The power of words

How language shapes our understanding of abstract concepts.

> "The findings indicate that language profoundly impacts abstract concepts, enhancing their formation and differentiation in the brain."

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The ability of the human mind to comprehend tangible and intangible concepts is a cornerstone of cognition. While we can easily understand and visualise concrete concepts like 'dog' or 'hammer', abstract concepts such as 'democracy' or 'peace' are more challenging due to their lack of physical form.

Researchers at the Brain Language Laboratory, part of the MatCo project at Freie Universität Berlin, have made significant strides in unravelling how our brains manage these different types of concepts.

By employing a sophisticated computational model known as a brain-constrained neural network, Friedemann Pulvermüller, Malte Henningsen-Schomers and Fynn Dobler have explored the intricate processes by which we learn both simple, concrete ideas and more complex, abstract ones.

Concrete vs. abstract concepts

Concrete concepts are relatively straightforward for our brains to process. For example, think of a dog: despite the vast differences between breeds such as poodles, huskies and chihuahuas, we recognise them all as dogs. This is because our brain synthesises these varying images to form a unified concept built from the commonalities between these breeds.

Abstract concepts, however, are more elusive. Take democracy, for instance. It can manifest in actions like voting in an election, raising your hand to cast a vote, or watching a debate in Congress. These actions to do not share a common visual form, nor a common motor movement. The challenge with abstract concepts is that they lack consistent physical features shared by all of their manifestations, making them harder for the brain to learn.

Moreover, consider the concept of 'freedom'. Freedom can be expressed through various actions and states, such as the right to speak one's mind, the absence of oppression or the ability to make personal choices. These different expressions do not have a single, identifiable form but are understood collectively through the abstract idea of freedom.

Learning mechanisms

The MatCo team developed a neural network designed to mimic human cortical areas to delve into how our brains learn these concepts. This network, equipped with layers corresponding to different brain regions, was trained with numerous examples to simulate the learning process. Crucially, the network consisted of neurons that mimic the learning mechanisms of the brain: when two neurons fire together, the synaptic connection between them becomes stronger. When only one of them fires, but the other does not, the connection weakens. When the network encountered concrete items like dogs, it formed strong connections between the neurons that respond to features all dogs have in common. This process is similar to how connections change in our brain during repeated sensory and motor experiences.

The neural network used in this study is known as a brain-constrained neural network because it incorporates constraints that mirror the actual structure and function of the human brain. The researchers modelled different cortical areas, such as those responsible for visual processing, hand movements and articulation and auditory processing. This design allowed them to create a more accurate simulation of how the human brain processes and learns information.

The training process

The training process involved exposing the network to various examples of both concrete and abstract concepts. For both types of concepts, the network was presented with images and motor movements. For examples of a concrete concept, it might see images of different dog breeds and perform an action, like throwing a stick to play fetch. These images and movements have a lot in common. Examples of abstract concepts were more varied: not all images the network saw and the movements it performed had something in common. Raising a hand in a vote and casting a ballot involve movements, but watching a debate would not. Through the neurobiological learning mechanism of the model, it formed strong, overlapping neural connections for concrete concepts, but only weak and fractured ones for abstract concepts.

To really learn abstract concepts, the network needed additional information beyond sensory data to form a coherent understanding. This is where verbal labels came into play. The MatCo team provided the network with words associated with each abstract concept. For instance, the examples of 'democracy' would be reinforced with the verbal label 'democracy'. This additional linguistic input was crucial for the network to form strong, lasting neural representations of abstract concepts.

The role of verbal symbols

The study found that verbal symbols significantly enhance the learning of abstract concepts. When the neural network learned concepts accompanied by words, it developed larger and more active neuronal assemblies. This was particularly evident with abstract concepts. Without verbal labels, the network's connections for abstract concepts were weak and did not sustain activity, indicating that our brains rely on language to fully understand and remember abstract ideas. The study shows that the core issue with learning abstract concepts might be correlation: when features of instances do not correlate well, they need the additional correlation of a shared word referring to all of them to be learned on a neurobiological basis.

Without the word 'democracy', it would be difficult for the brain to connect various democratic actions. The presence of a word helps integrate these disparate actions into a coherent concept, making it easier for the brain to comprehend and retain the idea of democracy.

The same applies to other abstract ideas. Consider 'justice'. This concept can encompass various actions and principles, such as fairness in legal proceedings, equitable treatment of individuals and the moral rightness of actions. Without the word 'justice', these different aspects would remain unconnected, making it challenging for the brain to form a unified concept.

Broader implications and future directions

These findings have profound implications for our understanding of cognitive processes. They suggest that while concrete concepts can be learned through direct sensory interactions, abstract concepts require correlated linguistic input to form strong, lasting neural representations. This research provides a neurobiological explanation for the critical role of language in learning and processing abstract ideas.

The study's results also align with the Whorfian hypothesis, which posits that language influences thought and perception. The findings indicate that language profoundly impacts abstract concepts, enhancing their formation and differentiation in the brain. This insight holds considerable implications for educational strategies, particularly in teaching abstract concepts to students.

