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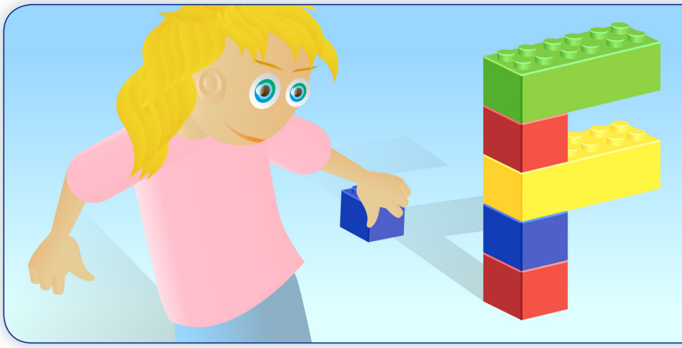

The human toolmaker

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Do you enjoy building airplanes, cars, houses, or robots with Lego blocks? Humans are the only animal species that can create complicated constructions from simple Lego blocks – our Lego building ability is "human-specific," since it is only found in human beings. What would our closest relatives, apes or monkeys, do with a box of Lego blocks? They would probably chew on them, and lose interest when they find out that they are not edible! Why are humans the only Lego builders in the animal kingdom? What happens in our brains when we build a Lego construction?
Let us first take a look at how humans differ from other animals.

HOW ARE HUMANS DIFFERENT FROM OTHER ANIMALS?

Humans can do a number of things that no other animals – not even our closest relatives (such as chimps and gorillas) – can do. We are the only species that has developed languages with a set of rules (a grammar) that requires words to be in a certain order. You might have seen monkeys calling each other (for example, a "koo" call is signaling friendliness), but you have never seen one writing a letter and wondering about spelling! We are also able to predict from the look of a friend's face or the sound of his/her voice how he/she feels about the world, whether he/she is happy or sad. In addition, we pass from generation to generation the knowledge that we have learned about the world and our universe – this is why we go to school! Going to school and teaching children about the world is part of the human "culture," another human-specific characteristic. Language, predicting a friend's mood, and culture are all examples of "human-specific" abilities. Why can we do all these things and other animals cannot? It is because our brain has developed extra machinery for these abilities: there are specialized parts of the brain that produce language or predict a friend's mood (see Figure 1).

In this article, we want to describe another ability that we think is human-specific: to build, use, and know about tools. But first, are we really the only tool users in the animal kingdom?

HUMANS ARE NOT THE ONLY TOOL USERS BUT THE MOST INTELLIGENT ONES!

Many kinds of animals use objects that they find in their environment for a specific purpose. Thus, they are using the objects as "tools" [1] (see Figure 2). For example, the Egyptian vulture picks up rocks

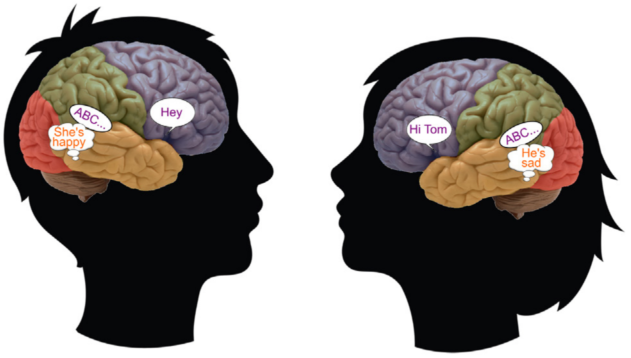


FIGURE 1 - Human-specific brain regions.
The cortex (the folded surface) of the human brain is divided into four parts: the temporal cortex (yellow), the occipital cortex (red), the parietal cortex (green), and the frontal cortex (blue). The human brain has developed specialized regions for understanding and producing words (language regions, purple font) and to predict what other people think and feel (orange font).

with its beak and uses them to pound the shell of an ostrich egg. When it cracks, the vulture can eat its favorite food. Octopuses carry around shells (sometimes even coconut shells) to hide underneath, or they tear off tentacles from jellyfish and wield them as a weapon when attacked. Chimps, our closest relatives, strip leaves off twigs to use as sticks for fishing termites out of a termite mound. The examples are endless. However, no chimp can do what a 2-year old child can do: use the stick for a different purpose if the situation asks for it. For example, a child might use a drumstick that is lying around to get a ball that rolled underneath the sofa. The child can do this because he/she is able to plan ahead and understand what the stick will do to the ball. So even though humans are not the only tool

