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'This chimp will kick your ass at memory games – but how the hell does he do it?'

Nicholas Humphrey

Darwin College, Cambridge, CB3 9EU, United Kingdom

Extraordinary evidence generates extraordinary claims. I discuss the remarkable memory skills of chimpanzees tested in the Kyoto Primate Laboratory, and suggest a novel – but deflationary – hypothesis to explain them. Could the chimpanzees, who have been highly trained to learn the sequence of Arabic numerals, have developed number–colour synaesthesia?

In 1967, Donald Farrer published a paper titled 'Picture memory in the chimpanzee' [1]. He described an experiment in which three young chimpanzees were presented with a row of four illuminated symbols, and had to learn to touch the correct one. During training, a fifth symbol, matching the correct symbol, appeared above the row. The task was therefore one that could be solved by using a 'match-to-sample' rule. However, the arrangements of symbols were such that the task could also be solved by learning the correct symbol in each row as a brute fact (there were 24 different rows in all).

The chimpanzees were trained until they were more than 90% accurate. At this point the sample symbol was omitted. Remarkably, all three chimpanzees continued to touch the 'correct' symbol as accurately as ever. Farrer concluded that his chimpanzees had never paid any attention to the sample, and instead had learned which symbol to touch by using 'picture memory'.

In 2000, Tetsuro Matsuzawa and colleagues published the first of a series of papers on 'working memory of numerals in chimpanzees' [2]. Their subjects were chimpanzees who had been trained to touch Arabic numerals, randomly positioned on a screen, in sequence. They proceeded to test the chimpanzees' memory by having the numerals appear for only a brief interval before being replaced by white squares. By 2011 their star subject, Ayumu, was able to perform with perfect accuracy on a task where nine numerals appeared for just 60 ms.

Farrer's findings went virtually unnoticed. Matsuzawa and colleagues', by contrast, immediately made waves in both academic and lay circles. In 2012, Ayumu featured prominently in a BBC film, 'Super smart animals'. In print and online, his performance was headline news: 'Primate can solve puzzle in the blink of an eye' (*Dail Mail*, February 10, 2012, http://bit.ly/KgEWLN); 'Smart chimp solves memory puzzle at unbelievable speed' (*Yahoo Canada News*, February 11, 2012, http://yhoo.it/L0VbLK). A blogger put it more colourfully still, in the words that furnish the title of this essay (*i09*, February 9, 2012, http://on.io9.com/JOVqdE).

Corresponding author: Humphrey, N. (humphrey@me.com).

Why was it that only the more recent study caught the public's imagination? The answer most likely is that Matsuzawa has always made a point of testing human subjects alongside the chimpanzees. The big news is that the chimpanzees did better. Farrer, however, never made any comparison to humans. True, a reader of his paper might independently have concluded that he had shown that picture memory comes more easily to chimps than to humans. But, significantly, Farrer himself never made this claim.

In 1979, I gave a radio talk, in which I made up for Farrer's reticence ('The mother of invention', BBC Radio Three, June 23, 1979). I argued on the basis of his experiment that chimpanzees do indeed possess a capacity for memorizing that, in the course of human evolution, has been lost.

I did not leave it there, however. I asked the obvious question: 'what selective advantage could have come from reducing memory capacity?', and suggested that 'the advantage of a poor memory actually lay with the disadvantage – or rather with the way our ancestors learned to cope with it. [. . .] Instead of picturing the world as made up of countless particular objects in particular relationships, they hit on the idea of conceiving it in abstract terms – abstract categories related by abstract rules and laws.'

Years later I developed these ideas in an essay that addressed, more generally, the 'uses of adversity' in evolution [3]. The theme of that essay was: one step backwards, two steps forward. In particular, one step backwards by giving up memory, but two steps forward by developing categorical thinking.

It was – and I still think is – a pretty story. Matsuzawa likes it too, and has suggested something similar [4]. Although we disagree over details, we have both embraced the crucial concept: that chimpanzees possess a capacity that human beings, for whatever reason, have lost.

