Stanford researcher explores whether language is the only way to represent numbers

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The Mental Calculation World Cup is a brutal contest, and one that threatens to fry the neurons of the unprepared. Over the course of a competition, contestants might be asked to add a string of 10 different 10-digit numbers, multiply 18,467,941 by 73,465,135, find the square root of 530,179 and determine which day of the week corresponds to Aug. 12, 1721 – all without writing anything down.

The speed with which the winners complete these tasks is remarkable. The World Cup record for finding the square roots of 10 six-digit numbers, for instance, is six minutes and 51 seconds. Even more remarkably, the holder of that record is 11 years old.

Priyanshi Somani, the tween-age reigning Mental Calculation World Champion in question, uses a method called "Mental Abacus." It's an increasingly popular teaching tool, particularly in India. And, according to a paper published online last week in the Journal of Experimental Psychology: General, it may represent one of the first known examples of non-language-based mental calculation. Michael Frank, an assistant professor of psychology at Stanford, is co-author of the paper, with David Barner, assistant professor of psychology at the University of California-San Diego.

Although animals and pre-language infants are able to keep track of small numbers and can approximately judge large quantities, they can't

conceptualize exact larger numbers. Infants can't distinguish between three and six apple slices.

This inability begins to disappear as infants develop the language skills necessary for counting, which suggests that mental representations of large, exact quantities are often tied to language.

"But," Frank said, "all of that leaves open the question of whether language is really the only way to represent numbers."

Mental Abacus, or MA, suggests the answer is no. It advises practitioners to visualize a 400-year-old style of abacus known as a soroban. Students often flick their fingers when they calculate, miming the movement of abacus beads.

Researchers have suggested that MA makes use of visual, instead of verbal, working memory. But the theory leaves a major question unanswered.

"There are a limited number of things that we explicitly remember," said Frank. People are only able to hold three to four separate items in the visual working memory at any one time. In contrast, an MA calculation might involve the manipulation of fifteen beads. "Given these limitations, we were confused about how a whole abacus could be represented in working memory."

In their paper, Frank and Barner address this mystery. The researchers demonstrated that MA does, in fact, involve visual manipulations of an imagined abacus – but that the visual working memory stores information about each abacus column, rather than each bead.

The researchers examined elementary school students in India's Gujarat Province, where MA is taught in a three-year afterschool program.

Children went through a series of timed addition games that adjusted their difficulty to the user's skill level.

Frank and Barner found that the children's impressive calculating abilities dropped off sharply when they were asked to add four-digit numbers.

Each new place value requires a new abacus column – the rightmost column is the ones place, the next is the tens place, and so on. The result suggests that MA users are unable to imagine more than three abacus columns at once.

On the other hand, increasing the number of imaginary beads necessary for a problem without increasing the number of columns had no effect. And when it came to counting how many beads were present on a flashcard, MA users were no faster than untrained adults.

The researchers concluded that the method doesn't increase the students' ability to hold a mental image of an abacus. Instead, it makes use of standard human visual memory.

"Clearly, the mental image doesn't carry all the details of the abacus itself," said Frank. "But we're zeroing in on what the image consists of."

The researchers also directly tested whether verbal or motor memory was in play during mental calculation. Participants were asked to calculate while drumming their fingers on the desk or repeating a book on tape.

In research subjects who had no experience with MA, verbal distractions significantly affected accuracy. Motor distraction had little effect.

MA users, on the other hand, showed only slight effects during both

tasks, suggesting that verbal working memory plays at most a minor role.

"The process is similar to what electronic calculators do," Frank explained. "You start by reading out the problem in Arabic numerals or words, but then you convert it to a representation that's really good for calculations." In an electronic calculator, this representation is binary. In MA, it may be an imaginary soroban.

The researchers are now studying whether children who learn MA at a young age experience any benefits to their mathematical or cognitive abilities. He and Barner will finish a longitudinal study on the topic this spring – possibly granting Priyanshi's World Cup victory a long-term importance she has yet to appreciate.

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