What genes can't learn about language

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Human language has long been viewed as a product of both genes and individual external experience or culture, but the key puzzle has always been to assess the relative contribution of each. Is language more like fashion hemlines or more like the number of fingers on each hand? On the one hand, we know that all normal people, unlike any cats or fish, uniformly grow up speaking some language, just like having 5 fingers on each hand, so language must be part of what is unique to the human genome. However, if one is born in Beijing one winds up speaking a very different language than if one is born in Mumbai, so the number-of-fingers analogy is not quite correct. The right answer must therefore cut a fine line between sufficient genomic constraint guaranteeing that every child will successfully develop an adult language and sufficient lability guaranteeing that no matter where they are born each child will acquire the language of its caretakers. Now a new study in a recent issue of PNAS (1) promises to shed light on this fine balance between cultural experience and genetic entrenchment to language's design, all within the context of biological evolution. It maintains that the linguistic particulars distinguishing Mandarin from Hindi cannot have arisen as genetically encoded and selected-for adaptations via at least one common route linking evolution and learning, the Baldwin–Simpson effect (2).

Deriving Minimal Genomes for Language

In the Baldwin–Simpson model, rather than direct selection for a trait, in this case a particular external behavior, there is selection for learning it. However, as is well known (2, 3), this entrainment linking learning to genomic encoding works only if there is a close match between the pace of external change and genetic change, even though gene frequencies change only relatively slowly, plodding generation by generation. Applied to language evolution, the basic idea of Chater *et al.* (1) is to use computer simulations to show that in general the linguistic regularities learners must acquire, such as whether sentences get packaged into verb–object order, e.g., *eat apples*, as in Mandarin, or object-verb order, e.g., *apples eat*, as in Hindi, can fluctuate too rapidly across generations to be captured and then encoded by the human genome as some kind of specialized ''language instinct.'' This finding runs counter to one popular view that these properties of human language were explicitly selected for, as argued in refs. 4 and 5, instead pointing to human language as largely adventitious, an exaptation (6), with many, perhaps most, details driven by culture. If this finding is correct, then the portion of the human genome devoted to language alone becomes correspondingly greatly reduced. There is no need, and more critically no informational space, for the genome to blueprint some intricate set of highly-modular, interrelated components for language, just as the genome does not spell out the precise neuron-to-neuron wiring of the developing brain.

> **Cultural evolution can sweep through populations as quickly as viral infections.**

Although such a result may prove surprising to Darwinian enthusiasts who see the hand of natural selection everywhere, perhaps more startling still is that Chater *et al.*'s report (1) also points to a rare convergence between the results from 2 quite different fields and methodologies that have often been at odds: the simulation-based, culturally-oriented approach of the PNAS study (1) and a recent, still controversial trend in one strand of modern theoretical linguistics (7–9). Both arrive at the same conclusion: a minimal human genome for language. The purely linguistic effort strips away all of the special properties of language, down to the bare-bones necessities distinguishing us from all other species, relegating such previously linguistic matters such as verb–object order vs. object–verb order to extralinguistic factors, such as a general nonhuman cognitive ability to process ordered sequences aligned like beads on a string. What remains? If this recent linguistic program is on the right track, there is in effect just one component left particular to human language, a special combinatorial competence: the ability to take individual items like 2 words, *the* and *apple*, and then ''glue'' them together, outputting a larger, structured whole, *the apple*, that itself can be manipulated as if it were a single object. This operation runs beyond mere concatenation, because the new object itself still has 2 parts, like water compounded from hydrogen and oxygen, along with the ability to participate in further chemical combinations. Thus this combinatorial operation can apply over and over again to its own output, recursively, yielding an infinity of ever more structurally complicated objects, *ate the apple*, *John ate the apple*, *Mary knows John ate the apple*, a property we immediately recognize as the hallmark of human language, an infinity of possible meaningful signs integrated with the human conceptual system, the algebraic closure of a recursive operator over our dictionary.

