Dyscalculia: Number games

Brian Butterworth hopes that his number games will help dyscalculic children — and open a window on how the brain processes numbers.

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In the mid-1980s, Paul Moorcraft, then a war correspondent, journeyed with a film crew into Afghanistan to produce a documentary about the fifth anniversary of the Soviet invasion. The trip took them behind Soviet lines. “We were attacked every fucking day by the Russians,” says the colourful Welshman. But the real trouble started later, when Moorcraft tried to tally his expenses, such as horses and local garb for his crew. Even with a calculator, the simple sums took him ten times longer than they should have. “It was an absolute nightmare. I spent days and days and days.” When he finally sent the bill to an accountant, he had not realized that after adding a zero he was claiming millions of pounds for a trip that had cost a couple of hundred thousand. “He knew I was an honest guy and assumed that it was just a typo.”

Such mistakes were part of a lifelong pattern for Moorcraft, now director of the Centre for Foreign Policy Analysis in London and the author of more than a dozen books.

He hasn't changed his phone number or PIN in years for fear that he would never remember new ones, and when working for Britain's Ministry of Defence he put subordinates in charge of remembering safe codes. In 2003, a mistaken phone number — one of hundreds before it — lost him a girlfriend who was convinced he was out gallivanting. That finally convinced him to seek an explanation.

At the suggestion of a friend who teaches children with learning disabilities, Moorcraft contacted Brian Butterworth, a cognitive neuroscientist at University College London who studies numerical cognition. After conducting some tests, Butterworth concluded that Moorcraft was “a disaster at arithmetic” and diagnosed him with dyscalculia, a little-known learning disability sometimes called number blindness and likened to dyslexia for maths. Researchers estimate that as much as 7% of the population has dyscalculia, which is marked by severe difficulties in dealing with numbers despite otherwise normal (or, in Moorcraft's case, probably well above normal) intelligence.

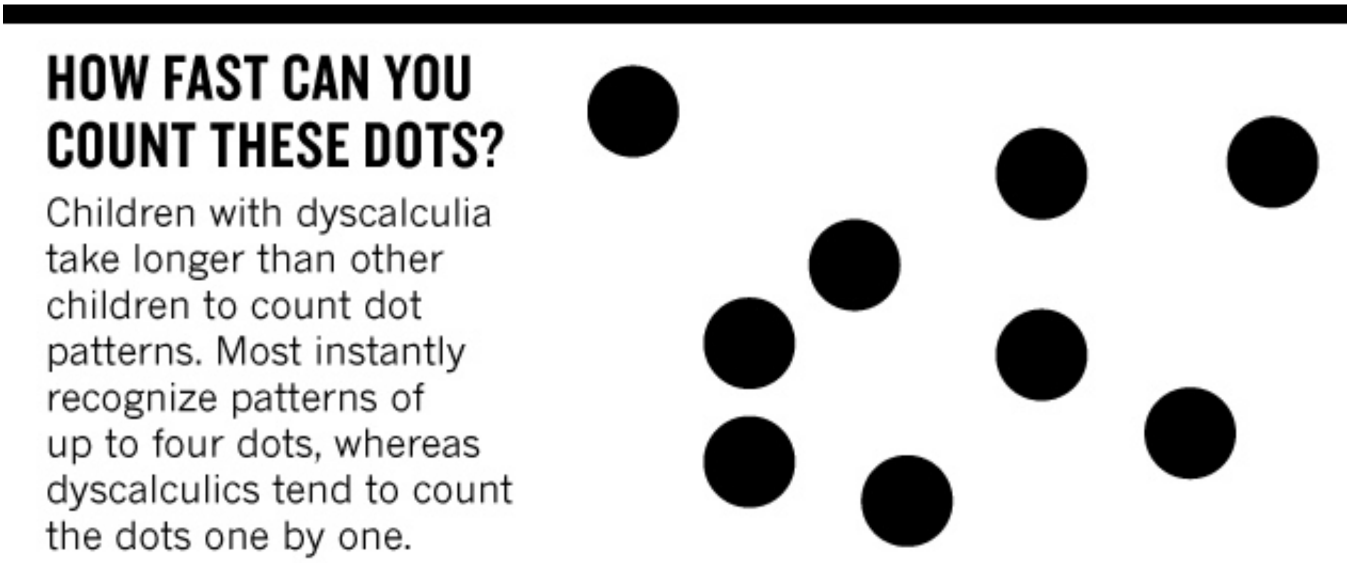
That combination has attracted neuroscientists such as Butterworth, who believe that the disorder illuminates the inner workings of the brain's number sense — the ability to understand and manipulate quantities. This sense is every bit as innate as vision or hearing, yet scientists disagree over its cognitive and neural basis, a debate that dyscalculics may help to settle.

