NEW VOICES

Counting on language in numerical thinking

Cassie Barton with the latest in our series for budding writers (see www.bps.org.uk/newvoices for more information)

People tend to think of maths and language as very separate entities, with our grasp of one having no effect on the other. But studies looking at the language of some isolated Amazonian tribes reveal that this may not be true – the way we process numbers could be linked very closely to the language we're thinking in.

The Pirahã and Mundurukú are communities based in lowland Amazonia, and both have had very little contact with the rest of the world until relatively recently. Linguists studying these groups have been surprised to find a lack of counting words in their vocabulary. For example, the Pirahã tribe have a word for 'one' and a word for 'two', but for everything else, the words *baagi* or *aibai*, which roughly translate to 'many', suffice. Likewise, research by Pica and colleagues (2004) found that the Mundurukú only have number words up to 'five' and even then are not in the habit of using them in a count sequence. This vague, minimalist way of talking about numbers leaves researchers wondering whether these Amazonians have a different way of imagining numbers, too.

Although in English, we're happy to use words like 'several', 'loads' or 'a few' to discuss quantities, like almost all languages ours comes with a full set of number words, which are extremely useful. Not only does it provide us with a useful shorthand for any quantity we can think of, but learning to count also helps us to learn that individual numbers are exactly one unit apart. Though it may seem simple, after we learn that 1 + 1 = 2, and anything plus one equals the next number in the sequence, we can move on to exact addition and subtraction. This paves the way for more complex mathematics, making everything from economics to scientific discovery possible.

As far as we know, only humans have this ability to understand exact numbers – and the evidence suggests that the ability is tied to our language skills. Many studies have found that human babies, and animals such as monkeys and rats, can tell different quantities apart but only approximately. For example, infants can tell the difference between four dots and eight dots, but not four dots and five (Xu & Spelke, 2000). This type of thinking – in which quantities are represented inexactly on a continuous scale, rather than as discrete numbers – is termed 'analogue' representation.

This isn't the kind of representation you'd normally see in human adults, who would easily be able to complete the task by counting. However, a study by Whalen et al. (1999) got adults to press a key a certain number of times – and made sure they went too fast to count verbally. The adults did all right for very small numbers, but after a point their accuracy began to vary – more so the higher the target number. This is a familiar pattern in studies of numerical cognition: the larger the quantity, the less precisely it is represented in the mind. The rule is termed Weber's law, and is a sign of analogue rather than exact processing.

All of these results have a common theme: in the absence of number language, analogue rather than exact representations are used. They all support the theory that learning names for numbers is an important step on the way to being able to process them properly. And this is where the Amazonian tribes come in: they are a rare set of people who have grown into adulthood without learning any words to associate with exact quantities. Does this mean that they can't think about numbers in the same way that we can?

A 2004 study by Pica and colleagues examined the number skills of the Mundurukú by presenting them with dot clusters. Their participants found it easy to make judgements about the

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approximate size of clusters; however, an exact subtraction task proved much harder for them. When asked how many dots would be left in a can if a certain number was taken out, the Mundurukú participants' responses were much less accurate than those of American controls. Their guesses also got more variable the higher the quantity they were dealing with, in another manifestation of Weber's law.

So it seems that non-counting individuals can't easily manipulate exact quantities, but the question that many researchers are trying to answer is whether they have an understanding of 'exact-ness' at all. Strange though it may sound, if learning to count is what teaches us the one-unit-apart principle discussed above, then people who never learn may miss out on this vital bit of knowledge. A study by Gordon (2004) claimed to find evidence for this, after a series of tests in which Pirahã participants matched a presented set of batteries with a set of their own. Although they performed well when smaller quantities were involved, for sets bigger than two or three their performance worsened as the quantity increased. This was taken as a sign that they were using analogue processing, and had no concept of an exact match.