This open-ended quality is quite unlike the frozen 10- to 20-word vocalization repertoire that marks the maximum for any other animal species (9). If it is simply this combinatorial promiscuity that lies at the heart of human language, making ''infinite use of finite means,'' then Chater *et al.*'s (1) claim that human language is an exaptation rather than a selected-for adaptation becomes not only much more likely but very nearly inescapable.

What Models Can't Tell Us About Language Evolution

However, one must bear in mind 2 important caveats regarding the scope of Chater *et al.*'s (1) findings. First, if it were indeed the case that language's shape was entirely culturally driven, then one might expect to see all language features rise and fall like hemlines. To be sure, to some extent that is precisely what we do observe: after all, you say to-MAY-to, and I say to-MAH-to. Such variations can, and have, been analyzed as culturally driven by an earlier generation of modelers, sociolinguists, and population geneticists (10–12). However, there is a key distinction to be drawn here between the values of linguistic features and the kinds of features them-

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selves, with the latter being largely fixed, just as hemlines rise and fall but hemlines have always been with us. Indeed, as far back as we can discern, human languages have always been just as complicated and fixed along certain dimensions. Despite many controversies in the field, most linguists agree on the following basic properties regarding human language, among many others: languages have always been either verb–object or object–verb; no language has ever used counting, forming a passive sentence like *John was kissed by Mary* by placing a special marker word after, say, the fourth position into the sentence, a result consonant with recent brain imaging studies, along with analysis of the abilities of linguistic savants (13, 14); all human languages (quite unlike any computer languages) permit the displacement of phrases so that, e.g., in English we can focus the topic of a sentence and say, *Mary*, *John kissed*; all languages draw from a fixed, finite inventory, a basis set, of articulatory gestures, such as whether or not to vibrate one's vocal cords, thus distinguishing a *b* from a *t*, but not all languages distinguish *b* and *t*, again a difference between permissible language kinds and their values.

The Chater *et al.* report (1) therefore pins down something valuable about possible adaptive selection for the latter, but stands mute on the former. Why? Because there has been no obvious phenotypic or genotypic variation in the kinds of core language properties as opposed to their values, it seems highly unlikely that this invariant core can even be a part of the Baldwin–Simpson simulation explored in ref. 1, because no variation means, mathematically, no evolutionary alternatives to even model. Indeed some of these properties, particularly promiscuous recursion harnessed to our conceptual dictionary, are arguably part of the very exaptation Chater *et al.* themselves endorse and so are beyond the scope of their present analysis.

Second, there remain inherent restrictions on our ability to ferret out biological adaptation generally and see into the past, more so than is sometimes generally acknowledged, simply because of limits on what we can measure given the signal-to-noise ratio of evolution by natural selection, and similarly constraining what computer simulations like the one in this issue of PNAS (1) can ever tell us. Since the pioneering study in ref. 11 we know that cultural evolution can sweep through populations as quickly as viral infections. By comparison, evolution by natural selection is orders of magnitude slower and weaker, its effects on gene frequencies easily swamped by the migration of even a few individuals per generation (15). Practically, this means that although we know without a doubt that adaptive selection has been involved in the shaping of certain traits, language being one of them, the data to establish this fact conclusively remains methodologically out of reach simply because it is infeasible to collect the requisite experimental evidence. To take a far more secure case than language, although we have long known that human blood group differences confer certain reproductive evolutionary advantages, geneticists have estimated we would require the complete age-specific birth and death rate tables for on the order of 50,000 individuals to confirm what must certainly be true (16, 17). Given the great costs coupled with the relatively small benefits of confirming what we already know, the pragmatic nature of science wins out and there is simply little enthusiasm in carrying forward the exercise.

Consequently, it is probably safe to say that neither this nor any other confirmation of adaptive advantage for one or another particular evolutionary story line about human language, no matter how compelling or how internally consistent its computer simulation logic, will be immediately forthcoming. To be sure, computer simulations can still establish boundary conditions on evolvability via the Balwin–Simpson effect or set directions for further inquiry, and Chater *et al.* (1) succeed admirably. Nonetheless, we should remain ever alert that there are always restrictions on restrictions, that neither this study nor others like it can tell us how human language actually evolved.

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