass all areas of mathematics, or even of arithmetic. Being able to recite the counting words in the correct order requires a sense of sequence but not a sense of numerosity. Even being able to count correctly a collection of objects – 'one, two, three …' – does not entail that the pupil understands that the numerosity of the collection is being established by this procedure. If you ask the pupil to say how many objects there are in the collection he or she may not be able to tell you (Fuson, 1992; Gelman and Gallistel, 1978).

Numerosity is the basis of school arithmetic. The four arithmetical operations – adding, subtracting, multiplying and dividing – are usually thought of in terms of the results of manipulating collections. For example, adding is the result on numerosity of the union of two or more discrete collections; and subtraction the result on numerosity of taking away a subcollection (Giaquinto, 1995, 2001). Indeed many teaching aids make use of collections of objects to demonstrate arithmetic in primary school.

However, there will also be areas of mathematics which do not depend so much on manipulating numerosities – algebra, geometry and topology, for example. It may be that dyscalculic pupils can master these areas, even though their arithmetic is poor.

Problems encountered by pupils with dyscalculia

One generally well-recognised feature of pupils with dyscalculia is difficulty in learning and remembering arithmetical facts (Geary, 1993; Geary and Hoard, 2001; Ginsburg, 1997; Jordan and Montani, 1997; Kirby and Becker, 1988; Russell and Ginsburg, 1984; Shalev and Gross-Tsur, 2001). In interviews with teachers (Bevan and Butterworth, forthcoming), difficulty remembering even the number bonds to 10 was overwhelmingly cited as the worst problem that pupils struggling with maths were up against.

A second feature of pupils with a mathematics disability is difficulty in executing calculation procedures. Temple, (1991) has demonstrated using case studies that these abilities are dissociable in developmental dyscalculia. However, case studies, while providing important theoretical information on cognitive structures, are not necessarily representative of the majority of dyscalculic pupils: such dissociations may be rare. Ashcraft, Yamashita and Aram (1992) found no dissociation between arithmetical fact ability and procedural ability in pupils with numerical processing difficulties. Russell and Ginsburg (1984) found that a group of dyscalculic pupils struggled with both written calculation and arithmetical fact retrieval. Geary (1993) suggests that *procedural* problems are likely to improve with experience, whereas *retrieval* difficulties are less likely to do so. Geary proposes that this dissociation emerges because procedural problems are due to a lack of conceptual understanding, while retrieval difficulties are the result of general semantic memory dysfunction. Ostad (1999) has noted that dyscalculic pupils use fewer procedures, and often apply their smaller repertoire in situations where they are not appropriate.

Third, even something as apparently simple as counting can be shown to be vulnerable in dyscalculic pupils. For example, Geary, Bow-Thomas and Yao (1992) found that dyscalculic pupils are less likely to detect counting errors than control group pupils.

However, it is possible that all these deficits result from a lack of conceptual understanding of the basic ideas of numerosity and, hence, arithmetic. This possibility is supported by what both dyscalculic pupils and their teachers describe as the main problem: understanding the basic concepts of arithmetic.

> ***Pupil A (8 years):*** *I sometimes don't understand whatever she* (the teacher) *says.*
>
> ***Pupil B (9 years):*** *I don't forget it, I don't even know what she's saying.* (Bevan and Butterworth, forthcoming)

Good memory for arithmetical facts could depend on being able to organise them into meaningful patterns, while poor memory will arise when the facts make little sense to the pupil. Similarly, if arithmetical procedures are just sequences of meaningless steps, then it is not surprising that they are hard to remember and frequently misapplied.

Dyscalculic pupils themselves say that they find it difficult to remember what the teacher says about mathematics:

> ***Pupil C (9years):*** *When you listen to the teacher, then you turn your head and you don't know nothing … If I remember something, and then the teacher says, 'Stop for a second, just listen to me' then as soon as she talks, yeah, and we come back, we do work, and I say, 'What do I have to do?' I always forget.*

Even in something as apparently simple as counting, dyscalculic pupils show a kind of rigidity that accompanies rote application of a procedure that is not properly understood. Geary, Bow-Thomas and Yao (1992) found that they believed that counting should be done strictly from left to right without skipping around, leading the authors to suggest that these pupils were counting in a rote, mechanical fashion without conceptual understanding. Normal pupils quickly come to understand that objects can be counted in any order, and that all orders will lead to the same result (Gelman and Gallistel, 1978).

Underlying processing deficits

Another approach to the study of developmental dyscalculia involves trying to see it as a consequence of cognitive deficits that are not specific to understanding numerosity. Proposals have included:

- abnormal representations in semantic memory (Geary, 1993);
- slow speed of processing (Fawcett and Nicolson, 1994);
- deficits of working memory (Ashcraft, Donley, Halas and Vakali, 1992; Hitch and McCauley, 1991);
- weak phonetic representations (Geary, Hamson and Hoard, 2000).

