How your brain perceives numbers.

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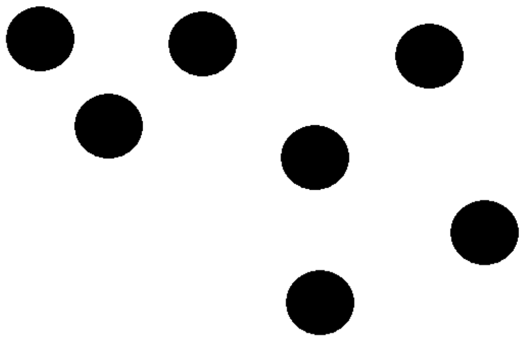
Take a look at the set of dots below. How many are there?

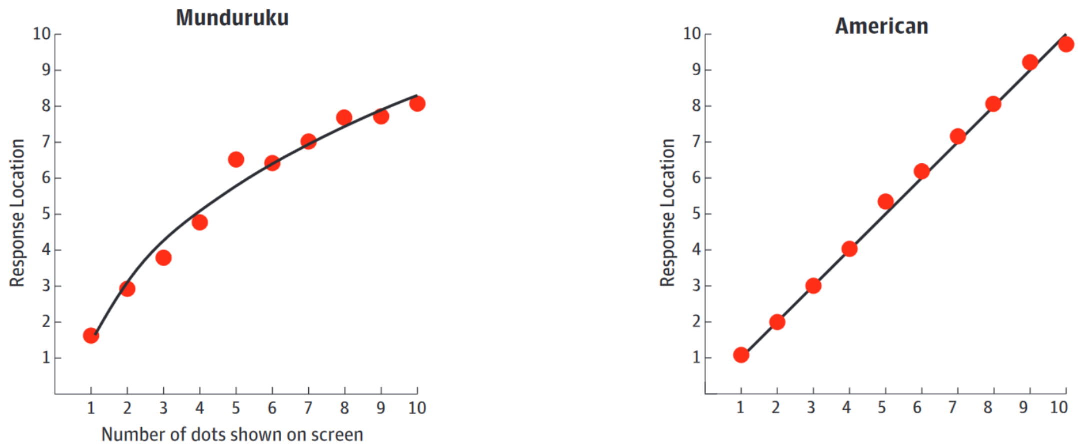


There are seven dots. Hopefully this is not a surprise since counting comes as second nature to most people; our exposure to numbers makes us think this ability is built into our brains. How could we not quantify the world around us? How could you even live without it? Admittedly, to function in a modern society, it is desperately needed. Otherwise financial failure, or even worse: embarrassment in front of peers is inevitable. Nevertheless, we are not born with this in our toolbox and some people never learn it.

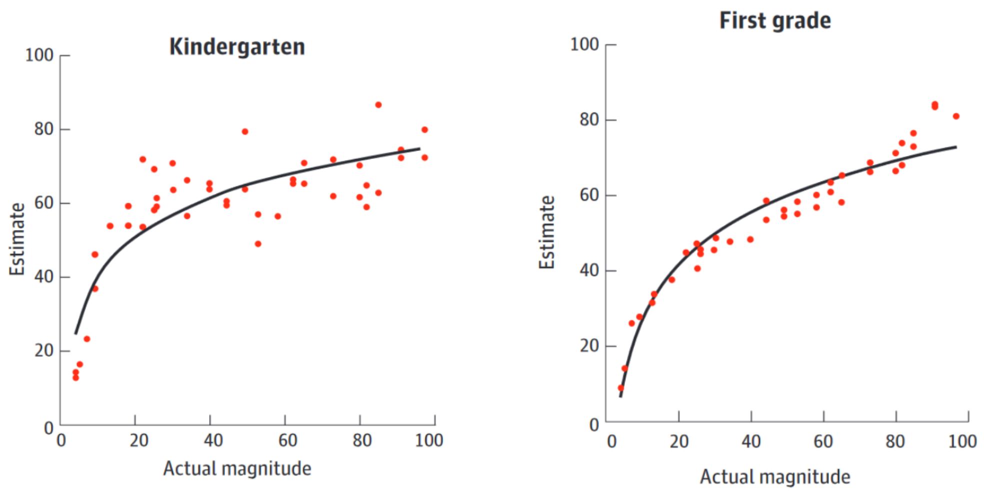
How did you know that there are seven dots? It is very unlikely that you just looked at it and just knew it was seven. Some people can do that but most cannot. You may have grouped together some of the dots which you can just know the quantity of. Perhaps the four on the right and the three on the left then added them together; four and three makes seven. You may have grouped some together (such as the four on the right) and then counted the others (five, six, seven). Most people don't count them all individually (although there is no shame if you did). Our brains seem to have the ability to recognise a quantity inherently but the upper limit is as low as just four. Beyond this, our notion of numbers quickly becomes *approximate.*