FIGURE 2 - Examples of animals using tools.
Chimpanzees tailor twigs to fish for insects (1, 2). Vultures pound rocks against ostrich eggs until they crack open and they can eat the content (3). Dolphins wrap sponge around their nose to protect the skin when scavenging for food on the ocean floor (4). Octopuses use halves of shells or other things they can find to hide and protect themselves (5). Dresser crabs often drape sea anemones on their backs as camouflage (6). Finches use twigs to pry out their meal from small holes (7). Sea otters carry stones around on their belly that they use to pound open clams and oysters (8). Some ants use leaves as containers for carrying food and water (9). Source of photos: http://www.mnn.com/earth-matters/wilderness-resources/photos/15-remarkable-animals-that-use-tools.

users, we are the only ones able to use tools in a highly intelligent way!

Not only are we very creative in transforming simple objects like Lego into complicated constructions like airplanes and robots but we are also very smart about making complicated tools for very specific purposes. We even build tools that work together in specific ways – like screws and screwdrivers or hammers and nails – and we design machines that can make these tools. We can even program computers that run the machines, which gives us free time to build even more!

But how did it all start?

THE ORIGINS OF TOOL TECHNOLOGY

Our ability to use tools in an intelligent way can even be seen in the earliest human tools we have found, which are made of stone. We think that early hominid (human-like) species, which were our extinct ancestors, used tools made from organic materials like sticks, leaves, and wood before using stone, but we cannot find any traces of them because these materials decay. This is why the first objects we know were used as tools are stones [2]. The oldest known stone tools were found in Ethiopia (Africa) about 2.5 million years ago. Typical stone tools are shown in Figures 3A,B. The stone tools that have been found clearly show