An advantage of this approach is that it can explain the frequently observed co-morbidity between dyscalculia and dyslexia, where dyslexics are known to suffer from these conditions.

Geary and colleagues (Geary, 1993; Geary, Hamson and Hoard, 2000; Geary and Hoard, 2001) have suggested that semantic memory difficulties may underlie the problems experienced by developmental dyscalculics in learning number facts, and may also underlie the co-morbid reading difficulties frequently found with dyscalculia. The argument is based on evidence that dyscalculic pupils have difficulty learning and remembering arithmetic facts, but it is possible that this deficit may be due to other factors, such as lack of conceptual understanding: empirical evidence for a general semantic deficit in dyscalculic pupils is thin.

Temple and Sherwood (2002) found that a group of pupils with arithmetical difficulties were slower at colour and object naming than controls: evidence for a generalised speed of access difficulty in this sample. However, the authors argued against a causal relationship between speed of access and arithmetic ability, one reason for caution being the small size of the group (four participants).

Another problem with the hypothesis arises in the light of evidence that semantic memory for numbers is mediated by a different system than general semantic memory. Neuropsychological studies indicate that number knowledge is dissociable from verbal semantic memory (Cappelletti, Butterworth and Kopelman, 2001), and that the semantic memory systems for numerical and non-numerical information are localised in different areas of the brain (Thioux, Seron and Pesenti, 1999). This functional and anatomical dissociation between the two memory systems makes it unlikely that the same semantic deficit can account for both maths and reading disability.

A related hypothesis is that dyscalculic pupils may be slower at processing information. Dyscalculic pupils' long reaction times in arithmetic tasks are well documented. In fact, Jordan and Montani (1997) showed that dyscalculic pupils could perform at normal levels on arithmetic tasks when allowed unlimited time, but were significantly worse than control pupils when a time limit was imposed. However, McLean and Hitch, (1999) compared dyscalculic pupils with a younger, ability-matched control group. The younger group were no faster at arithmetic than the dyscalculic pupils, indicating that dyscalculic pupils do not have a slow calculation speed relative to their level of attainment.

Geary and colleagues (Geary, 1993) have found mixed results on tasks involving speed of number processing and counting. Even when general speed of response differences are taken into account, dyscalculic pupils are much slower than controls on arithmetic tasks (Butterworth, Beron and Landerl, forthcoming). General speed of processing deficits do not, therefore, explain dyscalculia. Indeed, the *Dyscalculia Screener* includes a Simple Reaction Time test which allows the examiner to take into account individual differences in speed of processing.

Working memory difficulties have also been associated with developmental dyscalculia. Geary (1993) suggests that poor working memory resources not only lead to difficulty in executing calculation procedures, but may also affect learning of arithmetical facts. In general, the aspect of working memory that has been focused on is the phonological loop (Hecht, Torgesen, Wagner and Rashotte, 2001; Hitch and McCauley, 1991; McLean and Hitch, 1999; Swanson and Sachse-Lee, 2001), normally assessed by the number of spoken items (generally digits) which can be remembered in the correct sequence. It is true that dyscalculic pupils tend to have a shorter span than controls (e.g. Koontz and Berch, 1996), but there are complications to a simple causal picture.

However, Siegel and Ryan (1989) found that pupils with maths disability did less well than controls on a working memory task involving counting and remembering digits, but not on a non-numerical working memory task. This led them to speculate that there is a working memory system specialised for numerical information, and that pupils with mathematics difficulties have specific problems with this system. The tested pupils with and without maths difficulties using both digit and letter span (the latter being a measure of phonological working memory capacity that is not confounded with numerical processing).

McLean and Hitch (1999) gave dyscalculic pupils and age- and ability-matched controls a battery of working memory tasks. This study found that while there was a trend towards poorer digit span in dyscalculic pupils, there was no difference on a non-numerical task testing phonological working memory (non-word repetition). No evidence was found for a faster decay rate of phonological representations in dyscalculic pupils. The authors concluded that dyscalculic pupils do not have reduced phonological working memory capacity in general, although they may have specific difficulty with working memory for numerical information. On the other hand, they found that spatial working memory and some aspects of central executive function were poorer in dyscalculic pupils.

Moreover, Temple and Sherwood (2002) tested dyscalculic pupils and controls on forward and backward digit span, word span and Corsi blocks (a non-verbal test of working memory). This study found no differences between groups and no correlation between the working memory measures and measures of arithmetic ability.

On balance, although various forms of working memory difficulty may well co-occur with mathematics difficulties, there seems to be no convincing evidence implicating working memory as a causal feature in mathematics disability.

Subtyping dyscalculia

Another approach to the study of developmental dyscalculia has involved subtyping dyscalculics according to the presence or absence of other disorders, in an attempt to highlight underlying processes which may contribute to the co-morbidity of the disorders. An important correlate of mathematics disability is reading disability. It is estimated that 40 per cent of dyslexics also have mathematics problems (Lewis, Hitch and Walker, 1994). One of the most common ways of subtyping dyscalculic pupils is according to whether or not they have a co-morbid reading disability.