In order to see what the human mind's natural understanding of numbers is, we would need to isolate a group of people from even the concept of numbers. Such an experiment would obviously not be ethical but luckily, some languages don't have words for numbers that reach further than five. Any numbers greater than these are just referred to as "many". Some only have words for "one", "two" and "many". Languages like these are commonly found in tribes that are isolated from society at large like those in the Amazon. One such tribe is the Mundurukú. While we associate our numbers with a precise quantity, the Mundurukú do not. When shown a set of dots (randomly between 1 and 15) and asked how many there are, participants did not always give the same answer. The word for "three" (while by far most commonly used for three dots) was sometimes used for numbers much greater than three such as six or eight. Larger numbers received a whole range of responses beyond just "many". Phrases such as "all of my toes" or "two hands" were used.

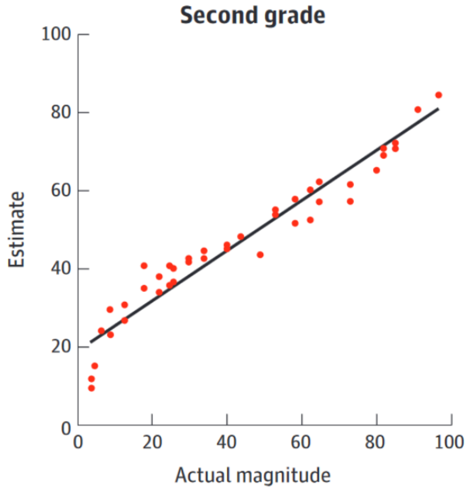
If you asked a member of the tribe "how many children do you have?" not only would they not be able to answer you but they would not even understand why you would want to quantify people (they apparently got suspicious because they were asked this question many times). Despite this, it is still clear that there was an understanding of “more” or “less” when presented with a large number of things in two sets. Even more perplexing is how they spread out numbers when presented with a number line. On one end of the line there was one dot and ten on the other end. They were then presented with a number of dots between them and asked to place it on the line. When this experiment was conducted on Americans, the response was predictably that numbers were evenly spaced in a linear fashion. On the other hand, the Mundurukú had the first few numbers spaced quite far apart and as the numbers got larger, the gaps between them got smaller. In fact when the response location was plotted against the number of dots, the graph was almost perfectly logarithmic. It seems obvious that the numbers should be spread out evenly. This is easily accepted when taught at school and it forms the foundation of all measurements.



In fact, we all thought of numbers this way before it was pointed out to us. A similar experiment to the one before but with numbers 0 to 100 was conducted on children in first grade and kindergarten which also gave logarithmic graphs (the first grader’s line being slightly straighter than kindergarten children). Strikingly, the effect vanishes when the children reach the second grade.[1]



[1] Strangely enough the straight line produced doesn’t go through the origin with low numbers being given an estimated value much higher than they actually have.



The obvious question is “Why do both indigenous tribes and children think numbers get closer together?” The answer is surprisingly simple. We perceive the percentage difference between numbers much more than the actual difference. The difference between 10 and 20 is the same as the difference between 80 and 90 however; 20 is twice as big as 10 whereas 90 is nowhere near double 80. This is what the mind naturally thinks about and is why this effect is seen. This is also why it feels so much better to get £5 off something that costs £40 but £5 off something that costs £5000 seems like nothing. (12.5% is much bigger than 0.1%)

This is by no means a bad intuition to have and the applications for our ancestors is clear. For example if some trees have some edible fruit, it would be helpful to know at a glance which one has more if the percentage difference is significant, if one tree has 21 and another has 42 then it’s worth the effort on the second tree much more than the first, but telling the difference between one with 41 and another with 42 doesn’t really matter.

Businesses have been exploiting our brain's flawed perception for a long time. Products are purposefully priced ending with a 99 instead of rounding up to the nearest pound (for example £7.99 instead of £8). *Everybody* knows that this is because we perceive the first digit of the price more than the final digits so when we see a seven instead of an eight, we think that it’s a bargain. Despite knowing this, it still works! Sometimes this effect is so strong that it’s worth increasing the price of a product just to get it to end with a nine. When two students from the University of Chicago and MIT arranged for an identical dress to be sold at three different prices: $34, $39 and $44, the dress sold best at $39 and not the cheaper $34. The 9 signals to us that there has been a discount even when there hasn’t.

