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This is your brain on math

Science is learning how humans take basic number sense to higher level

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By GEOFF KOCH / The Dallas Morning News

Put two piles of coins on a table, one with two pennies and the other with nine. It's a snap to tell where the profit is. Next, compare piles of two and three pennies. Even for a monkey, it's still a quick calculation.

Do it again, but this time compare stacks of 16 and 17 coins. Chances are, your selection process slows down. These math tendencies may come from a common set of nerve cell circuits seen in many species, new research suggests. Mathematical intuition may be as much a product of hardwiring as of hard work.

Scientists have known for years that young children and animals share the same basic math skills. Researchers suspected that these skills were built on brain circuitry descended from evolutionary ancestors. New ways of peering into heads confirm that the same regions of the brain light up when people and rhesus monkeys judge quantities.

"It's not a surprise; more like a relief, actually," says Earl Miller, a neuroscientist at the Massachusetts Institute of Technology.

Using scanning technology, Dr. Miller and others have found evidence of number-specific circuitry in the brains of people and animals. This same scanning technology, combined with a bit of evolutionary biology, is revealing secrets of the extreme math-elite, and of boys' apparent math advantage over girls.

As infants, boys and girls alike have no trouble telling the difference between snack sizes. Ten-month-olds who watch someone place one cracker in a pail and two crackers in another consistently choose the pail with the bigger reward. Small primates called tamarins peer longer at three Froot Loops than two. Even red-backed salamanders, faced with a choice, are more tantalized by the test tube that contains more fruit flies.

Despite the similarities in behavior, there was always the chance that underlying brain wiring was different. Calculators and abacuses both can add two plus three, even though the two machines take different approaches to the same result. Dr. Miller's relief comes from the fact that nature, by contrast, seems to have laid down one well-worn path to math.

To listen to the footsteps on this path, Dr. Miller and his collaborator, neuroscientist Andreas Nieder, inserted tiny wire electrodes directly into 50 individual brain cells per monkey. "It's a totally painless procedure," Dr. Miller notes. The two researchers published their results recently in the Proceedings of the National Academy of Sciences.

Recording from multiple electrodes allows researchers to pin down the contributions of different brain areas.

"We can answer: 'Where is certain information first encoded? And how is it processed later on?" says Dr. Nieder of the University of Tübingen in Germany.

Drs. Nieder and Miller found these number networks in two areas of the brain. The first is the prefrontal cortex. Situated behind the forehead, it is much like an executive or general manager, guiding and orchestrating complex behavior. The second is the parietal cortex. Place a hand on top of your head and you're near this region, the onsite civil engineer or architect, in charge of spatial reasoning.

These executives and engineers are not just in brains of humans. Scientists reason that there are sound evolutionary explanations behind the development of math intuition across much of the kingdom.

When you survive by foraging, it pays to be able to distinguish how much of a food resource exists. Faced with a choice between a clump of five bananas or six, if you continually chose the smaller quantity, then it's unlikely that you'd thrive as much as your more number-savvy peers.

In an environment with limited resources, distinguishing even subtle differences might be enough to increase competitive advantage, Dr. Miller says.

Among rhesus monkeys, a social pecking order exists and it's important for a monkey to know its position relative to the rest of the group. Knowing whether five or six monkeys have your back can help you decide whether you should opt for a posture of aggression or appeasement.

Compressed counting

Evolutionary theory helps explain another of Dr. Nieder and Dr. Miller's results. Numbers in the brain seem to be represented on a compressed number line, they found.

For example, your mental number line might count up "one, two, three ... " for small quantities. But by the time you get into the hundreds, the ticks on that line, still separated by the same distance, might count up "125, 150, 175 ... "

One advantage of this system is that larger numbers could be represented with a smaller proportion of nerve cells. The trade-off, though, is increased difficulty in discriminating between large numbers. Hence the trouble in judging stacks of 16 vs. 17 pennies.

