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Scientists crack brain's codes for noun meanings

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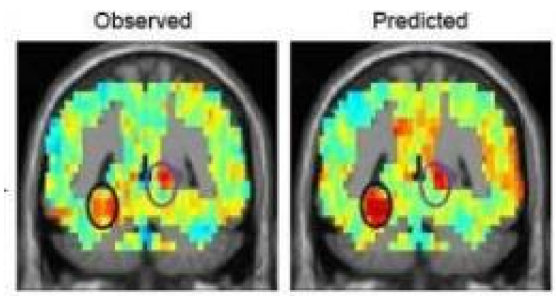

As one slice of the observed brain image from a human participant (left) and the theory (right) shows, the theory makes precise predictions, particularly about the two shelter-related coding areas in this slice (circled), where brighter red indicates more activation. Credit: Carnegie Mellon University

Two hundred years ago, archaeologists used the Rosetta Stone to understand the ancient Egyptian scrolls. Now, a team of Carnegie Mellon University scientists has discovered the beginnings of a neural Rosetta Stone. By combining brain imaging and machine learning techniques, neuroscientists Marcel Just and Vladimir Cherkassky and computer scientists Tom Mitchell and Sandesh Aryal determined how the brain arranges noun representations. Understanding how the brain codes nouns is important for treating psychiatric and neurological illnesses.

"In effect, we discovered how the brain's dictionary is organized," said Just, the D.O. Hebb Professor of Psychology and director of the Center for Cognitive Brain Imaging. "It isn't alphabetical or ordered by the sizes of objects or their colors. It's through the three basic features that the brain uses to define common nouns like apartment, hammer and carrot."

As the researchers report today in the journal PLoS One, the three codes or factors concern basic human fundamentals: (1) how you physically interact with the object (how you hold it, kick it, twist it, etc.); (2) how it is related to eating (biting, sipping, tasting, swallowing); and (3) how it is related to shelter or enclosure. The three factors, each coded in three to five different locations in the brain, were found by a computer algorithm that searched for commonalities among brain areas in how participants responded to 60 different nouns describing physical objects. For example, the word apartment evoked high activation in the five areas that code shelter-related words.

In the case of hammer, the motor cortex was the brain area activated to code the physical interaction. "To the brain, a key part of the meaning of hammer is how you hold it, and it is the sensory-motor cortex that represents 'hammer holding,'" said Cherkassky, who has a background in both computer science and neuroscience.

The research also showed that the noun meanings were coded similarly in all of the participants' brains. "This result demonstrates that when two people think about the word 'hammer' or 'house,' their brain activation patterns are very similar. But beyond that, our results show that these three discovered brain codes capture key building blocks also shared across people," said Mitchell, head of the Machine Learning Department in the School of Computer Science.

This study marked the first time that the thoughts stimulated by words alone were accurately identified using brain imaging, in contrast to earlier studies that used picture stimuli or pictures together with words. The programs were able to identify the thought without benefit of a picture representation in the visual area of the brain, focusing instead on the semantic or conceptual representation of the objects.

Additionally, the team was able to predict where the activation would be for a previously unseen noun. A computer program assigned a score to each word for each of the three dimensions, and that score predicted how much brain activation there would be in each of 12 specified brain locations. The theory generated a prediction of the activation for apartment based only on the patterns derived from the other 59 words. As one slice of the observed brain image from a human participant (left) and the theory (right) shows, the theory makes precise predictions, particularly about the two shelter-related coding areas in this slice (circled), where brighter red indicates more activation.

To test the theory, the team used the word scores to identify which word a participant was thinking about, just by analyzing the person's brain activation patterns for that word. The program was able to tell which of the 60 words a participant was thinking about, with a rank accuracy as high as 84 percent for two of the participants, and an average rank accuracy of 72 percent across all 10 participants (where pure guessing would be accurate 50 percent of the time).

One absent code in the study that is essential for the human species concerns sex or love or reproduction. "Our vocabulary of 60 test nouns lacked any words related to the missing dimension, such as 'spouse' or 'boyfriend' or even 'person,'" Just said. "We certainly expect some human dimension to be part of the brain's coding of nouns, in addition to the three dimensions we found."

"With psychiatric and neurological illnesses, the meanings of certain concepts are sometimes distorted," Just said. "These new techniques make it possible to measure those distortions and point toward a way to 'undistort' them. For example, a person with agoraphobia, the fear of open spaces, might have an exaggerated coding of the shelter dimension. A person with autism might have a weaker coding of social contact."

Another implication is in developing and testing domain expertise at the neural level. "We teach to the mind but we are shaping the brain, and now we can give the brain a test of how well it has learned a concept," says Just. "If an instructor knows how an advanced concept is represented in the brains of experts in that area, she will be able to teach to the brain test. We can do it for hammers and carrots right now. In the near future isotope and telomere may soon be on some brain researcher's agenda."

More information: dx.plos.org/10.1371/journal.pone.0008622

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