Rourke and his colleagues (Rourke, 1993) have compared pupils with arithmetic difficulties only and pupils with better arithmetic scores than reading scores. Pupils with arithmetic difficulties only were more likely to have difficulties with spatial and psychomotor abilities whilst pupils with reading difficulties were more likely to struggle with verbal tasks. The authors suggest that these findings indicate that co-morbid maths and reading difficulties result from left-hemisphere dysfunction, while specific difficulty with mathematics stems from right-hemisphere dysfunction.

However, Rourke's constellation of 'right-hemisphere' symptoms is similar to the supposedly 'left-parietal' constellation found in Gerstmann's Syndrome (Gerstmann, 1940). In addition, a recent attempt to replicate Rourke's findings (Shalev, Manor and Gross-Tsur, 1997) failed, the authors found no qualitative difference between pupils with both reading and mathematics disability and pupils with mathematics disability only. Pupils with both disorders scored more poorly on several measures, but the authors concluded that this was unsurprising, given that the presence of more than one disorder indicates relatively widespread brain dysfunction.

Fayol, Barrouillet and Marinthe (1998) attempted to test Rourke's hypothesis regarding the causal relationship between neuropsychological deficits and arithmetic difficulties. They conducted a longitudinal study in which nursery school pupils were given tests of finger agnosia, graphisthesia and simultagnosia. These neuropsychological measures correlated with simple arithmetic tests given at the same time. However, except (oddly) for word problem solving, general intelligence in nursery school was a better predictor of arithmetic in the first year of school than were the neuropsychological tests. This finding suggests that correlation, in this case, is not causation. Another set of deficits which are associated with developmental dyscalculia are finger agnosia, dysgraphia and difficulties with left–right discrimination. Taken together this group of symptoms constitutes developmental Gerstmann's Syndrome (Kinsbourne and Warrington, 1963). However, since it appears that the four symptoms can appear individually and in any combination, and are frequently associated with other conditions (Kinsbourne and Warrington, 1963; Spellacy and Peter, 1978), it is unlikely that the symptoms are related in terms of a single underlying deficit.

Other conditions that have been associated with dyscalculia are:

- attention deficit hyperactivity disorder (ADHD) (Badian, 1983; Rosenberg, 1989; Shalev, Manor and Gross-Tsur, 1997);
- poor hand–eye co-ordination (Siegel and Feldman, 1983);
- poor memory for non-verbal material (Fletcher, 1985);
- poor social skills (Rourke, 1989).

Shalev and Gross-Tsur (1993) examined a group of seven pupils with developmental dyscalculia who were not responding to intervention. All seven were suffering from additional neurological conditions, ranging from petit mal seizures through to dyslexia for numbers, ADHD and developmental Gerstmann's Syndrome.

In summary, while it is clearly the case that dyscalculia is frequently co-morbid with other disabilities, causal relationships between the disorders have not been proven. In addition, the utility of subtyping dyscalculics according to neuropsychological or cognitive correlates will not be clear until it has been shown that the different subtypes display qualitatively different patterns of numerical deficit.

Relatively few studies have examined differences between subtypes on tasks involving numerical processing. Shalev, Manor and Gross-Tsur (1997) found that pupils with co-morbid mathematics and reading difficulties were more profoundly impaired than pupils with specific maths problems on subtraction and division; they also had lower verbal intelligence quotient (IQ) scores. In addition they, scored consistently lower on most of the *WISC-III* subtests, although this difference did not reach statistical significance. However, the pattern of numerical impairment was the same for both groups. This study found no evidence for dissociation between the two groups in numerical processing, although pupils with co-morbid mathematics and reading difficulties tended to be more impaired than pupils with specific mathematics problems.

Jordan and Montani (1997) compared a group of pupils with specific maths disability with a group of pupils who had mathematics disability in the context of more general academic difficulties. Pupils with maths disability only were better able to execute back-up strategies in arithmetic, and were able to perform at a normal level under untimed conditions, although their performance dropped under timed conditions. Pupils with more general difficulties struggled under both conditions. The authors suggested that pupils with specific mathematics difficulties are able to compensate under untimed conditions because of relatively good verbal or conceptual skills.

However, although this study also indicates that pupils with general difficulties have quantitatively more difficulty than pupils with specific mathematics disability, again there is no evidence that the pattern of numerical impairment is qualitatively different between the two groups. More detailed examination of the numerical abilities of groups of pupils are in order before it is certain that subtyping developmental dyscalculics according to this framework is a useful approach.