Compressed counting is similar to the way sensory information, such as light intensity, is processed in the brain. "We suggest that the brain has built upon principles that were originally developed for lower-level abilities, like perception," Dr. Nieder says. These basic principles might be the foundation of high-level human-only abilities, such as complex counting.

More brainpower

The hardwiring of these higher-level tasks is what interests Michael O'Boyle, a neuropsychologist at the University of Melbourne in Australia. He studies the brains of whiz kids who ace the math portion of the college entrance exam.

It turns out it's not just hard work that puts these kids in the top 1 percent of test takers. Scans show brains with a higher than average activation level. "They have more processing power," says Dr. O'Boyle, who is moving to Texas Tech University in August.

For everyone, genius or otherwise, the brain's processing power is split into two hemispheres. Logical, sequential thinkers often think of themselves as left-brained. Those who are more intuitive and better at synthesizing diverse ideas often tout their right-brained status.

It's a rough distinction and there are lots of subtleties that scientists have discovered over the years. For instance, now they know that the left hemisphere is better at perceiving fine details, like individual brush strokes in an impressionist painting. The right hemisphere is better at taking in the big picture.

Extreme math-heads are equally good at brush strokes and big-picture processing, Dr. O'Boyle reported in a recent issue of the journal Neuropsychology. This suggests lots of interaction and cooperation between hemispheres.

Some amount of cooperation between the two sides of the brain happens for everyone. But compared with single-side processing, most people slow down and make more mistakes when using both halves of their head.

Math brains, by contrast, work considerably faster and make fewer mistakes when hemispheric handshaking is involved.

"The bottom line is that, for spatial reasoning and higher-level tasks, these kids can call on bigger guns than the rest of us," Dr. O'Boyle says.

Why more boys

Beyond piecing together the brains of the math elite, Dr. O'Boyle is interested in another puzzle - why boys are more likely to be members of that elite than girls.

Math-giftedness appears six to 13 times as often in boys, the American Psychological Association reports. Prenatal exposure to testosterone, which selectively benefits the right hemisphere of the brain, is thought to be one reason.

"It's part of the hunter-gatherer story," Dr. O'Boyle says. Tens of thousands of years ago, it paid off for men, the hunters, to analyze patterns of animal migration and use dead reckoning to find prey in different locations. So there was strong selective pressure for enhanced right brain activity.

Today this boosted right brain activity is used to piece together complex computer programs or apply a variety of concepts to solve an especially thorny math problem. It's also part of the reason university math and computer science departments are predominantly full of men, Dr. O'Boyle says.

In U.S. universities, men receive 70 percent of all math doctorates and represent 76 percent of mathematics faculties, the Mathematical Association of America reports.

But even the brains of nonmath professors are remarkable math machines. While systems to gauge the magnitude and distance between small numbers seem hardwired, ancient history and current wiring do not hopelessly chain the human brain. And no matter their SAT score, people are capable of much more than comparing piles of pennies.

After language

"As soon as we develop language, a precise counting system builds up on the older magnitude system, allowing us to perform arithmetic and math," says Dr. Nieder. "Animals and human infants solely rely on the magnitude system; only adult humans are able to count in a precise way."

Precise counting is a step on the way to making sense of complexity. In addition to basic wiring for numbers, other mental circuitry helps people relate to mechanical systems, physical objects and other living creatures. Much like a computer that works to open and read files of different formats, people seem compelled to reconcile the different results returned by these different sets of circuitry.

Children show this drive when they struggle with their basic intuition to learn the meanings of words like seven, write Johns Hopkins' Lisa Feigensen, Harvard's Elizabeth Spelke, and Stanislaus Dehaene, research director at INSERM, the French equivalent of the U.S. National Institutes of Health. Newton and Liebniz may have been doing the same thing when they invented calculus, "stretching their systems of numerical and mechanical knowledge so as to reconcile them," the scientists write in an upcoming article in the journal Trends in Cognitive Sciences.

It's not clear that this drive allows people to transcend the hard and fast wiring in their skulls. It may be easy enough to step off the path for math that shows up on the neuroscientists' brain scans, but finding your way to an interesting destination is another matter.