For Butterworth, scientific curiosity eventually gave way to advocacy. “I thought, it's not enough to just try to identify the cause,” he says. In the past decade, he has crusaded to get dyscalculia recognized — by parents, teachers, politicians and anyone who will listen. And he is using his scientific insights into the condition to help dyscalculic children. “What's the point of telling someone they have dyscalculia if you can't help them?” he says.

Finding the number

Christopher, a chatty nine-year-old in a rumpled blue sweatshirt and white polo shirt, sits beside Patricia Babtie, a teacher who specializes in dyscalculia and tutors children across Greater London. On a sturdy-looking laptop, Christopher (not his real name) is navigating Number Sense, a suite of educational computer games designed by Butterworth and his colleague Diana Laurillard at the Institute of Education in London.

By developing treatments for dyscalculia, Butterworth hoped to test competing theories about the cognitive basis of numeracy. If, as he believes, dyscalculia is at heart a deficiency of basic number sense and not of memory, attention or language, as others have proposed, then nurturing the roots of number sense should help dyscalculics such as Christopher. "It may be the case that what these kids need is just much more practice than the rest of us," Butterworth says. Christopher's school is one of several in London working with the software, and students in Cuba, Singapore and elsewhere will also soon start using it.



Christopher starts with a game involving a number line — a spatial representation that scientists believe is key to number sense. "What is the number that is right in the middle between 200 and 800? Do you know it?" Babtie asks. Christopher shrugs. "Think of any number that is bigger than 200 and smaller than 800 and put it in this box. It could be 201," she says. He enters 200, and Babtie reminds him that the number needs to be greater than 200. He selects 210, probably mistaking it for 201. A classic sign of dyscalculia is difficulty in grasping the place-value system, according to Babtie. "That will do fine," she says. A soft computer voice tells Christopher to "find the number and click it". The game involves zooming in and zooming out to rescale the number line, and Christopher talks through each move — a strategy that Babtie encourages — but it takes him more than a minute to locate 210. His classmates, meanwhile, are learning to multiply two-digit numbers.

Some children at Christopher's school have more profound numeracy problems. One nine-year-old classmate says that she doesn't know if 50 is greater or less than 100; another the same age confuses four dots for five and routinely tots up small sums on his fingers, a common strategy for dyscalculics.

“OK, time to stop. We'll do some more of this another day,” Babtie says to Christopher, after 20 frustrating minutes. It is clear he would rather be back in class than here in this room practising a skill his classmates learned years ago.

How many are there?

Butterworth, now 69, straddles the academic and public spheres. A fellow of the British Academy, the United Kingdom's national body for the humanities and social sciences, he made his name probing obscure speech and language disorders and has appeared in the British media for many years. In a *Sunday Times* article in 1984, for example, Butterworth claimed that the speech patterns of former US president Ronald Reagan indicated Alzheimer's disease. Reagan was diagnosed with the condition a decade later.

