Cortical quotients

In a recent Editorial (1997 *Perception* 26 249–252) I asked why elephant brains are much larger than ours though their behaviour is in many ways simpler and their locomotion lumbering—compared especially with insects such as ants, which have only minute pinhead brains. As insects have sophisticated pattern recognition, learning, navigation, and architectural skills, they are far from being mere stimulus-controlled reflex automata. They have indeed what might be called a high IQ.

For ‘IQ’ of vertebrates, it has been established that absolute brain size (or weight) is less important than the ratio of brain to body weight. This ratio—known as the cephalic quotient (CQ)—follows a two-thirds power law with body weight across species. The human brain has a uniquely high CQ, and though larger animals such as elephants and whales have larger brains, their CQs (and IQs) are much lower than ours. It is generally supposed that the controlling of larger bodies needs larger brains—but why? I would have thought the control problems of a flying insect, or a bird, must be far greater than for elephants or whales or humans. The speculative suggestion was made that large brains are needed, especially for humans, for processing ‘virtual realities’ of social understanding and imagination of ‘soap operas’ for sophisticated social living.

It is intriguing that the two-thirds power law for brain to body weight holds for vertebrates (dinosaur brains falling in line with modern reptiles), but with somewhat different added constants (shifting the parallel log–log plots) for reptiles, birds, and mammals. *Homo sapiens* is exceptional in lying above the EQ (encephalisation quotient) plot for mammals, following a unique development over the last five million years. Did this result from the memory, imaginative processing, and emotional demands of human social soap operas? Somehow, we took off from our biological origins, with tools and art and language; but it is a chicken-and-egg problem which came first: brain

![Figure 1](image-url)

**Figure 1.** Log–log plot of brain weight against body weight for some 200 species of living vertebrates. They fall along lines with a slope of two-thirds (so brain weight varies as the cube root of the square of body weight). *Homo sapiens* lies above the line for other mammals (shown in a ring). From *The Workings of the Brain: Development, Memory and Perception* Readings from *Scientific American* Ed. R R Llinás (1990, New York: W H Freeman). See also Jerison (1973).
development making these possible, or these new activities developing the brain. Perhaps our questioning created ever more problems leading to the human runaway cortex.

A noted characteristic is not only large relative brain size, especially of the cortex, but also the deep convolutions of the human brain. Folded convolutions increase the surface area but decrease the effective volume. This suggests that surface sensory and motor maps are important, and need to be larger for larger bodies. But these maps involve only a small part of total human brain function; so why should they, as is often suggested, be important for human intelligence? Why should the limiting surface be so useful, though interconnections lose a degree of freedom? This is just what integrated-chip designers are trying to avoid, to get more active elements into a given volume.

Perhaps we should look more closely, not only at EQ across species, but also at what we might call SQ, the surface/volume quotient of brains. Humans and porpoises would come high. It might be useful to know relations between IQ, EQ, and SQ more fully. Unfortunately, comparative anatomy and physiology are out of fashion, so there is a sad lack of recent evidence. Couldn't PET and NMR scans supply useful data for comparing various brain regions in living animals?

Do we know enough about the relative richness of neuronal connections across species? Speaking from ignorance, may I ask, hoping for answers: Have small brains that developed early in evolution got tricks lost to later and larger brains? If so, why have such apparent inefficiencies of design crept in? Is it simply that larger bodies can support larger brains without undue cost, so evolutionary pressure for compactness is reduced? What would our CQ and SQ do for the IQ of an imaginary ant of our size?

There is evidence that the neurons of small brains of insects are somewhat denser than ours, though of course an elephant's or a human brain could not be packed into an insect, whose body size is limited in practice for lack of lungs. Conceivably, if our brains had retained the packing density of ants and bees, Einstein would not have been exceptional; but it is interesting that Einstein had a normal rather small human brain.

Now that we can assemble neuron-like silicon components in almost biological numbers and densities, it is time to consider whether artificial brain designs, for AI, should follow from mammals or from insects. If insects have efficiency tricks lost to larger brains, they might be the better bet, and in any case should not be ignored. Robots are ridiculously clumsy compared with insects (being comparable to elephants), so insects should hold design secrets well worth discovering. The numbers of their neurons are in the range of practical computers—but is this so for the richness of their interconnections? Do we know enough of these microstructures to be sure that we are not missing some useful tricks for AI? Given that our cortex, treasured for its 'higher functions', throws away a whole degree of freedom for interconnections, is this suggestive for super-biological IQ?

It may be that our cortical design is handicapped through being based on past needs: what was efficient, being now less than optimal. Perhaps the development of the cortex was set by previously much more important surface maps—before computations of association regions had so much to do—and so expanded with convolutions at ultimate cost to us, of sadly limited computing brains. If so, the surface/volume quotient (SQ) is not a positive benefit for IQ, but rather a handicap, which might be avoided by redesign, in biological or artificial brains. Perhaps convolutions are needed for providing nutrient for high metabolic processes, or even for cooling the brain. However this may be, we surely need more knowledge of the past and its influences on the present—using comparative studies—for interpreting what we can see in ourselves, and for designing future artificial brains.

Richard L Gregory

Reference
Jerison H J, 1973 Evolution of the Brain and Intelligence (New York: Academic Press)