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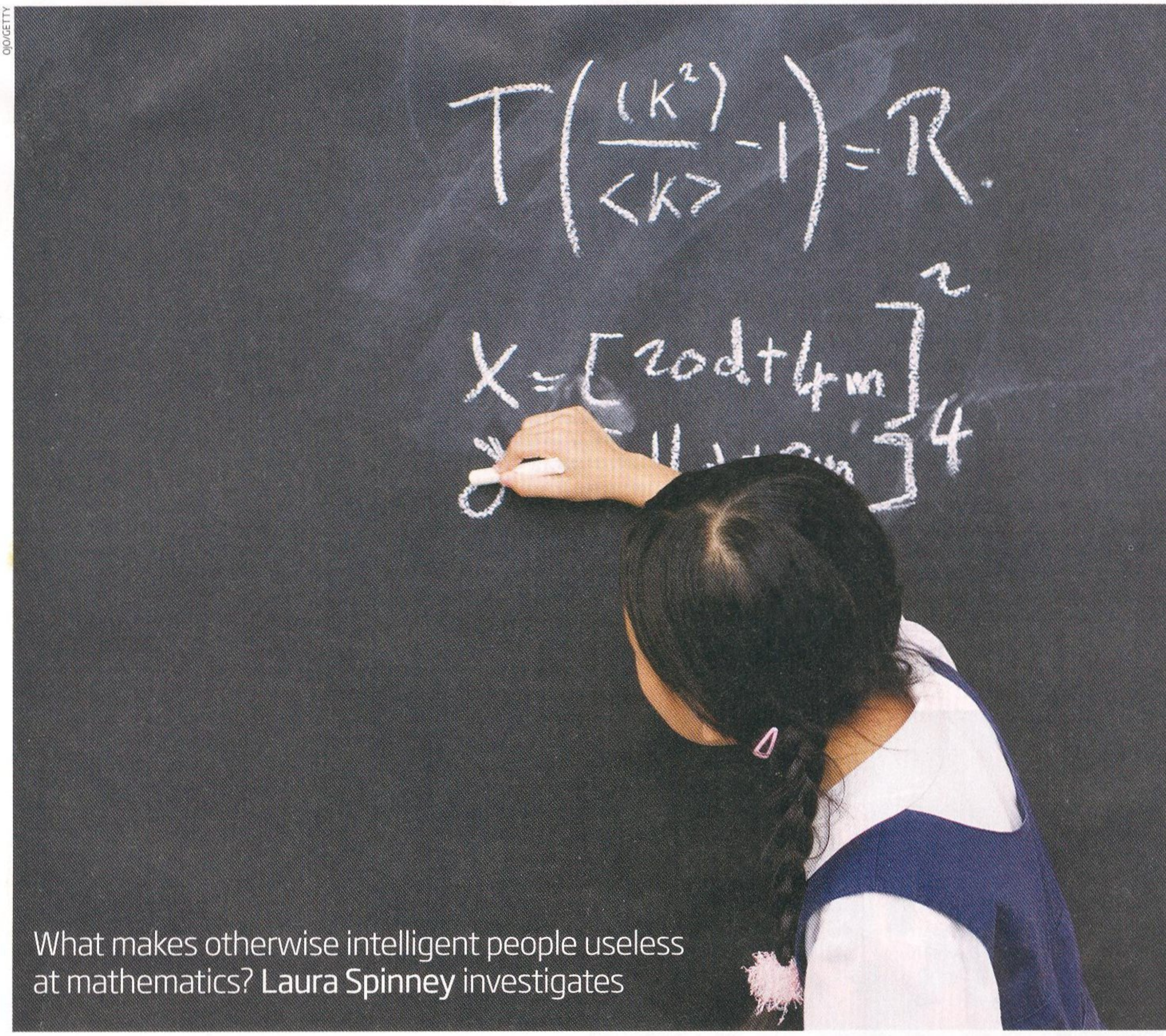
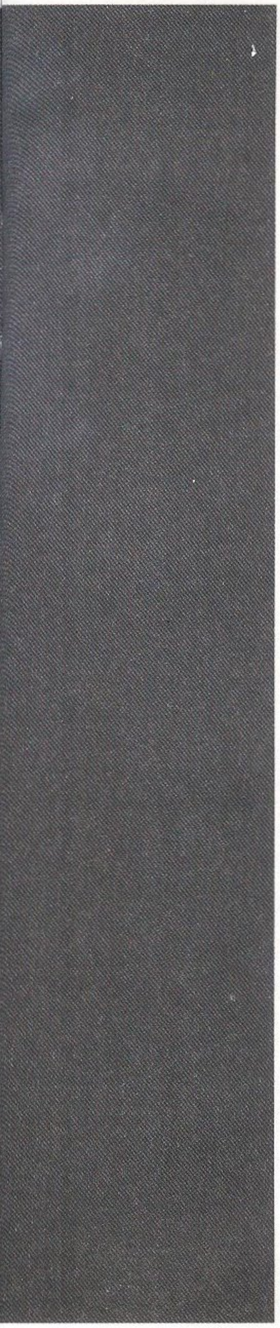