It is clear that mathematics disabilities frequently co-occur with a range of other deficits. However, it is still far from clear that these deficits play any causal role in developmental mathematics disability. Not only has no single underlying process been identified that predicts dyscalculia, there is no evidence for qualitatively different patterns of impairment across dyscalculia subtypes, as would be expected if different subtypes corresponded to different underlying causes. There is also no robust empirical evidence causally relating any of these correlates to numerical ability. In addition there is very little coherent theory that could explain such causal relationships. Currently the most likely explanations for overlap between different disabilities are anatomical or genetic: damage to a brain area or failure of that area to develop normally may affect one or more cognitive functions depending on the extent and severity of the damage (Shalev and Gross-Tsur, 1993).

Evidence for the independence of mathematical abilities

The studies described above have attempted to get at the root of maths disorders by examining various abilities, not obviously related to number processing, which are hypothesised to underlie dyscalculia. This approach involves an implicit assumption that the representation and manipulation of numerical information is a higher-order function, which is based upon the abilities described. However, evidence from neuropsychology and research with animals and very young pupils suggests that number processing is not only independent of other abilities, but is also manifested at a very basic level. Numerical abilities, including arithmetic, are mediated by areas in the parietal lobe (Cipolotti and van Harskamp, 2001; Dehaene, DehaeneLambertz and Cohen, 1998).

Neuropsychological evidence has shown that the ability to understand numbers and to calculate is dissociable from language (Butterworth, 1999); from semantic memory for non-numerical information (Cappelletti, Butterworth and Kopelman, 2001); and from working memory (Butterworth, Cipolotti and Warrington, 1996).

Not only are numerical abilities independent of other abilities, they also appear to be biologically based. Starkey, Spelke and Gelman (1990) have shown that six- to eight-month-old babies can detect numerical correspondences between otherwise unrelated items presented in different sensory modalities. Wynn (1992) has presented evidence that preverbal five-month-old babies can represent the numerosities of small collections of objects, and can reason meaningfully about them, even performing simple calculations. The babies were apparently aware that when one object is added to two objects, the result should be three objects, and that when one is taken away from three, two should be left. At 11 months, infants not only recognise different numerosities, but know which of two numerosities is larger (Brannon, 2002). It is thought that these infant abilities form the basis for acquiring more sophisticated numerical skills such as counting (Fuson, 1988). If an infant is born without these capacities, then the trajectory of learning arithmetic may be very different, and very difficult.

Thus number processing appears to be a function which emerges in infants at a very early age, and is independent of other abilities. This argues against a role for language-related abilities such as semantic or working memory in developmental dyscalculia. It seems likely that numerical skills usually acquired in an educational context, such as comprehension of numerical symbols, counting, and simple calculation, are built primarily upon early mechanisms for processing small numerosities. Deficits in these mechanisms also seem to be a good candidate for a basic deficit underlying dyscalculia.

All in all, the evidence points to the existence of a 'number module' based in the parietal lobe (Butterworth, 1999) specialised for dealing with numerical representations. We propose that the underlying cause of dyscalculia is likely to be related to dysfunction of this system.

This argument is not to suggest that verbal or memory abilities are not involved in numerical processing, particularly at higher levels; for example, language is necessary for counting. However, general problems with language or with memory might be expected to have a relatively broad impact on academic skills. Not only are maths disabilities specific to numbers, but within this specificity is a broad range of deficits. The evidence described above suggests that dyscalculic pupils may have problems with digit span, memory for number facts, speed of processing of numbers, counting, representing single-digit numbers, number matching, and executing calculation procedures. Conversely, there currently seems to be little reason to believe that they have problems with non-numerical tasks involving verbal or memory abilities. It is proposed here that the simultaneous breadth and specificity of this disability is best understood in terms of a specific *numerical* processing deficit.

Chapter 3 details the development of the *Dyscalculia Screener* on the basis of this conclusion.

Standardisation details

The sample for the dyscalculia standardisation was drawn from 21 infants, primary, junior and secondary schools in England (all references to year groups are therefore English). The schools were chosen to be reasonably representative of schools in the UK according to type, size and range of pupil ages.

In these schools, tests from the nferNelson *Mental Mathematics* series were administered to the pupils as follows.

Test	Year group	Number of pupils
Mental Mathematics 6	1	226
Mental Mathematics 7	2	263
Mental Mathematics 8	3	265
Mental Mathematics 10	5	248
Mental Mathematics 12	7	261
Mental Mathematics 14	9	234

Table 1*: Number of pupils in specific year groups who were administered* Mental Mathematics *tests*

The *Mental Mathematics* tests were administered in November/ December 2001.

Pupils were then selected for inclusion in the standardisation of the *Dyscalculia Screener* on the basis of their *Mental Mathematics* test scores. The standardisation sample was selected such that the distribution of *Mental Mathematics* test scores was skewed towards the lower performing pupils. Subsequently weighting was applied in the standardisation analyses to restore the distribution to that observed nationally. This sampling strategy was chosen to maximise the sensitivity of the standardisation to those pupils likely to be dyscalculic, while retaining representativeness overall.