A later study by Frank et al. (2008) found similar results using a similar population, but put forward a subtly different interpretation. They noted that their Pirahã participants performed fine when they were matching a line of batteries with a line of their own; the problems arose when they had to manipulate what they saw, for example by reproducing a cluster as a line or memorising a quantity to reproduce later. The Pirahã understood exact numbers just fine, the experimenters proposed, but having no number words meant that they had no easy way of processing what they saw. If you or I were shown a set of, say, seven batteries, and we were asked to memorise the quantity, we would use the word 'seven' as a convenient placeholder rather than holding the complex image of a pile of batteries in our minds. This isn't too taxing, so we'd find it easy to produce seven batteries later and lay them out however we like. Having no such shortcut, the Pirahã are forced to rely on their mental image and match objects one-to-one. This produces much shakier results for large quantities, because the cognitive demand is larger.

This is all strong evidence for the role of language. However, language isn't necessarily the sole key to thinking mathematically; there are plenty of other differences between these Amazonian tribes and the developed world. The Pirahã and the Mundurukú don't have money, don't trade, and don't show other behaviours that require numeracy. Some psychologists have argued that this cultural difference is the cause of both their lack of number language and their lack of numerical ability – they simply have no need for either.

The influence of culture is hard to quantify, but there is evidence that learning to count isn't all it takes to understand exact numbers. A 2008 study by Dehaene and colleagues looked at how Mundurukú participants imagined number lines. The basic idea behind this (based on work by Siegler & Booth, 2004, 2006) is that very young children draw number lines unevenly, with the larger numbers squashed up at the end. Not long after learning to count, they switch to spacing the numbers evenly like a ruler, reflecting a switch from analogue to exact processing. As you'd expect, Dehaene's study found that Mundurukú place clusters of dots on a number line in the same way that children do, unlike their American counterparts.

However, another finding was more surprising. A subset of the Mundurukú had attended school and learned to count in Portuguese, and when given standard numerals this group did place them evenly on the number line. This looks like more evidence for the language theory. However, these findings didn't hold when the same group was given dot clusters to place. Like their non-educated peers, they placed the dot clusters unevenly, which suggests that learning a count sequence wasn't enough to alter the way they think about the underlying quantities behind the number sequence. Dehaene and colleagues have suggested that instead, other aspects of their education – such as learning to use rulers – have effected the shift in numeral placement. On the other hand, it may be that there's a critical period in which learning to count can alter your underlying representations; by attending school a bit too late, the Mundurukú children may simply have missed the boat.

A recent study by Flaherty and Sengras (2011), based in Nicaragua, has contributed further to the culture-language debate. The deaf community in Nicaragua are eternally popular with linguists, because thanks to their history they offer a unique opportunity to look at sign language in development. With the introduction of special schools for the deaf in the 1970s, deaf children in Nicaragua came together in large numbers for the first time. Immediately, they began seeking out ways to communicate with each other, and the beginnings of a new sign language began to develop. Several generations down the line, there is now a fully-fledged Nicaraguan sign language. What's interesting about this is that it's possible to meet several different levels of counting ability in the deaf community, who are otherwise fully integrated into Nicaragua's numerate culture: from adults who grew up before the seventies, and learned a sign language count sequence late or never, through to teenagers who grew up with the language and learnt to sign-count as children.

The experimenters set deaf participants from several generations some object-matching and quantifying tasks, similar to those described in the Amazonian studies above. They found that the participants who hadn't learned to count performed worse in several areas: matching clusters of tokens to lines, counting non-spatial items (i.e., taps on the arm), and changing notes in their native currency into coins. Like the Pirahã and Mundurukú, the non-counting participants in this experiment may have relied on one-to-one matching, and performed poorly in tasks where this strategy doesn't work well. For example, the tapping task involved memorising the number of taps as they went along, something best achieved when a count sequence is available. So although they live in a fully numerate culture, it appears that this isn't enough for the non-counters to achieve the same levels of numeracy as their peers. Having a count sequence to use improves performance markedly.

From these studies, it looks like neither culture nor learning to count is enough on its own to ensure numerical understanding of the kind we have in our own highly numerate society. Having a count sequence in the language is certainly very important for numeracy, but it may not be enough – it needs to be supported by a level of cultural immersion. In any case, there are more ways of thinking and talking about numbers than you'd first imagine, and our own way of doing it is by no means universal.

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