While the effect of subtracting one from a price is well known, the effect of adding one is less widely known. This conveys that there is something extra than the nice round number. This may seem ridiculous but think about how KFC emphasises their eleven herbs and spices. Not just ten but that little bit extra. Greg Rowland, founder of The Semiotic Alliance asserted that “Eleven has just gone that one past ten. It has recognised that there is an order to things, and now it is exploring the distance beyond. Eleven is opening the door to the infinite, but it's not going too far. It is … bourgeois rebellion at its most finite!” Two more, on the other hand doesn’t work nearly as well. That one extra can also convey that something is off, that it's not as reasonable as the round numbers. It's 2001: A Space Odyssey, not 2000. In 1984, it's Room 101 that the main character is tortured in, not Room 100, which sounds much less scary.

We also love to split numbers into different groups, and one of the first ways that people thought of was odd numbers and even numbers. In the West, odd numbers were seen as luckier and generally better than even numbers (at least by the medieval Christian Church). In India, gifts or donations are always given in odd numbers and there are many other similar traditions with odd numbers. This begs the question: why do these numbers have a mystical nature to them even in unrelated cultures? While there is no definitive answer, it may have something to do with the fact that we actually take longer to process odd numbers than even numbers.

I will show a series of two digit numbers, they will either be even-even, odd-odd or a mixture. If they are both even or both odd, perform a simple action like clenching your fist.

72

38

17

92

99

60

If you were paying very close attention to how long each one took you, it was probably longer when they were both odd. Terence Hines performed this test and was so confused by the results that he thought that he had made a mistake. People took 20% longer with odd numbers. We don't just associate numbers with non-numeric values because of tradition but because we are also hard wired to think differently about them. This also might be why in English,[2] the word for odd also means weird, as popularised by Shakespeare.

For a long time, it was accepted that the human capacity for numbers and the ability to understand them came from the same area of the brain as our ability to understand language, and that they came along with language if it included numbers (unlike the Mundurukú). However, with the treatment of certain patients who had very specific injuries to their brain, it was discovered that it is handled by an entirely different area. Cognitive neuropsychologist Brian Butterworth studied one patient who had a stroke which affected the left hemisphere of her brain. Her reasoning and memory skills were unaffected, however, "she was unable to deal with numbers above four." The most bizarre aspect was that when shown the written word for a number above four, she wouldn't be able to tell if it was even a

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[2] English is actually the only major European language with unrelated words for odd and even, most other languages have some form of "even" and "not-even" instead.

real word. Somehow when we see a word for a number it makes us think differently to if it were a regular word. Another patient had a degenerative disease which affected a different part of the brain to the woman, namely that which allows for language comprehension. His speech was very rudimentary, consisting of a few set phrases, he couldn't read and he couldn't write. Despite this, he was still able to do "multi-digit multiplication and division" and unlike the woman, he could perfectly "read [and write] number words like "two" or "eight"."

This is the reason why people who have high general intelligence can, simply put, be really bad with numbers. This area of the brain might be affected in some way[3]. Such a situation led to the discovery of the neurological disorder "dyscalculia", which is commonly described as dyslexia but for numbers. This affects "between three and six percent of the population". The symptoms include exactly what you would expect: the ability to learn mental arithmetic is incredibly difficult and sometimes just impossible. This does not prevent them from being able to perform other mathematical reasoning like geometry. When given a calculator to help them, they can perform just as well as other students. Despite the obvious need for accommodation, dyscalculia is far less studied than dyslexia (many of you reading will never have heard of it before reading this). People with this disorder are more likely to be depressed than their counterparts so clearly more research is needed and knowledge of it should be wider spread in society.

I hope after reading, you will have seen that numbers are not a purely logical system that we have built into our brains inherently but rather something that we discovered and added new meaning to thanks to our brain's strange way of thinking.

Sources:

Alex's Adventure in Numberland, chapter 0. - Mundurukú tribe, logarithmic perception of numbers and related images.

Alex Through the Looking Glass, chapter 1. - pricing strategies and odd-even perception

https://youtu.be/n3x8fIdsla4 - Different area of the brain for maths and for language.

https://youtu.be/p_Hqdqe84Uc
https://www.dyslexicadvantage.org/calculator-use-accommodation-no/
https://www.bdadyslexia.org.uk/dyscalculia/how-can-i-identify-dyscalculia - dyscalculia

[3] There are many other factors as you would expect since very few things only have one cause when it comes to medicine.