Year group	1	2	3	5	7	9	Total
Number of pupils	92	99	95	87	84	92	549

***Table 2**: Number of pupils in specific year groups who were administered the* Dyscalculia Screener

The standardisation of the *Dyscalculia Screener* was conducted in February 2002.

Standardisation results

This section looks at the results obtained from the standardisation data and explains how the standard scores were computed.

Chart 1, opposite, shows the relationships between the Simple Reaction Time measured in milliseconds (ms) and age of pupil. This is a quartile graph and the middle line is the average (median) reaction time. The top line is the lower quartile and 25 per cent of pupils will have an average reaction time higher than the values shown on this line. Note that high values of reaction times reflect slow reactions and hence low performance. The bottom line is the upper quartile and the top 25 per cent of pupils will have an average reaction time lower than the values shown on this line. As expected, older pupils react faster than younger pupils with 14 year olds reacting around 250ms on average compared with 440ms for six-year-old pupils. The difference in the reaction time between the top 25 per cent and the bottom 25 per cent of pupils decreases with age, which means that the variability in reaction times reduces with increasing age.

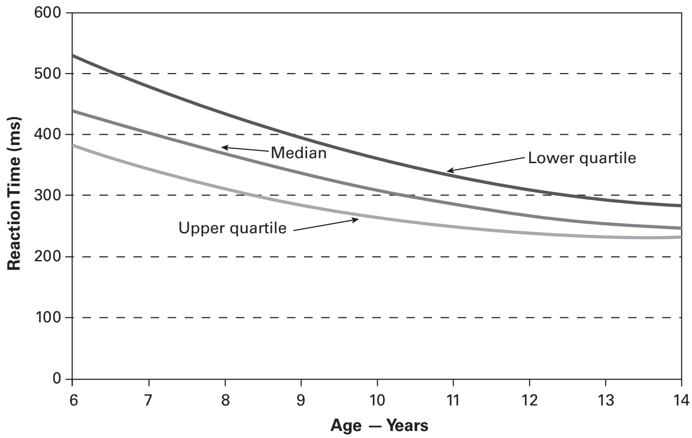


***Chart 1**: Simple Reaction Time median from standardisation*

Charts 2 to 5 show quartile graphs for Dot Enumeration, Numerical Stroop, Arithmetic Achievement test: addition and multiplication. The results from these charts show a similar pattern to that seen in Chart 1. In all cases the average reaction times decrease with age and there is more variability in the reaction times for younger pupils than for older pupils.

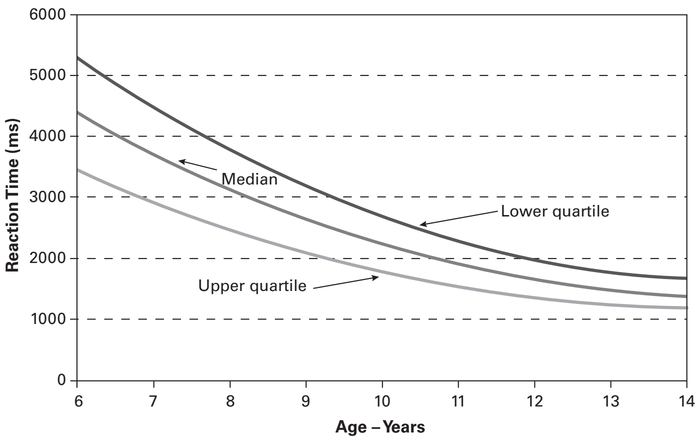


***Chart 2**: Dot Enumeration reaction time median from standardisation*

Pupils aged 9, 11 and 13 years were not used in the study and the results shown in the charts for these age groups have been estimated based on the results from the other age groups.

