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Human exceptionalism

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How the unique capacities of human cognition arose in evolution is a question of enduring interest. The difficulty of finding the best allometric and developmental frame for brain evolution and growth, however, leads researchers to routinely identify predictable features of the human brain as exceptional.

Are the human brain and cognition exceptional? Absolutely. The list of exceptional features, however, grows too long, due to a general proclivity to declare any difference between humans and their primate relatives a distinct human adaptation. Quite often, this proclivity for exceptionalism prevents the research community from finding the frame in which humans are ordinary and from understanding continuity in evolution. In the end, the truly exceptional features of human brain organization are obscured.

Although it has been demonstrated time and again that humans have the predicted volume of cortex given their brain size [1–3] and, moreover, that the size of apparently large parts (frontal, temporal, parietal, and insular regions of the cortex) fall where the allometry of each would predict [4], the belief that the relative size of the cortex and its parts are the products of special selection in humans reappears in each new line of investigation and is difficult to dispel. For example, Montgomery *et al.* [5] have shown conservation of brain-related genes in the primate lineage for a collection of genes originally investigated for their role in presumed selective cortical expansion in humans. Because duration of development is both logically and empirically linked to brain size [6], and human development is conspicuously long, distinctions about the rate and duration of human brain development are repeatedly proposed. Comparing the developmental processes of several species properly is a complex task, however, and the assumption of human exceptionalism, in combination with small databases and daunting normalization problems, leads inevitably to misjudgments.

Comparing the growth of the brain from birth to approximately adolescence in a sample of macaques, chimpanzees, and humans using MRI, Sakai and colleagues [7] argue for several specific points, but we will concentrate on one emphasized in their abstract:

> …the rapid increase in cerebral total volume and proportional dynamic change in the cerebral tissue in humans during early infancy, when white matter volume increases dramatically, did not occur in chimpanzees. A dynamic reorganization of cerebral tissues of the brain during early infancy, driven mainly by enhancement of neuronal connectivity, is likely to have emerged in the human lineage after the split between humans and chimpanzees and to have promoted the increase in brain volume in humans.

Their analysis is straightforward: the total volume and the gray and white matter volumes from birth to approximate adolescence are plotted (6 years in chimps, 11 years in humans, and 4 years in macaques) and the graphs are stacked on top of each other, visually equilibrating duration. Comparing brain development in this way, only the human curve shows a sharp upswing in brain volume from birth, ceasing at approximately 2 years of age. Is this, however, an appropriate comparison? The relative state of maturation of neural development at birth varies widely across animals [8,9]. Human birth shows the effects of selection for earlier birth due to a marked degree of 'cephalopelvic disproportion' [10] – and the present study actually documents the 'cephalo-' component of this disproportion directly.

In the past fifteen years, we have assembled and modeled in increasing detail a corpus of over 250 neurodevelopmental events in eighteen mammals, including the macaque and the human, but not the chimpanzee [9] (see also www.translatingtime.net). This database includes a number of events: the onset and offset of the neurogenesis, synaptogenesis, and early function of identified structures and cell groups, as well as the growth of total brain volume. Although we have not yet modeled the chimpanzee, knowledge of the size of the adult chimpanzee brain and the duration of its gestation allow us to estimate a slope and intercept to a regression equation through the series of developmental events by reference to the same relationship in the other species [9]. In Figure 1A, we show the modeled developmental trajectory for humans and macaques and the estimated chimpanzee trajectory, inserting the new measured points in the developmental range we have modeled. The Sakai *et al.* measurements conform to each species' prediction well and show no evidence for discontinuities or accelerations in the growth of the human brain compared to the macaque or chimpanzee.

The source of the claim of difference may be seen if the same graphs are plotted on a linear scale of days on the *y* axis, with the position of birth in each species marked (Figure 1B). The curve for humans has a greater exponent, which means that each subsequent developmental step takes relatively and absolutely longer to make in the large human brain. Birth in humans occurs somewhat earlier in the series of neural events than it does for macaques and chimpanzees, a point that has been remarked for years, but