What makes otherwise intelligent people useless at mathematics? **Laura Spinney** investigates

When numbers don't add up



People who struggle with arithmetic may have no problem with more conceptual maths

"Dyscalculics fail to see the connection between a set of objects and the numerical symbol that represents it"

JILL, 19, from Michigan, wants to go to university to read political science. There is just one problem: she keeps failing the mathematics requirement. "I am an exceptional student in all other subjects, so my consistent failure at math made me feel very stupid," she says. In fact, she stopped going to her college mathematics class after a while because, she says, "I couldn't take the daily reminder of what an idiot I was."

Last November, Jill got herself screened for learning disabilities. She found that while her IQ is above average, her numerical ability is equivalent to that of an 11-year-old because she has something called dyscalculia. The diagnosis came partly as a relief, because it explained a lot of difficulties she had in her day-to-day life. She can't easily read a traditional, analogue clock, for example, and always arrives 20 minutes early for fear of being late. When it comes to paying in shops or restaurants, she hands her wallet to a friend and asks them to do the calculation, knowing that she is likely to get it wrong.

Welcome to the stressful world of dyscalculia, where numbers rule because inhabitants are continually trying to avoid situations in which they have to perform even basic calculations. Despite affecting about 5 per cent of people – roughly the same proportion as are dyslexic – dyscalculia has long been neglected by science, and people with it incorrectly labelled as stupid. Now, though, researchers are starting to get to the root of the problem, bringing hope that dyscalculic children will start to get specialist help just as youngsters with dyslexia do.

For hundreds of millions of people this really matters. "We know that basic mathematical fluency is an essential prerequisite for success in life, both at the level of employment and in terms of social success," says Daniel Ansari, a cognitive neuroscientist at the University of Western Ontario in London, Canada. A report published in October 2008 by the British government claimed that dyscalculia cuts a pupil's chances of obtaining good exam results at age 16 by a factor of 7 or more, and wipes more than £100,000 from their lifetime earnings. Early diagnosis and remedial teaching could help them avoid these pitfalls.

People with dyscalculia, also known as mathematics disorder, can be highly intelligent and articulate. Theirs is not a general learning problem. Instead, they have a selective deficit with numerical sets. Put simply, they fail to see the connection between a set of objects – five walnuts, say – and the numerical symbol that represents it, such as the word "five" or the numeral 5. Neither can they grasp that performing additions or subtractions entails making stepwise changes along a number line.

This concept of "exact number" is known to be unique to humans, but there is long-standing disagreement about where it comes from. One school of thought argues that at least some elements of it are innate, and that babies are born with an exact-number "module" in their brain. Others say exact number is learned and that it builds upon an innate and evolutionarily ancient number system which we share with many other species. This "approximate number sense" (ANS) is what you use when you look at two heavily laden apple trees and, without actually counting the apples, make a judgement as to which has more. In this view, as children acquire speech they map number-words and then numerals onto the ANS, tuning it to respond to increasingly precise numerical symbols.