Furthermore, these results suggest **potential applications in artificial intelligence and machine learning**. By integrating linguistic input and forms of more biologically plausible learning, AI systems could improve their ability to understand and process abstract concepts, making them more effective in tasks requiring high-level cognitive functions.

Educational and cognitive implications

Understanding the pivotal role of language in concept formation can transform educational approaches. For instance, when teaching abstract ideas, using clear and consistent verbal labels can significantly aid students in understanding and retaining these concepts. This method can make learning more effective and engaging.

Moreover, this research sheds light on cognitive development and language acquisition. It highlights the importance of linguistic input in shaping our cognitive abilities, especially concerning abstract thinking. These insights are invaluable for educators, psychologists and cognitive scientists aiming to refine learning methodologies and cognitive development theories.

In practical terms, this could mean incorporating more verbal explanations and discussions in classrooms when teaching complex subjects. Teachers could use storytelling, metaphors and detailed descriptions to help students grasp abstract concepts more effectively. This approach not only aids in understanding but also fosters critical thinking and deeper cognitive engagement.

The MatCo project

The MatCo project, previously featured in the November 2023 issue of the European Dissemination, continues to offer groundbreaking insights into the material constraints enabling human cognition. This latest research from the Brain Language Laboratory underscores the fundamental role of language in binding abstract concepts, providing a neurobiological explanation for cognitive processes. The project's ongoing exploration of these themes promises to produce further valuable insights into human cognition and the role of language in shaping our understanding of the world.

MatCo's contributions extend beyond theoretical research. Their findings have practical applications in education, artificial intelligence and cognitive therapy. By understanding how the brain uses language to form concepts, we can develop better teaching methods, create more intuitive AI systems, and devise more effective therapies for cognitive impairments.

Future research directions

The findings from this study open several avenues for future research. One potential direction is exploring how different languages influence the formation and retention of abstract concepts. Given that languages vary widely in structure and vocabulary, it would be intriguing to see how these differences affect cognitive processes.

While a delve specifically into the issues of multilingualism would be interesting, it is not the focus of immediate future research within MatCo. As we will be working together on a few more dissemination articles, it would be good to put the focus on issues we are working on. Here is my rephrasing suggestion for the highlighted text: One potential direction is exploring how more realistic concept structures interact with language. Most concepts exist in a taxonomic hierarchy: for example, a Golden Retriever is a type of dog, and a dog is a type of animal. How does such a rich taxonomic structure influence concept learning?

Conclusion

Words are more than sounds or marks on paper; they are powerful tools that shape our thinking and understanding of the world. This research demonstrates that language is essential for learning and remembering abstract concepts. By exploring how our brains use words to form ideas, we gain a deeper understanding of the fundamental processes driving human cognition.

Find out more

For those interested in delving deeper into this subject, the full papers and interactive data visualisations are available on the Freie Universität Berlin website and the Language Learning journal. This ongoing research continues to shed light on the profound connections between language, perception and cognition.

Visit the MatCo project page to stay up to date with the project teams' latest advancements from the MatCo project. Whether you are simply curious about cognitive science or are studying it in depth, engaging with this cutting-edge research can provide invaluable insights into the remarkable ways our brains use language to shape our understanding of the world.

Key publications from the MatCo project

Constant, M., Pulvermüller, F. and Tomasello, R. (2023) 'Brain-constrained neural modeling explains fast mapping of words to meaning', *Cerebral Cortex*, 33(11), pp. 6872-6890. doi: 10.1093/cercor/bhad007.

Dobler, F.R., Henningsen-Schomers, M.R. and Pulvermüller, F. (2024), Verbal Symbols Support Concrete but Enable Abstract Concept Formation: Evidence From Brain-Constrained Deep Neural Networks. *Language Learning*, 74: 258-295. doi: 10.1111/lang.12646.