I now confess I suspect we may both have been duped. For I am no longer convinced that Matsuzawa's findings tell us anything about memory as such.

To explain, let me go back to a recent conference in Kyoto (June 9, 2011). Matsuzawa's opening address to the Association for the Scientific Study of Consciousness, which of course featured Ayumu, was followed by a lecture by David Eagleman about synaesthesia. Eagleman drew attention to the fact that, when humans have synaesthetic colour associations, these are almost always to elements of well-learned sequences of arbitrary symbols: numbers, letters of the alphabet, days of the week, and so on. He provided preliminary evidence that overlearned sequences are stored in an area of parietal cortex that just happens to abut the colour-coding area in the temporal lobe. And, in line with Ramachandran's suggestion that 'leakage' can occur between neighbouring cortical areas [5,6], he suggested that synaesthetic associations to elements of sequences do in fact result from leakage between the sequence area and the colour area.

In discussion, I pointed out that, if Eagleman is right, synaesthesia must be a peculiarly human phenomenon, because it is only humans who ever learn sequences of arbitrary symbols. Or, at least so it was until Matsuzawa got to work! Now, close to Kyoto, there live the first non-human animals to have learned just such sequences. My question, then, was whether these very special chimpanzees might be experiencing synaesthetic associations to numerals on the screen; and whether this might be helping them remember the numerals' position, even after they have disappeared.

These questions were left hanging at that point. However, had I but known it, there is already plenty of evidence from human synaesthetes that their colour associations can indeed aid recall [7,8]. Here is testimony from a case in point: 'When asked how she memorized so many digits, [C] reported that for her, each digit has a specific colour, and it is the colours that make it easy for her to remember the digits. [...] When she sees a black digit, her 'photism' for the digit is experienced as a colour overlaying the digit' ([9], p. 548).

I now believe that we have here a provocative – and theoretically enticing – hypothesis for what is occurring with the chimpanzees. I suggest that the trained chimpanzees have indeed developed number–colour associations that are activated as 'photisms' as soon as the numeral appears on the screen. Then, even if the numeral is replaced by a white square, the number–colour – having no competition from other colours at the same location – persists as a sort of after-image. Thus, the chimpanzees, when they touch what look to us like blank white squares, are touching what look to them like colours belonging to a well-known sequence.

As it happens, Matsuzawa's own group has recently found evidence that chimpanzees do make implicit synaesthetic associations between lights and sounds – with brightness being related to high pitch and darkness to low pitch [10]. This is, of course, still a far cry from demonstrating that they experience number–colours. But it surely makes the hypothesis more plausible.

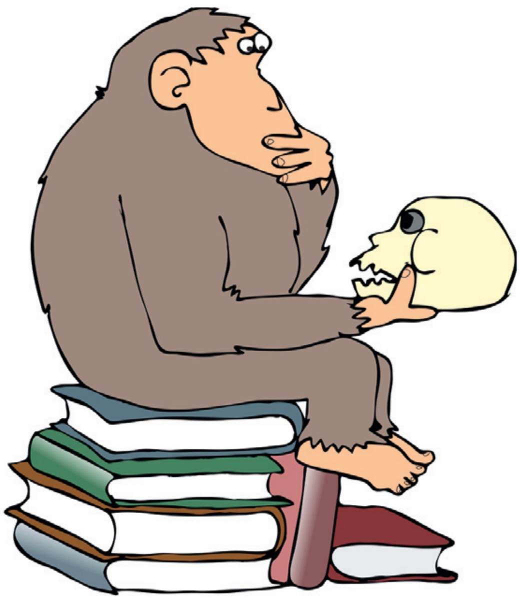
Matsuzawa has stressed that his chimps perform better when younger (personal communication) – Ayumu's performance has in fact now begun to decline as he grows older – which might suggest that over-training cannot be critical. But actually this evidence cuts both ways. For there is new evidence from humans that synaesthetic associations decline with age, presumably because the leaking pathways in the cortex get pruned [11]. If the same is true for chimps, we might expect their performance on the 'memory task' to peak at a relatively young age.