The debate over exact number is directly relevant to dyscalculics, as tackling their problem will be easier if we know what we are dealing with. If we have an innate exact number module that is somehow faulty in people with dyscalculia, they could be encouraged to put more faith in their ability to compare magnitudes using their ANS, and learn to use calculators for the rest. However, if exact number is learned, then perhaps dyscalculia could be addressed by teaching mathematics in ways that help with the process of mapping numbers onto the ANS.

So how do the two models stand up? The innate number module theory makes one obvious prediction: babies should be able to grasp exact numbers. This was explored in the early 1990s. Using dolls, a screen and the fact that babies stare for longer at things that surprise them, developmental psychologist Karen Wynn, then at the University of Arizona in Tucson, showed that five-month-old infants could discriminate between one, two and three. They look for longer if the number of dolls that come out from behind the screen does not match the number that went in.

Some teams have taken a different approach to show that we are born with a sense of exact number. They argue that if exact number is learned, it ought to be influenced by language. Brian Butterworth from University College London recently did tests of exact number on children aged 4 to 7 who spoke only Warlpiri or Anindilyakwa, two Australian languages that contain very few number words. He found no difference in performance between the indigenous children and a control group from English-speaking Melbourne (*Proceedings of the National Academy of Sciences*, vol 105, p 13179). This, he says, is evidence that "you're born with a sense of exact number, and you › map the counting words onto pre-existing concepts of exact numbers".

Both of these approaches, however, have been criticised. Neuroscientist Stan Dehaene of the Collège de France in Paris points out that Wynn's finding also fits the rival theory – that babies enter the world with only an intuition about approximate number. This is because the ANS is concerned with ratios, so is reasonably reliable when the numbers involved are small, but falls off as the proportional size difference shrinks. A size ratio of 1:2 is more easily discernable than 9:10. Wynn tested babies on small numbers and, as Dehaene points out, "one versus two is a large ratio".

Count on learning

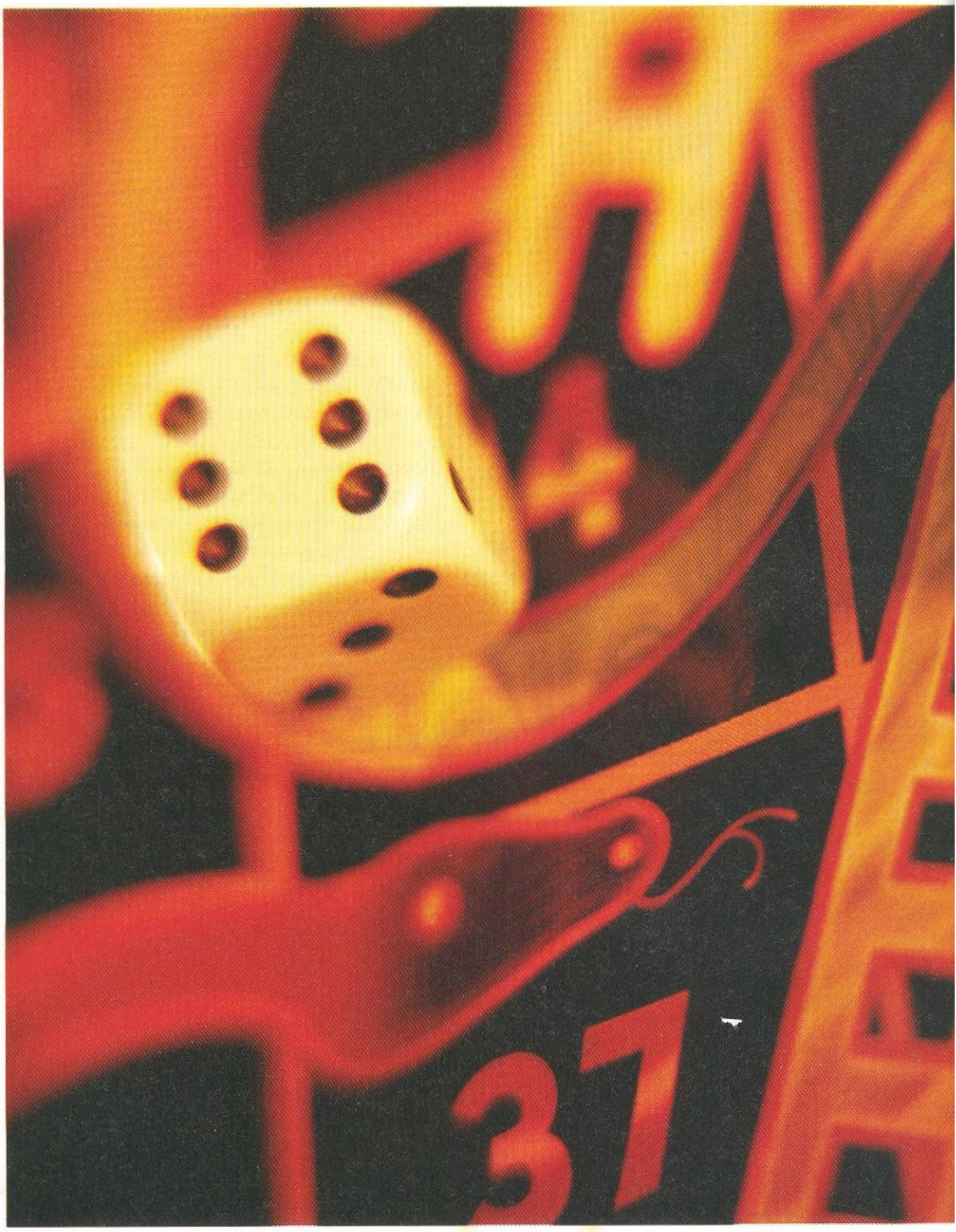
What is more, Dehaene has worked with an Amazonian tribe whose language only contains words for numbers up to five, and says it provides good evidence for the idea that exact number is learned (see "One, two, lots").