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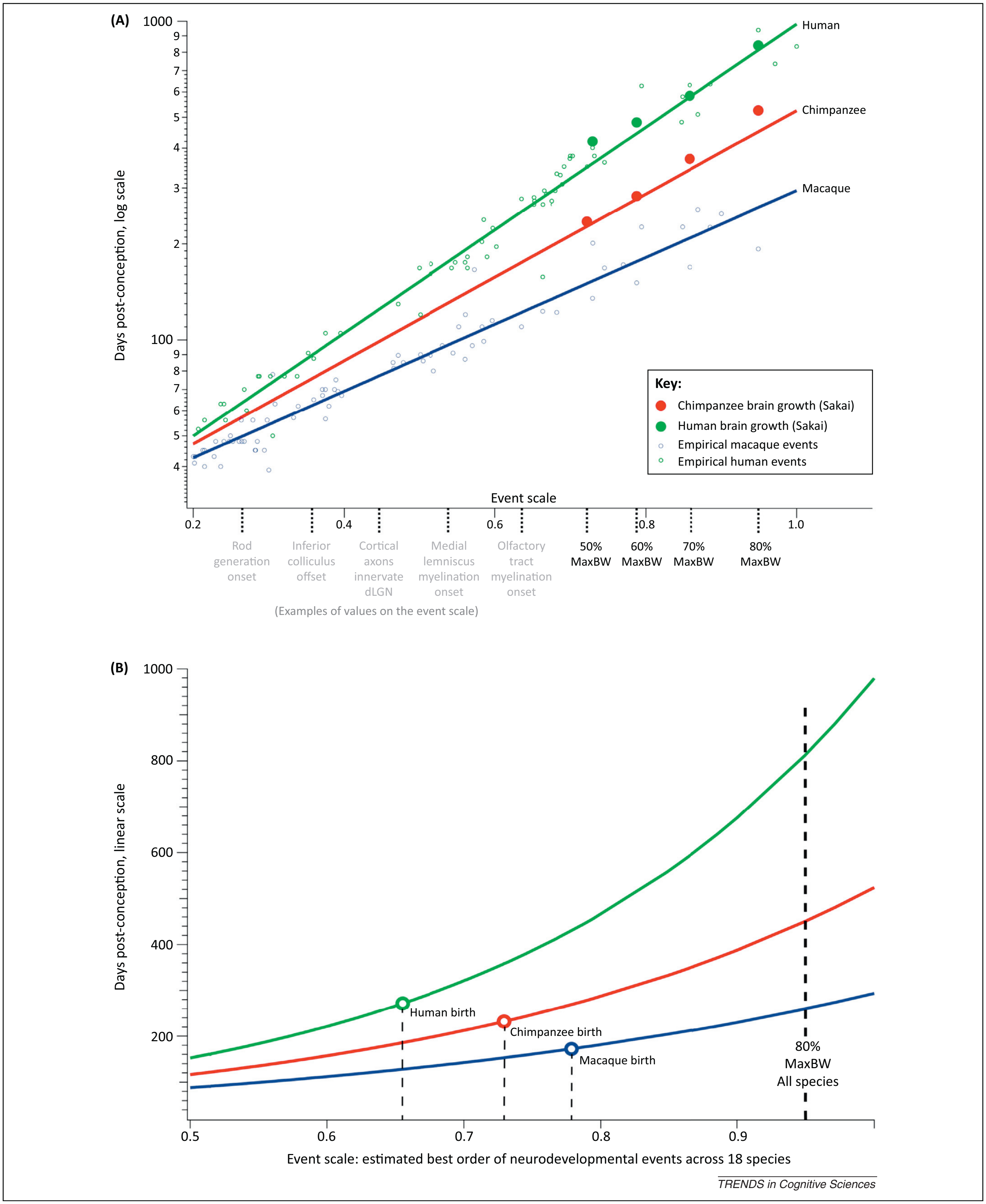

Figure 1. Maturation of the primate brain around birth. The *x* axis of both graphs represents the 'event scale', a statistical best ordering of 271 events in neural development set to range between zero and one. **(A)** Five examples of these events are placed on the scale, shown in gray, as well as brain volume points, shown in black. This panel shows the predicted developmental schedules for humans, chimpanzees, and macaques. The human and macaque lines are generated by empirical data (as plotted), whereas the chimpanzee line is estimated based on its brain size and gestation period. Data from the supplementary materials of Sakai *et al.* [7] were used to determine the post-conceptional day that percentages of maximum brain weight were reached in humans and chimpanzees. **(B)** The second half of the event scale is expanded to show the variable position of birth in each species with respect to neural development. For comparison to (A), and in order to show its varied maturational distance from birth across these three species, 80% maximum brain weight is indicated.

which now can be specified with relative accuracy. Thus the Sakai *et al.* data actually confirm that the human brain is growing at the rate predicted for it size, but the authors compare initial points that are discrepant for brain maturation across species, by taking birth as 'maturational zero'. The change in human brain volume over development is not exceptional and needs no special explanation. It falls in line with what would be predicted from human adult brain size and from gestational length. The same analysis can be performed for white and gray mater volumes independently.

We believe that the essential problem is not normalization techniques, but the initial assumption that human brains are unique and that any observed difference in growth might likely result in 'enhancement of neuronal connectivity', a self-serving pronouncement of the type made in general lectures on human evolution. The predictable features of brain growth are remarkable enough. Why, for example, does it take a human only approximately 180 days to generate its full complement of neurons compared to a mouse's 20 days, but then more than 3000 days to bring that same complement of neurons to adolescence, whereas the mouse requires only 100 [9]? Framing comparisons between animals accurately, without the assumption of exceptionalism, can point researchers to the peculiar features of development that demand explanations.

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