It may be objected that synaesthesia is rare in humans (around 4% of adults [12]). So, if a group of humans were to be put through the same training as the chimpanzees – learning a sequence of arbitrary symbols on a screen – it is unlikely that more than a few would develop colour associations. Then why should the chimpanzees be any more susceptible than the majority of humans? I do not have a strong answer. But I would point out that, since *ex hypothesi* no chimpanzees in previous history have experienced synaesthesia, the syndrome will not have been exposed to natural selection. Thus, the reason it occurs may be just that the propensity for this kind of cross-cortical leakage has not been curtailed – as it apparently has been in humans.

I admit I do not particularly welcome this explanation of the chimpanzees' remarkable performance. If right, it makes their performance a kind of artefact of their experience in the laboratory, rather than evidence of a superlative natural skill that has evolved as an adaptation to living in the wild. It means we have to throw out the beautiful theory of an evolutionary trade-off between memory and language, because we no longer have reason to believe our ancestors had the extra memory capacity to trade. And, of course, we are still left with the problem we came in with. What was going on in Farrer's experiment?

Let us return to the bare facts. Farrer's chimpanzees took a long time to learn by rote a task that humans could have solved in a trice by applying a rule. Yet, presumably humans too could have learned the task by rote if they were obliged to (after all there were only 24 patterns). So, perhaps Farrer's chimpanzees were proving not so much their superiority at remembering as their inferiority at rule-following.

This is, I now suspect, what Farrer himself thought. It was I who made the mistake of over-romanticizing his experimental finding 40 years ago. I worry that we may be doing it again with the findings coming from Kyoto.



A chimpanzee marvels at the inferior memory of human beings? (Image credit: Dennis Cox, www.clipartof.com)

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References

1 Farrer, D.N. (1967) Picture memory in the chimpanzee. *Percept. Mot. Skills* 25, 305–315
2 Kawai, N. and Matsuzawa, T. (2000) Numerical memory span in a chimpanzee. *Nature* 403, 39–40
3 Humphrey, N. (2001) The deformed transformed. *CPNSS Monograph*, DP 55/01. Reprinted in Humphrey, N. (2002) *The Mind Made Flesh: Essays from the Frontiers of Evolution and Psychology*, pp. 165–202, Oxford University Press
4 Matsuzawa, T. (2009) Symbolic representation of number in chimpanzees. *Curr. Opin. Neurobiol.* 19, 1–7
5 Ramachandran, V.S. and Hubbard, E.M. (2001) Synaesthesia: a window into perception, thought and language. *J. Consc. Stud.* 8, 3–34
6 Rouw, R. and Scholte, H.S. (2007) Increased structural connectivity in grapheme-color synesthesia. *Nat. Neurosci.* 10, 792–797
7 Yaro, C. and Ward, J. (2007) Searching for Shereshevskii: what is superior about the memory of synaesthetes? *Quart. J. Exp. Psychol.* 60, 681–695
8 Gross, V.C. *et al.* (2011) Superior encoding enhances recall in color-graphemic synesthesia. *Perception* 40, 196–208
9 Smilek, D. *et al.* (2002) Synesthetic color experiences influence memory. *Psychol. Sci.* 13, 548–552
10 Ludwig, V.U. *et al.* (2011) Visuoauditory mappings between high luminance and high pitch are shared by chimpanzees (Pan troglodytes) and humans. *Proc. Natl. Acad. Sci. U.S.A.* 108, 20661–20665
11 Wagner, K. and Dobkins, K.R. (2011) Synesthetic associations decrease during infancy. *Psychol. Sci.* 22, 1067–1072
12 Simner, J. *et al.* (2006) Synaesthesia: the prevalence of atypical cross-modal experiences. *Perception* 35, 1024–1033

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