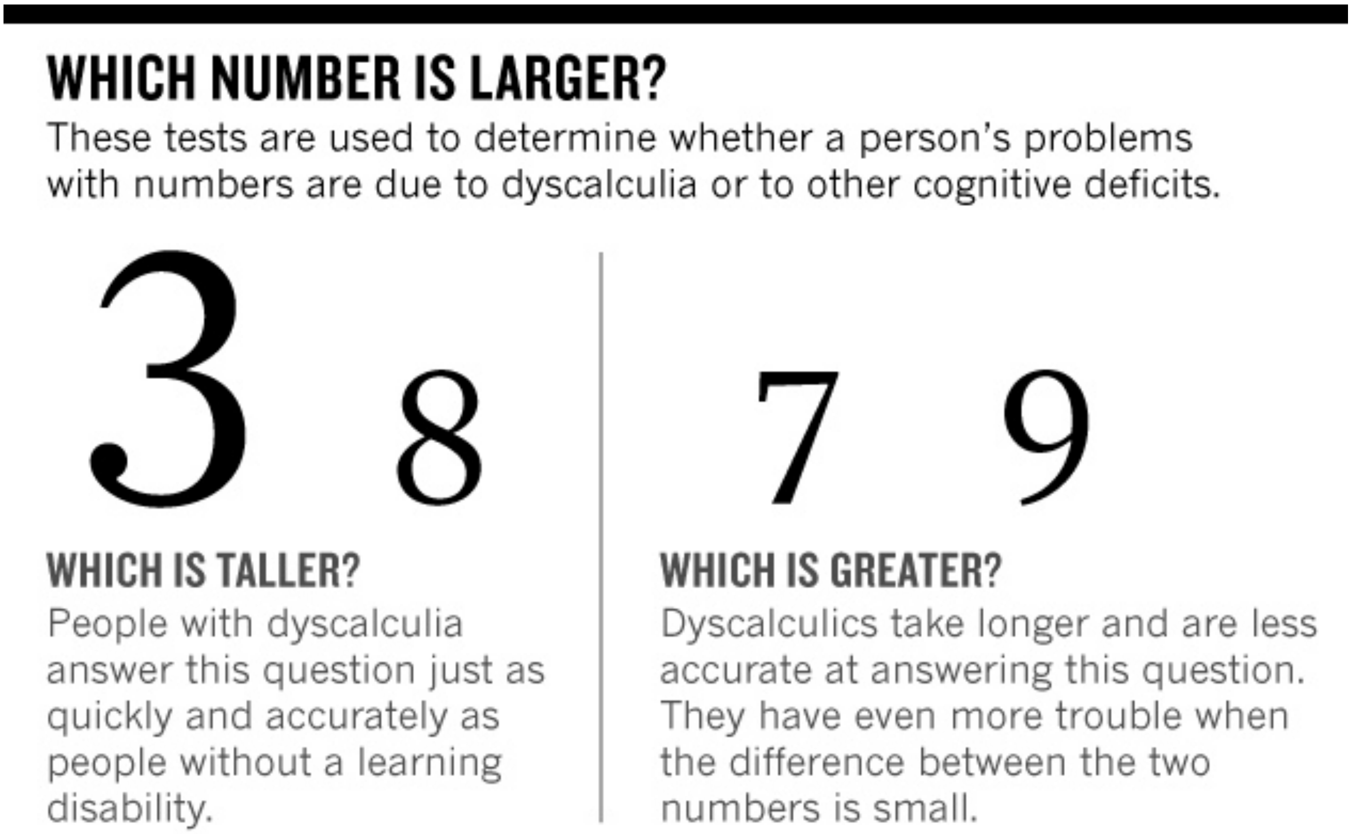
In the late 1980s Butterworth studied a stroke patient who would change the course of his professional life. The woman, a 59-year-old former hotel manager from Italy, fared about average on verbal IQ tests and had a good memory, but when Butterworth's Italian colleagues asked her to count, she would start, “*uno, due, tre, quattro*,” and then stall. “*Miei matematica finisce alle quattro*” — my mathematics stops at four — the woman, known as CG, would tell them.

Neurologists had presented case studies of 'acalculic' patients such as CG from the early twentieth century onwards, if not before, but “people hadn't thought a lot about the specific brain areas involved in calculation”, says Butterworth. Brain scans of CG revealed a lesion in the parietal lobe, a part of the brain just above the ears. Later, Butterworth found another patient with the opposite pattern of disability: neurodegeneration had robbed him of speech, language and much of his knowledge, save for the ability to do intricate calculations. Butterworth grew more certain that numerical abilities relied on specialized brain networks, and not only on those supporting general intelligence, as many scientists believed at the time.