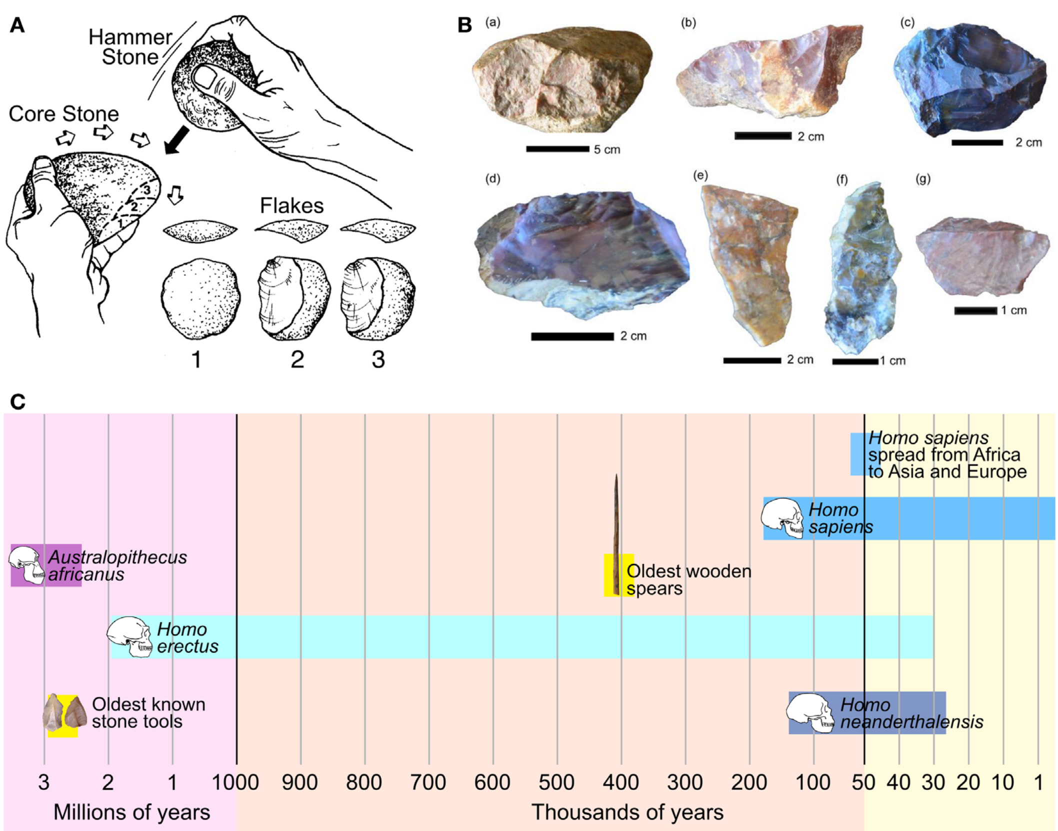


FIGURE 3 - The origins of stone tool technology.
A. Flaked stone tool production. Our extinct ancestors used a "hammer stone" to knock off flakes from a "core stone." The flakes had sharp edges and were used as cutting tools. Adapted from Science, Vol. 291, Ambrose SH, Paleolithic technology and human evolution, p. 1749 (2001). Reprinted with permission from AAAS.
B. Examples of stone tools: (a–d) core stones and (e–g) flakes. Reprinted with permission from Macmillan Publisher Ltd.: Scientific Reports, 3, Ao et al., p. 2, copyright Nature Publishing Group (2013).
C. Simplified timeline of human species and tool use evolution.

that they have been made by intelligent toolmakers. Hominids made these tools by hitting one rock (called "core stone") with a "hammer stone," thereby knocking off flakes (see Figure 3A). Both the flakes and the cores of the stones were used as tools. The flakes had sharp edges, so they could be used as cutting tools.

In order to break flakes from the core, the core stone had to be hit by the hammer stone just at the right angle. This means that the core and hammer stones had to be held firmly and that force had to be applied in a very precise way. Humans and their ancestors could only accomplish this because they have what we call a precision grip, which means that our thumb can touch the tips of our other fingers. The way that stone tools were prepared shows that our ancestors understood the characteristics of the stones and how they could use the resulting tools on other objects (like using a sharp-edged stone to slice meat). Importantly, there is evidence that the early hominids taught each other how to produce stone tools, which they passed to the next generation – they developed a culture of using and building tools.

Stone tool technology did not only change the different grips that our hands can accomplish, but it also changed our brain (see Figure 4).

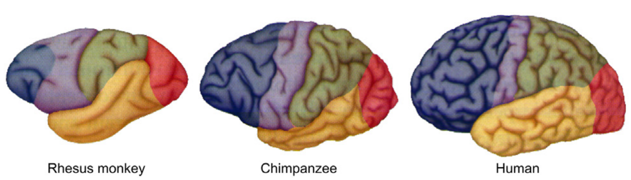


FIGURE 4 - Evolution of the brain from rhesus monkey (left), to chimpanzee (middle), and to human (right).
Parts of the brain that have developed most in the human brain are the prefrontal cortex (dark blue, part of the frontal cortex in blue) and the parietal cortex (green). These parts of the brain are important when you use tools. The temporal cortex is shown in yellow and the occipital cortex in red.

OUR BRAIN HAS SPECIALIZED MACHINERY FOR KNOWING AND USING TOOLS (CALL IT OUR "LEGO BUILDING NETWORK")

What happens in your brain when you use tools, or build a complicated Lego construction? Different parts of your brain are specialized in processing information from different senses (see Figure 5). When you look at Lego blocks, what you see is sent from your eyes to the back of your brain, where the visual cortex is located (in the occipital cortex, see Figure 5A). The visual cortex will extract things like shape, size, and color of the blocks. Once you have decided what you want to build, the motor cortex that controls all movements (located in the frontal cortex, see Figure 5) will tell your muscles what to do and in what order. But the motor cortex needs to know where the Lego blocks are (an arm length away and piled up, the one you want to use first is in the middle) and how they are oriented (the long end