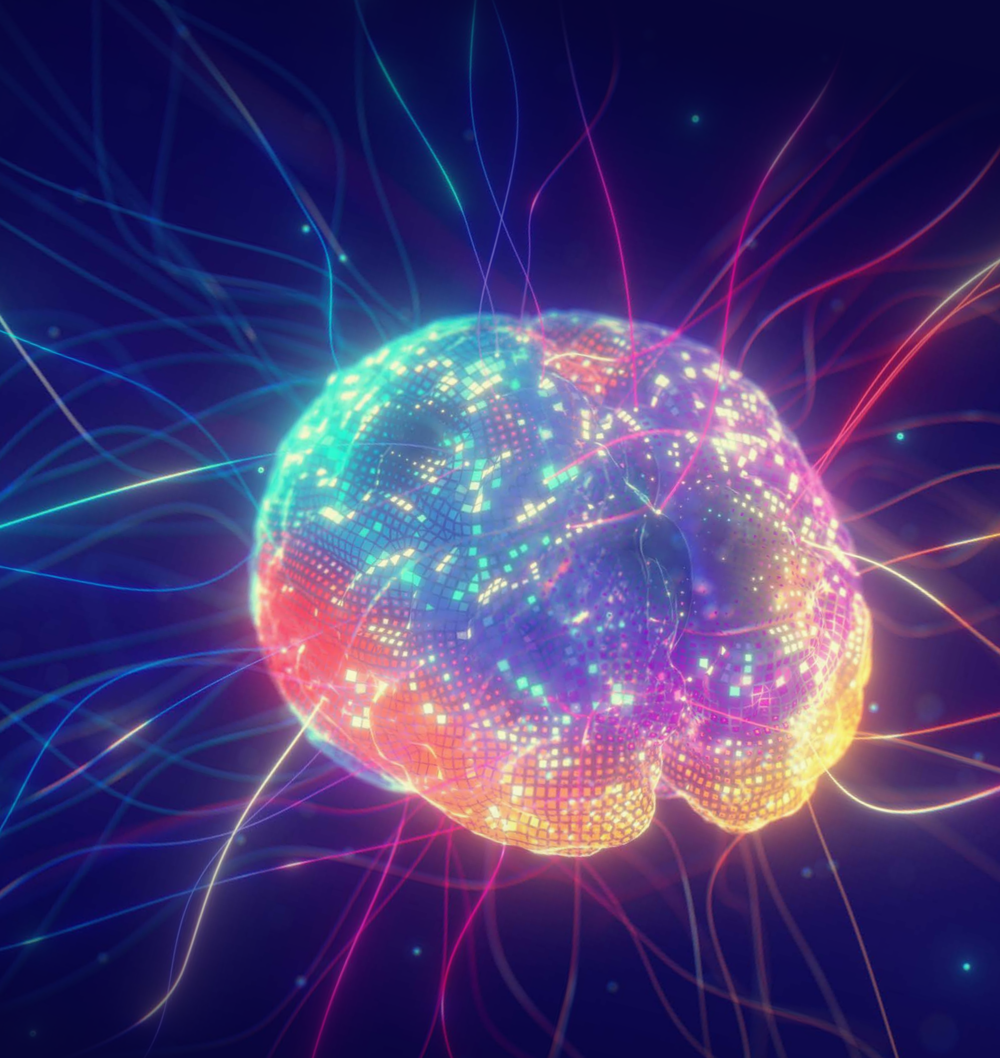
Henningsen-Schomers, M.R. and Pulvermüller, F. (2022a) 'Influence of language on perception and concept formation in a brain-constrained deep neural network model', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 378(1870), p. 20210373. doi: 10.1098/rstb.2021.0373.

Henningsen-Schomers, M.R. and Pulvermüller, F. (2022b) 'Modelling concrete and abstract concepts using brain-constrained deep neural networks', *Psychological Research*, 86(8), pp. 2533–2559. doi: 10.1007/s00426-021-01591-6.

Nguyen, P.T.U., Henningsen-Schomers, M.R., Pulvermüller, F., Causal Influence of Linguistic Learning on Perceptual and Conceptual Processing: A Brain-Constrained Deep Neural Network Study of Proper Names and Category Terms. *Journal of Neuroscience*, 44(9). doi: 10.1523/JNEUROSCI.1048-23.2023.

Pulvermüller, F. (2023) 'Neurobiological mechanisms for language, symbols and concepts: Clues from brain-constrained deep neural networks', *Progress in Neurobiology*, 230, p. 102511. doi: 10.1016/j.pneurobio.2023.102511.

Pulvermüller, F., Tomasello, R., Henningsen-Schomers, M.R. (2021) *et al.* Biological constraints on neural network models of cognitive function. *Nat Rev Neurosci* 22, 488–502. doi: 10.1038/s41583-021-00473-5.



PROJECT NAME

Material Constraints Enabling Human Cognition (MatCo)

PROJECT SUMMARY

Compared to our closest living relatives, who typically use fewer than 100 words, humans can build vocabularies of tens of hundreds of thousands of words. The ERC-funded Advanced Grant project 'Material Constraints enabling Human Cognition', or 'MatCo', will find out why. It will use novel insights from human neurobiology. These will be translated into mathematically exact computational models to find new answers to long-standing questions in cognitive science, linguistics and philosophy. The project will also explore how semantic meaning is implemented for gestures and words and, more specifically, for referential and categorical terms. To identify human cognitive capacities, MatCo will develop models replicating structural differences between human and non-human primate brains. The results will shed light on the biologically constrained networks.

PROJECT LEAD PROFILE

Friedemann Pulvermüller is Professor of Neuroscience of Language and Pragmatics at the Department of Philosophy of the Freie Universität Berlin, PI at the Berlin School of Mind and Brain at the Einstein Center of Neuroscience Berlin and at the Research Cluster 'Matters of Activity' of the German Research Foundation at the Humboldt University. He had taken PhDs in linguistics and psychology at the universities of Tübingen and Konstanz, before joining the Medical Research Council's Cognition and Brain Sciences Unit at Cambridge University as a Programme Leader in the Neuroscience of Language in 2000. In 2011, he moved to the Freie Universität to direct the Brain Language Laboratory Berlin. He has published over 300 publications, including a book on 'Neuroscience of Language' (Cambridge University Press, 2003).

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