Supporters of the idea that exact number is learned also point to research showing how young children actually acquire an understanding of numbers. First they learn what the number word "one" means, then "two" and so on until, around the age of 4, they suddenly grasp the underlying concept of the number line and counting. "There is something very special occurring in development with exact numbers, and with the understanding of number words," says Dehaene.

For now, the idea that exact number is learned has the upper hand, suggesting that dyscalculia is a learning problem. To complicate things further, however, new research indicates that this may only be part of the story.

It was long thought that the ANS contributes little to performance in mathematics. As it is essential for survival skills such as foraging, it was assumed that everyone would have comparable abilities with approximate number. This myth was exploded in 2008 when Justin Halberda of Johns Hopkins University in Baltimore, Maryland, tested the ANS in 64 14-year-olds and was "blown away" by the variability he found (*Nature*, vol 455, p 665).

The teenagers, all of whom fell within the normal range for numeracy, watched an array of dots made up of two colours flash onto a computer screen. In each case, they had to say which colour was more numerous. As expected, their judgements became less accurate as the size ratio of the two sets shrank towards 1:1. The surprise was how much faster accuracy fell off in some kids than in others, with the poorest performers having difficulty with ratios as large as 3:4.



KATHY COLLINS/TAXI

"First children learn what "one" means, then "two", and so on until they suddenly grasp the underlying concept"

There was a further surprise in store when the team compared the teenagers' ANS scores with their mathematics test results from the age of 5 and up. "I literally jumped out of my seat when I saw the correlation going all the way back to kindergarten," says Halberda. The link remained even after IQ, working memory and other factors had been controlled for, and it only held for mathematics, not for other subjects. A subsequent larger study, including some children with dyscalculia, confirmed the suspicion that those with the number disorder had markedly lower ANS scores than children with average ability. This implicates a faulty ANS in dyscalculia.

Case closed? Not quite. The problem is that two other groups have come up with conflicting findings. In 2007, Laurence Rousselle and Marie-Pascale Noël of the Catholic University of Louvain (UCL) in Belgium reported that dyscalculic children, when asked to compare the magnitude of collections of sticks – say, five sticks versus

A game like snakes and ladders can help children develop a sense of exact number

ONE, TWO, LOTS

Amazonian hunter-gatherers called the Mundurucú only have words for numbers up to 5. Does this affect the way they think about mathematical problems? Experts who think that the human concept of exact number is innate would predict not. However, Stan Dehaene of the Collège de France in Paris is among a growing number who believe that exact number is learned and therefore affected by our culture. He decided to test this idea with the Mundurucú.