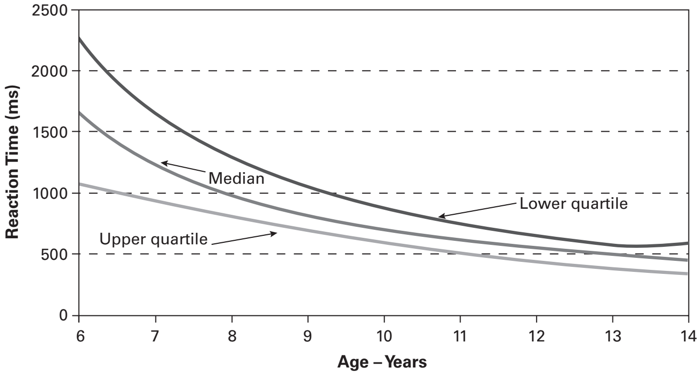


***Chart 3**: Numerical Stroop reaction time median from standardisation*

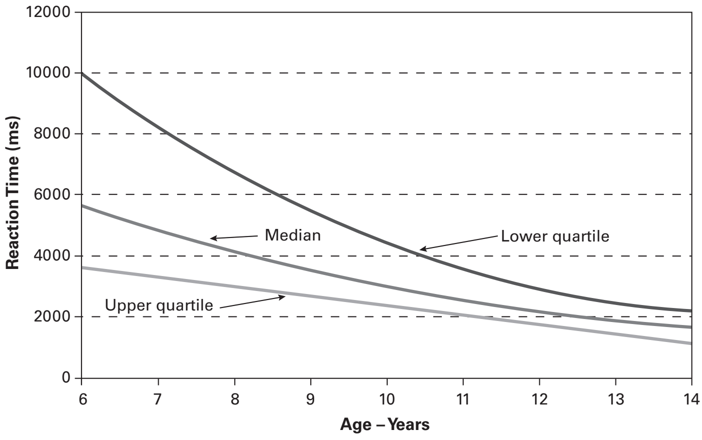


***Chart 4**: Addition reaction time median from standardisation*

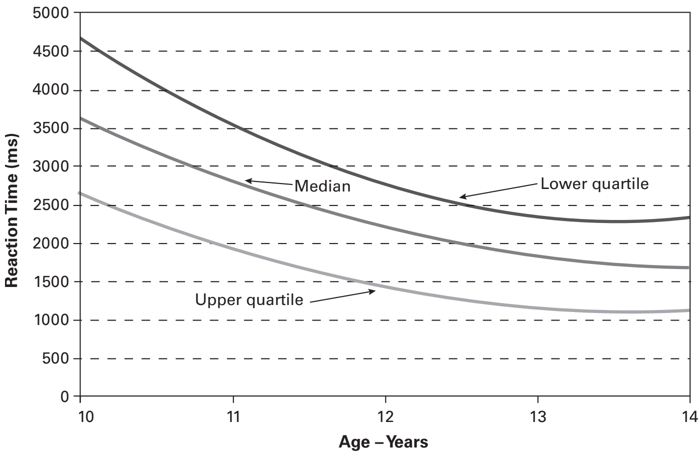


***Chart 5**: Multiplication reaction time median from standardisation*

Subtest/Age	6 yrs	7 yrs	8 yrs	10 yrs	12 yrs	14 yrs
Dot Enumeration	91%	91%	91%	91%	91%	93%
Numerical Stroop	80%	83%	88%	90%	93%	95%
Addition	65%	79%	82%	89%	92%	89%
Multiplication				78%	88%	88%

***Table 3**: Average percentage of questions the pupil answered correctly, according to age and subtest*

Pupils in general score high on Dot Enumeration and younger pupils count dots as well as older pupils but as shown in Chart 2 younger pupils take longer to count the dots than older pupils. The percentages correct for Numerical Stroop, Addition and Multiplication increase with age but there is not much difference in performance between 12 and 14 year olds.

Derivation of the standardised scores

The standardised scores were calculated as follows:

- The median reaction time was calculated for each pupil for each of the tests. Reaction times below 60ms were excluded from the calculations of the medians as it was very unlikely that a pupil could respond this fast. For Dot Enumeration, Numerical Stroop, Addition and Multiplication, the median reaction times are calculated only for those questions which a pupil answered correctly.

- The median reaction times for Dot Enumeration, Numerical Stroop, Addition and Multiplication were adjusted to take into account the base Simple Reaction Time. The adjustment used was a simple difference between the median reaction time of the test and the base Simple Reaction Time.
- An inverse efficiency measure was computed for Dot Enumeration, Numerical Stroop, Addition and Multiplication tests for each pupil, to take into account those pupils who were getting some of the questions wrong. The inverse efficiency measure is the adjusted median reaction times (calculated above), divided by the proportion of questions which a pupil answered correctly in a test.
- The inverse efficiency measures for Dot Enumeration, Numerical Stroop, Addition and Multiplication tests and the median Simple Reaction Time were the raw measures used to calculate the standard scores. The standard scores were adjusted for age and the average was set to 100 and the standard deviation was set to 15. For simplicity the standard scores were mapped onto a stanine scale comprising nine bands (refer to Figure 1 on page 34). Further analysis of the data identified pupils who were guessing the answers to most of the questions in a test. It is possible that these pupils were guessing because of an inability to answer the questions, but other causes cannot be excluded. If a pupil guesses on most questions in a particular test, then the maximum stanine score for that test is set to 2.

Inter-correlations between individual tests

	Dot Enumeration	Numerical Stroop	Addition	Multiplication	*Mental Mathematics*
Dot Enumeration	1	.426	.352	.353	.369
Numerical Stroop	.426	1	.334	.399	.332
Addition	.352	.334	1	.351	.265
Multiplication	.353	.399	.351	1	.131
Mental Mathematics	.369	.332	.265	.131	1

***Table 4**: Pearson correlations of the stanines for each possible pair of test scores*

The correlations are all statistically significant. The correlation between the two capacity measures that are used to identify dyscalculia and the *Mental Mathematics* achievement test are reasonably high.