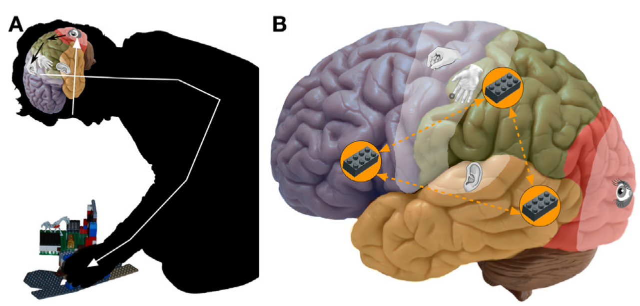
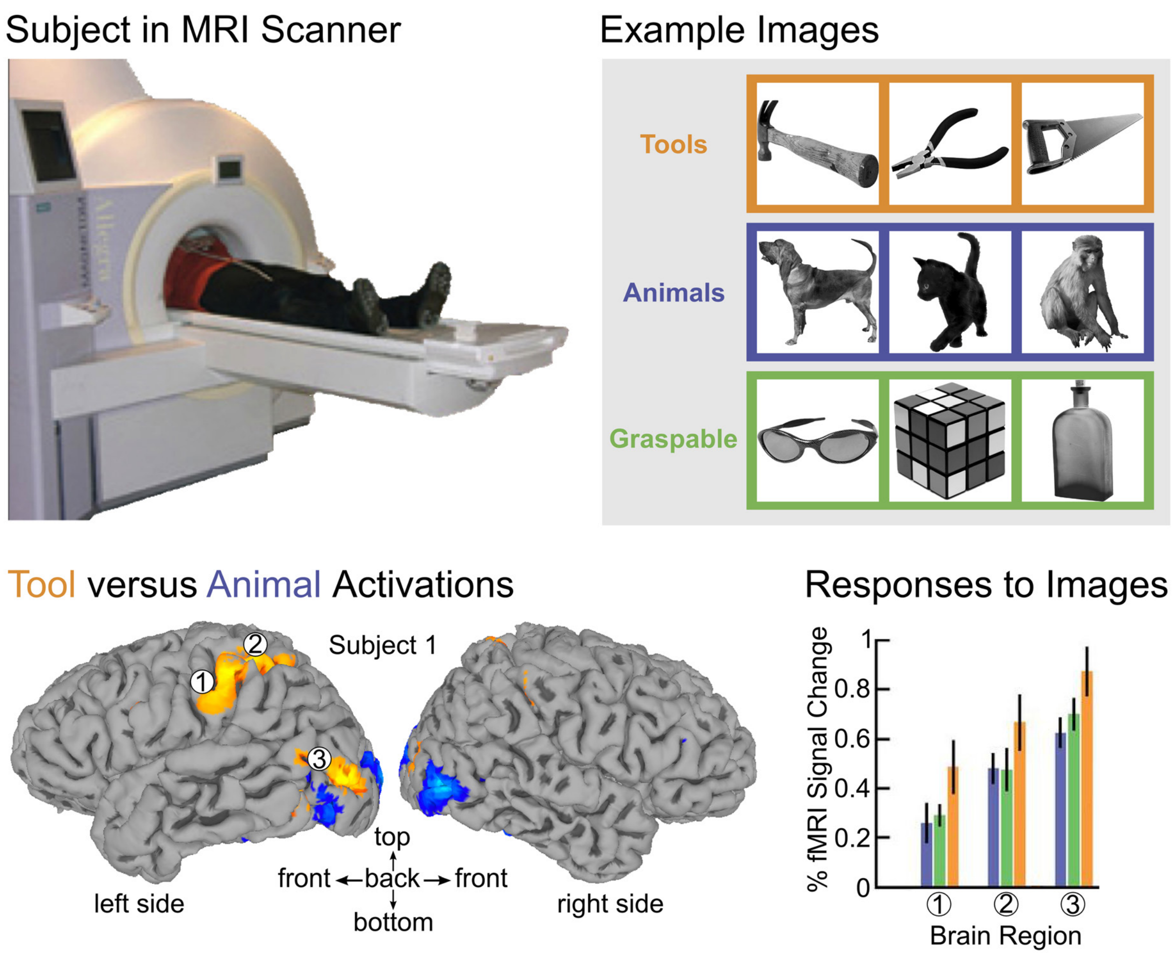