Genetics and the vagaries of brain development disrupted these networks in dyscalculics, Butterworth proposed. And Moorcraft was one of Butterworth's most revelatory subjects because of the great disparity in his abilities in different domains. Butterworth and his colleagues also tested 31 eight- and nine-year-old children who were near the bottom of their class in mathematics but did well enough in other subjects.

Compared with normal children and those with dyslexia, the dyscalculic children struggled on almost every numerical task, yet were average on tests of reading comprehension, memory and IQ.

The study confirmed for Butterworth that developmental forms of dyscalculia are the result of basic problems in comprehending numbers and not in other cognitive faculties. But determining exactly what those problems are would prove challenging.



Like nearly all human cognitive abilities, number sense is evolutionarily ancient — tens if not hundreds of millions of years old. Studies of chimpanzees, monkeys, newborn chicks, salamanders and even honeybees point to two parallel systems for representing quantities. One, called the approximate number sense, distinguishes larger quantities from smaller ones, be they dots flashing on a screen or fruits in a tree. Studies on monkeys reveal that certain neurons in a specific fold of the parietal lobe fire more vigorously in response to increasingly higher numbers. A second ancient number system allows humans and many other animals to instantly and precisely recognize small quantities, up to four. Primate studies show that individual neurons within the same fold, called the intraparietal sulcus, seem tuned to particular quantities, such that when a monkey is performing a task that involves numbers, one neuron will fire for the number 1, a different one will fire for 2 and so on.

People who are poor at distinguishing approximate quantities do badly in maths, suggesting that the approximate-number system is crucial. And some work shows that dyscalculics are poor at recognizing small numbers, suggesting that this ability is also fundamental to numeracy. Moreover, scans of people with dyscalculia suggest that their intraparietal sulci are less active when processing numbers and less connected with the rest of the brain compared with numerate children and adults.

Yet Butterworth views such results as consequences, not causes, of the poor numerical abilities that characterize dyscalculia. He argues that another cognitive capacity is even more fundamental to number sense. He calls this 'numerosity coding': the understanding that things have a precise quantity associated with them, and that adding or taking things away alters that quantity.

But Stanislas Dehaene, a cognitive neuroscientist who studies numerical cognition at INSERM, France's national institute for research on medicine and health, near Paris, sees number sense as being supported by a broader set of cognitive features. Approximation and a sense of small numbers, while critical, are not enough for humans to precisely grasp large numbers, he says. Language, he argues, empowers humans to integrate the two number systems — giving them the ability to intuitively distinguish, say, 11,437 from 11,436. Butterworth's concept of numerosity coding may be an important part of number sense, says Dehaene, but there is still much to learn about it — for instance, whether it is present in other animals or in children from a very early age.

One of Butterworth's favourite papers is titled 'Six does not just mean a lot: preschoolers see number words as specific'. In it, the developmental psychologist Barbara Sarnecka, now at the University of California, Irvine, and Susan Gelman, at the University of Michigan in Ann Arbor, showed that young children who could not yet count past two nonetheless understood that adding pennies to a bowl containing six somehow altered its number, even if the children couldn't say exactly how. If numerosity coding is fundamental, it predicts that dyscalculics such as Moorcraft or Christopher struggle to enumerate and manipulate all numbers, large and small. Butterworth hopes that, by honing this ability, the Number Sense games will help support his research ideas.

Three months on, Christopher seems to be faring better at the number-line game, going so quickly that Babtie asks him to slow down and explain his reasoning for each move. Babtie says that dyscalculic children tend to learn much more quickly when they talk through what they do. She also believes that Christopher's maths anxiety, a near-universal trait of child and adult dyscalculics, is fading.

He moves on to a Tetris-like game called Numberbonds, in which bars of different lengths fall down the screen, and he is asked to select a block of the correct size to fill out a row. This emphasizes spatial relationships, which some dyscalculics also struggle with. The blocks move too quickly at first, frustrating Christopher, but he soon gets the hang of it, and when Babtie suggests he stop for the day, he begs for ten more minutes.

"Every day they go to school. Every day there's a maths class. Every day they're shown up to be incompetent."

