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Our Brains Have a Map for Numbers

It is as if there is a number line in our heads

By Emilie Reas

"*Come on*. Get out of the express checkout lane! That's way more than twelve items, lady."

Without having to count, you can make a good guess at how many purchases the shopper in front of you is making. She may think she's pulling a fast one, but thanks to the brain's refined sense for quantity, she's not fooling anyone. This ability to perceive numerosity – or number of items – does more than help prevent express lane fraud; it also builds the foundation for our arithmetic skills, the economic system and our concept of value.

Until recently, it's remained a puzzle how the brain allows us to so quickly and accurately judge quantity. Neuroscientists believe that neural representations of most high-level cognitive concepts – for example, those involved in memory, language or decision-making – are distributed, in a relatively disorganized manner, throughout the brain. In contrast, highly organized, specialized brain regions have been identified that represent most lower-level sensory information, such as sights, sounds, or physical touch. Such areas resemble maps, in that sensory information is arranged in a logical, systematic spatial layout. Notably, this type of neural topography has only previously been observed for the basic senses, but never for a high-level cognitive function.

Researchers from the Netherlands may have discovered an exception to this rule, as reported in their recently published *Science* paper: a small brain area which represents numerosity along a continuous "map." Just as we organize numbers along a mental "number line," with one at the left, increasing in magnitude to the right, so is quantity mapped onto space in the brain. One side of this brain region responds to small numbers, the adjacent region to larger numbers, and so on, with numeric representations increasing to the far end.

To examine how the brain responds when perceiving quantities, the researchers conducted functional magnetic resonance imaging of the brain while participants viewed different numbers of dots on a screen. They included multiple versions of the task, keeping key features — like dot size, circumference and density — constant, to be certain that any effects were indeed attributable to dot quantity, rather than dot shape or size. The participants weren't asked to judge the number of dots, to ensure that brain activity related to perceiving quantity, rather than counting. The researchers then looked for brain activity that systematically varied with the number of dots the participants viewed.

The scientists identified a region, a few centimeters wide, in the right superior parietal lobe (in the upper back part of the brain) that mapped numerosity. One edge of this patch (closer to the middle of the brain) responded maximally to small quantities, and the opposite edge (closer to the outside of the brain) responded to the largest quantities. The location and layout of this map was remarkably consistent across all eight individuals' brains. Earlier studies reported that this same brain area in humans, and single neurons in an analogous part of the monkey brain, responded to numerosity. However, these studies had not detected this systematically organized map.

The researchers more closely examined how activity in this neural map related to the numbers and types of dots the participants viewed. They found that the parietal cortex map represented relative, not absolute, quantities. For instance, a given region might respond to two dots in one task condition, but to three in another; but across tasks, it always responded to small numbers of dots. Furthermore, the amount of cortex devoted to a given quantity varied, such that disproportionately more area represented small quantities, and less area represented large quantities. The map was more selective for smaller than larger numerosities. This system makes intuitive sense, as it corresponds with our subjective experience. It's much easier to distinguish between one or two cookies left in the jar, than between eleven and twelve cookies. In light of these findings, this finer discrimination for smaller quantities might arise from their overrepresentation in the brain.

This isn't the first time neuroscientists have observed maps in the brain. In fact, it's well established that sensory and motor information, including representations of our visual surroundings, bodily space or sound frequency, is also topographically organized to subserve vision, touch, taste, smell and movement. For example, a homunculus, or "little man," is mapped onto the brain's motor and somatosensory cortices, such that different regions of this cortical map support movement and sensation in different body parts. The brain areas devoted to feeling the face and lips are adjacent, and the area responsible for toe movement lies next to that involved in ankle movement. This new study reveals that such maps aren't limited to sensory and motor functions, but also exist for an abstract feature - numerosity.

Why might the brain devote a specialized map-like region to processing a higher-order cognitive concept like numerosity, but not other higher-order functions? Past research has shown that the ability to perceive quantity closely resembles our basic senses and is distinct from acquired mathematics skills. For instance, studies have shown that while arithmetic functions are language-dependent, quantity-based judgments are language-independent, and these distinct processes activate different regions of the brain. Whether you're a math whiz or failed high school algebra, you can still readily judge, almost subconsciously, that there are about twenty books on a shelf or a few dogs running in a park. In fact, this skill has been observed in both infants and animals, indicating that it may be innate, much as hearing, seeing and touch are inherent sensory functions.

This explanation – that numerosity is an intuitive sense – may adequately account for the presence of a numerosity map in the brain. However, it's not entirely clear from this study whether the organized brain responses were directly related to *conceptualizing* numbers, or might instead reflect lower-level *sensory* features of the dots. Indeed, the researchers found that the numerosity map didn't respond to digits (i.e., 1, 2, 3), raising questions over what numeric information was actually mapped. For now, we can only speculate whether this patch of cortex maps an ingrained "number sense," visual features, or some combination of the two.

This discovery not only reveals an exception to the rule that brain maps exist exclusively for sensory features, but also raises the possibility that the brain contains maps for other abstract information. If numerosity is represented by a topographic brain system, might other higher-order concepts share a similar map-like organization? Just how many more hidden maps are lurking in our brain?

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