Retrieving data files for research purposes

The *Dyscalculia Screener* produces comma separated files (csv) that can be imported into other analysis packages. This may prove useful if you want to use the *Dyscalculia Screener* for research purposes.

To access the files you need to use your Windows Explorer:

1. Double-click on the Windows Explorer icon on your desktop;
2. Choose the hard drive of your computer by clicking on that option on the left-hand side of the screen;
3. Open the folder named: Program files;
4. Open the nferNelson folder;
5. Open the Dyscalculia folder;
6. The csv files are all shown here and labelled logically (e.g. Test1) – simply open the individual files, as you need them.

The layout of the files for each subtest are as follows:

Simple Reaction Time File – Test1.csv

Field	Description
1.	Pupil surname
2.	Pupil first name
3.	Pupil ID
4.	Pupil age in months
5.	School name
6.	School year
7.	Class group
8.	Test date (DD/MM/YYYY)
9.	1 (file number)
10.	Sex (M/F)
11.	*Ignore field*

12. *Ignore field*
13. *Ignore field*
14–18 Test 1 practice results, one field per result
19–58 Test 1 results (right hand), one per result

Dot Enumeration File – Test2.csv

Field Description

1. Pupil surname
2. Pupil first name
3. Pupil ID
4. Pupil age in months
5. School name
6. School year
7. Class group
8. Test date (DD/MM/YYYY)
9. 2 (file number)

10–14. Test 2 practice results, two fields per result: (1=correct/0=incorrect, response time)

15–82. Test 2 results, two fields per result: (1=correct/0=incorrect, response time)

Numerical Stroop File – Test3.csv

Field Description

1. Pupil surname
2. Pupil first name
3. Pupil ID
4. Pupil age in months
5. School name
6. School year
7. Class group
8. Test date (DD/MM/YYYY)
9. 3 (file number)

10–14. Test 3 practice results, two fields per result: (1=correct/0=incorrect, response time)

15–56. Test 3 results, two fields per result: (1=correct/0=incorrect, response time)

Note: Fields 15–16, 21, 29, 31, 34, 38, 49–52, 54 are not used, for pupils under 10 years old.

Addition File – Test4.csv

Field	Description
1.	Pupil surname
2.	Pupil first name
3.	Pupil ID
4.	Pupil age in months
5.	School name
6.	School year
7.	Class group
8.	Test date (DD/MM/YYYY)
9.	4 (file number)
10–14.	Test 4 practice results, two fields per result: (1=correct/0=incorrect, response time)
15–54.	Test 4 results, two fields per result: (1=correct/0=incorrect, response time)

Note: Ignore fields 19, 28–30, 32–34, 38, 41–43, 53, as these fields are not used.

Multiplication File – Test5.csv

Field	Description
1.	Pupil surname
2.	Pupil first name
3.	Pupil ID
4.	Pupil age in months
5.	School name
6.	School year
7.	Class group
8.	Test date (DD/MM/YYYY)
9.	5 (file number)
10–14.	Test 5 practice results, two fields per result: (1=correct/0=incorrect, response time)
15–54.	Test 5 results, two fields per result: (1=correct/0=incorrect, response time

Summary File – summary.csv

Field	Description
1.	Pupil surname
2.	Pupil first name
3.	Pupil ID
4.	Pupil age in months
5.	School name
6.	School year
7.	Class group
8.	Test date (DD/MM/YYYY)
9.	Median Reaction Time of Simple Reaction Time
10.	Standard age score of Simple Reaction Time
11.	Stanine of Simple Reaction Time
12.	Per cent correct of Dot Enumeration (all)
13.	Per cent correct of Dot Enumeration (just valid)
14.	Median reaction time of Dot Enumeration
15.	Efficiency measure of Dot Enumeration
16.	Standard age score of Dot Enumeration
17.	Stanine of Dot Enumeration
18.	Per cent correct of Numerical Stroop (all)
19.	Per cent correct of Numerical Stroop (just valid)
20.	Median reaction time of Numerical Stroop
21.	Efficiency measure of Numerical Stroop
22.	Standard age score of Numerical Stroop
23.	Stanine of Numerical Stroop
24.	Per cent correct of Addition (all)
25.	Per cent correct of Addition (just valid)
26.	Median reaction time of Addition
27.	Efficiency measure of Addition
28.	Standard age score of Addition
29.	Stanine of Addition
30.	Per cent correct of Multiplication (all)
31.	Per cent correct of Multiplication (just valid)
32.	Median reaction time of Multiplication
33.	Efficiency measure of Multiplication
34.	Standard age score of Multiplication
35.	Stanine of Multiplication

Note: Ignore fields 36–40.

Where to go next

As a relatively new recognised condition there is, at present, very little useful information about dyscalculia available. The following are some useful books, websites, organisations and software programs, but as many of their titles suggest they deal primarily with dyslexia. The nferNelson website (www.nfer-nelson.co.uk) and Brian Butterworth's own site (www.mathematicalbrain.co.uk) will also continue to provide up-to-date information on dyscalculia and new material to help pupils with this learning difficulty.