Working with his colleague in the field, Pierre Pica, and others, Dehaene has found that the Mundurucú can add and subtract with numbers under 5, and do approximate magnitude comparisons as successfully as a control group. But last year the team discovered a big cultural difference. They asked volunteers to look at a horizontal line on a computer screen that had one dot at the far left and 10 dots to the right. They were then presented with a series of quantities between 1 and 10, in different sensory modalities - a picture of dots, say, or a series of audible tones - and asked to point to the place on the line where they thought that quantity belonged.

English-speakers will typically place 5 about halfway between 1 and 10. But the Mundurucú put 3 in the middle, and 5 nearer to 10 (*Science*, vol 320, p 1217). Dehaene reckons this is because they think in terms of ratios - logarithmically - rather than in terms of a number line. By the Mundurucú way of thinking, 10 is only twice as big as 5, but 5 is five times as big as 1, so 5 is judged to be closer to 10 than to 1.

The team conclude that "the concept of a linear number line appears to be a cultural invention that fails to develop in the absence of formal education". With only limited tools for counting, the Mundurucú fall back on the default mode of thinking about number, the so-called "approximate number system" (ANS). This is logarithmic, says Dehaene. When it comes to negotiating the natural world - sizing up an enemy troop or a food haul - ratios or percentages are what count. "I don't know of any survival situation where you need to know the difference between 37 and 38," he says. "What you need to know is 37 plus-or-minus 20 per cent."

seven – performed no worse than controls. However, they struggled when asked to circle the larger of two numerals, such as 5 and 7. Ansari's team has obtained a similar result. Both teams conclude that in dyscalculic children the ANS works normally, and the problem comes in mapping numerical symbols onto it.

How to account for these contradictory findings? Halberda, Ansari and Dehaene believe that there may be different types of dyscalculia, reflecting different underlying brain abnormalities. So in some dyscalculic individuals, the ANS itself is damaged, while in others it is intact but inaccessible so that individuals have problems when it comes to mapping number words and numerals onto the innate number system.

The existence of such subtypes would make dyscalculia harder to pin down, and make it difficult to design a screening programme for schoolchildren. At the moment, the condition goes widely unrecognised, and testing is far from routine. But where it is tested for, the tests are relatively crude, relying on the discrepancy between the child's IQ or general cognitive abilities and their scores in mathematics. Nevertheless, perhaps one day all children entering school will be assessed for various types of dyscalculia. Then teachers may be able to start intervention programmes based on teaching tools that are currently being tested.

One such tool, called The Number Race, in which children compete against a computer for rewards in a series of treasure hunts and other games, has been created by Dehaene and his colleague Anna Wilson. It assumes that the problem lies with the exact number system, so begins with tasks that the ANS is good at, involving numerical comparison, and gradually moves to more difficult tasks such as addition and subtraction. Testing of its effects is ongoing, but early indications are that it may help to bolster dyscalculic children's concept of number and simple transformations of numerical sets.

Even those researchers who remain convinced that dyscalculia is caused by a faulty exact number module believe that intervention could help. "After all, genetics isn't destiny – well, not entirely – and the brain is plastic," says Butterworth. His team is testing a piece of software that it designed in collaboration with the London Knowledge Lab to strengthen dyscalculic schoolchildren's basic number concepts. He suspects this will not be enough, however: "It may be the case that the best we can do is teach them strategies for calculation, including intelligent use of calculators, and get them onto doing more accessible branches of mathematics, such as geometry and topology."

Ansari also points out that children with dyscalculia could be helped immediately by practical measures already in place in schools for pupils with dyslexia, such as extra time in exams. And, of course, simply recognising dyscalculia as a problem on a par with dyslexia would make a huge difference. As Jill says, now that she knows what her problem is, "it's easier to have the confidence and the perseverance to keep working until I get it". That, in turn, means the condition becomes less damaging to her self-esteem and perhaps, ultimately, to her chances in life. ■

Laura Spinney is a writer based in Lausanne, Switzerland