FIGURE 5 - Tool-specific brain activations or the Lego building network.
A. Simplified flow of information processing: what we see is sent to the visual cortex (bright red) and transferred by the parietal cortex (green) to the motor cortex (bright blue) which then sends action commands to the muscles.
B. Tool (Lego building) network. In addition to the basic processing steps that all objects undergo as shown in A, the human brain has additional machinery (tool-specific regions) for processing objects that we use as tools. Tool-specific regions (orange/Lego) are most commonly found in the left half of the brain and in the back part of the temporal cortex (yellow), the front part of the parietal cortex (green), and in the lower part of the frontal cortex (blue). These regions form a network and they communicate with other parts of the brain that are specialized in processing information from our senses (seeing: visual cortex, eye/bright red; hearing: auditory cortex, ear/bright yellow; touch: somatosensory cortex, palm/bright green) and with the motor cortex (hand/bright blue) that sends action commands to our muscles. Scientists study how these different tool-specific regions help us to use tools.

is facing you). The parietal cortex, which is located between the visual cortex and the motor cortex (see Figure 5), translates sight information into something that the motor cortex can understand. This is how you will be able to stretch your arm the right length and grasp the Lego block from the correct side.

Our brain and the brains of monkeys and apes are pretty similar when it comes to recognizing and handling objects. However, only in our brain, there is additional machinery that is specialized in processing information about objects that we use as tools. Think of it as a "Lego building network," or a special computer program. It involves several regions ("tool regions") all over the brain that communicate with each other and form a network (see Figure 5B). Scientists believe that this special machinery allows us to use tools in a highly intelligent way. How exactly each of the tool regions contributes to our tool use abilities is part of ongoing research (see Box 1 for



BOX 1 - How do scientists study the tool network in the human brain?
Scientists typically measure brain activity in people while they lie in a magnetic resonance imaging (MRI) scanner and view pictures of tools like in the study by Ryan Mruczek and colleagues [3] (see figure, top left). In this study, people in the scanner looked at images of tools (for example, a hammer), animals, or other objects that can be grasped (graspable objects) but are not tools (for example, a bottle that you grasp when you drink from it; see figure, top right). The scientists found several brain regions that responded better to looking at tools than to looking at animals, these regions were "tool-specific" (see figure, bottom left). Moreover, the same brain regions responded better to looking at tools than to looking at other graspable objects, even though these objects are very similar to tools (much more than animals are; see figure, bottom right). With this study, Mruczek and colleagues identified brain regions that are highly specifically responsive to looking at tools.

an example of how scientists identify and study tool regions in the brain).

SO WHY ARE WE THE ONLY LEGO BUILDERS IN THE ANIMAL KINGDOM?

Certain areas in our brains (along with other parts of our body, like our hands) have developed further than in other animals' brains, which allows us to do things that no other animal can do. Comparing human and other animals' brains helps scientists find out what makes our brains special. The better we understand how our brain works, the better we can find solutions to help people who have difficulties in doing certain things.

Movies - The movies illustrate how the left half of the brain activates when someone looks at tools: basic sight activations turning into tool-specific activations. Movie 1 shows the activations when looking at the brain half from the side, Movie 2 shows the same when looking at the brain half from behind, and Movie 3 shows the same when looking at the brain half from the bottom.

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Riverside Elementary School

Riverside Elementary School serves children from prekindergarten through fifth grade in Princeton, NJ, USA. Our diverse student body includes children from more than 23 different countries, and we all love to learn about brains! We also have a science lab, a courtyard with frogs, and box turtles, a team of dedicated teachers and support staff, and a great principal who always supports new opportunities for learning. Fourth grade students are either in Ms. Levy's or Mr. McGovern's classroom, and Mr. Eastburn is their teacher in the science lab.

AUTHORS

Tanja Kassuba

I study how our brain recognizes objects that we see, hear, or touch (or smell!) and how our brain enables us to use objects as tools. Outside the lab I like to hang out with my friends and play with my friend's dog Renny (see photo) or my nieces. I also love looking at colorful photos from National Geographic, and my favorite animals are sharks.

Sabine Kastner

Scientist and Professor, she studies how people use their brains to pay attention to specific activities (e.g., how can it be that you do not hear your parents calling for dinner when you play a videogame or read a book). Sabine also enjoys spending time with her two kids and loves the Beatles.