Further reading

The Mathematical Brain by **Brian Butterworth (1999)** London: Macmillan

Mathematics for Dyslexics: A Teaching Handbook by **Steve Chinn and J. R. Ashcroft (1997)** London: Whurr Publishers.

What to do when you can't learn the times tables by **Steve Chinn (1997)** Baldock, Herts.: Egon Publishers

What to do when you can't add and subtract by **Steve Chinn (1999)** Baldock, Herts.: Egon Publishers

Guidance to Support Pupils with Dyslexia and Dyscalculia **(DfES 0512/2001)** London: Department for Education and Skills

Elementary Mathematics and Language Difficulties by **Eva Grauberg (1997)** London: Whurr Publishers

Count on Your Computer by **Di Hillage (2000)** Wakefield: SEN Marketing

Dyslexia and Maths by **Julie Kay and Dorian Yeo (April, 2003)**. London: David Fulton Publishers.

Dyslexia, Dyspraxia and Mathematics by **Dorian Yeo (2002)** London: Whurr Publishers

Useful websites

www.bda-dyslexia.org.uk
www.dyscalculia.org.uk
www.dyslexia-inst.org.uk
www.mathematicalbrain.com
www.nfer-nelson.co.uk

Useful organisations

The Dyslexia Institute
133 Gresham Road
Staines
Middlesex
TW18 2AJ

The British Dyslexia Association
98 London Road
Reading
RG1 5AU

Specialist schools

Although there are currently no schools that can be said to specifically cater for pupils with dyscalculia, those schools that have been identified as offering good provision for dyslexic pupils are likely to have experience of dealing with similar learning difficulties in maths. CreSTeD (The Council for the Registration of Schools Teaching Dyslexic Pupils) is a registered charity which is supported by the The British Dyslexia Association and The Dyslexia Institute that produces a register of schools that 'offer excellent and appropriate provision for dyslexic pupils', these schools have gone through an established registration procedure which involves being been visited by a trained consultant to ensure they meet the basic criteria set by the Council and subsequent visits at three yearly intervals to ensure that the criteria are maintained.

The CReSTeD Register is published twice a year and is available from the British Dyslexia Association and the Dyslexia Institute, as well as from the CreSTeD. For more information about CReSTeD or for a copy of the Register, please contact: Christine Manser, CReSTeD Administrator, Greygarth, Littleworth, Winchcombe, Cheltenham, Gloucestershire GL54 5BT. Tel/Fax: 01242 604852. Email: admin@crested.org.uk. Website: www.crested.org.uk

Useful software

The Flying Carpet
Nicholl Education Ltd (www.pyramidmaths.com)

A program with mathematical challenges and games designed for a wide ability range to develop confidence and skill with numbers, shape, logic, chance, time, dates.

Intellimathics
Inclusive Technology (www.inclusive.co.uk)

A multi-feature tool that allows students to use a variety of on-screen manipulatives to solve maths problems. Suitable for pupils who have Maths difficulties.

MathBase 1
Richard Glenberg (author) (www.mathsproject.com)

Very easy-to-use program by a specialist SEN teacher, which focuses on basic numerical concepts. The earliest levels don't use words or numerals at all. Could even help children with severe learning difficulties.

Megamaths Tables
Logotron (www.logotron.co.uk)

Lively animations and bright graphics created along the theme of hearts, clubs, spades and diamonds number cards to help pupils with their table facts.

Number Plane and Number Train
Sherston Software (www.sherston.com)

Programs that provide numeracy activities including recognising and reading numerals and number names. Positive feedback is provided if pupils make mistakes to encourage them to keep trying.

NumberShark
White Space (www.wordshark.co.uk)

A program that is specifically for number work, which contains a wide variety of games. Useful not only for reinforcing number skills, but also for helping pupils who have problems in understanding. basic concepts of number.

Table Aliens
Sherston Software (www.sherston.com)

A program that provides a range of activities set around an 'Aliens from Another Planet' theme – a fun way to encourage pupils to learn their times tables.

Table Road
Granada Learning (www.granada-learning.com)

A program designed to help pupils learn and practise multiplication tables. The non-age specific nature of the context and characters makes it suitable for use with students who have struggled to master multiplication tables.

Other programs

BBC Maths Workshop series, Logotron (www.logotron.co.uk)
Chefren's Pyramid, Nicholl Education Ltd
(www.pyramidmaths.com)
Crystal Rain Forest, Sherston Software (www.sherston.com)
Maths Circus Acts 1, 2 and 3, 4Mation (www.4mation.co.uk)
MicroSmile software, Smile Mathematics
(www.smilemathematics.co.uk)
Mission Control, Sherston Software (www.sherston.com)
MyWorld, SEMERC (www.semerc.com)
Zoombini's Adventures, Broderbund,
(available from www.r-e-m.co.uk)

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