The Number Sense games, including a snazzy-looking iPhone version of Numberbonds, are intended to nurture the abilities that, Butterworth contends, are the root of numerical cognition and the core deficit of dyscalculia — manipulating precise quantities. In a game called Dots to Track, for example, children must ascribe an Arabic numeral to a pattern of dots, similar to those on dice. When they enter the wrong value — and they often do — the game asks the children to add or remove dots to achieve the correct answer.

As the summer holidays approach, Babtie is worried that Christopher and the other students she has been working with won't practise the games at home, returning in the autumn the worse for it. But in early October when school is back, Christopher announces that he will challenge himself with a number line that stretches from 950 to 9,000, "if you'll allow me", he adds. At first he flounders, but quickly starts to understand the game and locates a string of four-digit numbers, beaming with each correct response.

Other students are improving more slowly, but it is not easy to say why. Dyslexia, attention deficit hyperactivity disorder and autism spectrum disorder are common among dyscalculics, and it can be difficult to untangle these problems, says Babtie. The nine-year-old who counted on his fingers nine months ago can now deal with numbers below 6, but still struggles to distinguish 9 from 10. Yet with the right practice and attention from teachers and parents, dyscalculic children can thrive, says Babtie, who emphasizes that computer games are a supplement, not a replacement, for one-on-one tutoring.

Butterworth knows that it will take a controlled evaluation of Number Sense before he can say if the game genuinely improves numeracy in dyscalculic children. Small studies of other computer-based interventions hint that they might help. Dehaene reported in 2009 that Number Race, a game his group developed, modestly improved the ability of 15 dyscalculic kindergarten children to discern the larger of two numbers, but that it had no effect on their arithmetic or counting. Meanwhile, a Swiss team reported in 2011 that a game that involves placing a spaceship on a number line helped eight- to ten-year-old dyscalculics with arithmetic. The researchers also studied the children in an fMRI scanner during a task that involved arranging numbers. They found that one month after training, the children showed increased activation in the intraparietal sulcus and reduced neural activation elsewhere in the parietal lobes — a hint that their improvements in arithmetic were related to changes involving brain areas that respond to number.

Butterworth hopes to monitor the brains of students such as Christopher as they practise Number Sense, to see if their parietal lobes are indeed changing. But he has been turned down by every funding source he has applied to. Although dyscalculia, like other learning disabilities, takes a toll on productivity (one report estimated that low numeracy costs the United Kingdom £2.4 billion (US$4 billion) per year, mostly in lost wages) it doesn't attract much attention or money. In the United States, for example, the National Institutes of Health spent $2 million studying dyscalculia between 2000 and 2011, compared with more than $107 million on dyslexia.

Butterworth's team now has tentative plans to evaluate its software with researchers at the Cuban Neurosciences Center and the University of Pedagogical Sciences in Havana next year, and the group is also placing the game in other countries, including China and Singapore. “The Cubans, curiously, are putting money into this, even though they've got very little,” Butterworth says, commending the strength of the country's education system.

Although an emeritus professor, technically retired, Butterworth continues to research the neurodevelopmental roots of number sense, recently showing that guppies, like humans, possess approximate and precise number systems, and that dyscalculic adults have no more trouble telling the time than numerate people.

He hopes that Number Sense — if it can improve dyscalculia — will help him in the academic debate over the cognitive basis of numeracy. But Dehaene, probably his most fervent opponent in that debate, isn't counting on classroom computer games to resolve it. His Number Race game and its successor, Number Catcher, incorporate a multitude of numerical skills, so even if the game works, it won't address the theoretical differences about which skills are most essential to number sense or most compromised in dyscalculics. “I quickly realized that the interest of the children was to have a fun game full of ideas and variety, and that was not very compatible with an analytic approach,” he says.

Butterworth, too, says that he is ultimately more motivated by helping children. In the course of his studies, he was struck that children “were very, very distressed by being bad at maths. So every day they would go to school, every day there's a maths class, every day they're shown up to be incompetent in a way other kids in their class are not”, he says.

Moorcraft can commiserate. When he occasionally meets dyscalculic children, he tells them that he, too, counts with his fingers under the table, that they have nothing to be embarrassed about and that, with the practice that he never got, they can get up to speed.

Moorcraft is also completing a book on dyscalculia with one of Butterworth's postdocs. “I have written an introduction,” he says. “I just hope the chapters are in the right order.”