

THE WISDOM OF
BONES

IN SEARCH OF HUMAN ORIGINS



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Leslie and Pete knew that some other tissue or organ system had to diminish in size to compensate for the increase in brain size, or else the metabolic budget for humans would never balance. (Unlike governments, bodies that run at a persistent deficit quickly cease to exist.) As they analyzed the size and metabolic demands of various tissues in the human body, they quickly perceived the answer: the human gastrointestinal tract is unusually small for a primate of our body size, by almost exactly the amount that is needed to compensate for the increase in brain size. This finding led them to articulate the expensive organ hypothesis (which might also be called the 'brain versus brawn' theory): in order to evolve larger brains, hominids had to evolve smaller guts.

When they hear this explanation, some people leap to the incorrect conclusion that humans with bigger guts are therefore less intelligent, or even less brainy. As Leslie and Pete point out, the relationship is a broad-scale one that applies across species, not to the relatively minor variations within the species. Besides, as a person thins or fattens, his gut does not lengthen or shorten; it is only that his girth – 'gut' only in the colloquial usage – changes. However, Leslie's and Pete's conclusions imply that braininess probably coevolved with predatory behavior and that a relatively encephalized species, like *Homo erectus*, was almost certainly an effective hunter. As Bob Martin observed, a high-quality diet is essential for a mother nursing a big-brained baby; Leslie and Pete would add that such a diet is also imperative for a big-brained mother or father simply to maintain herself or himself on a daily basis. Brains and diet are inextricably intertwined, for the Nariokotome boy one and a half million years ago and for us today too.

CHAPTER 12

A Balanced Perspective

Brains and diet were an important part of 15K's ecological adaptations, but so was his way of moving about the world. We had known, of course, that *Homo erectus* walked upright. Because Eugène Dubois's first momentous discovery in Java in 1891–92 included both a skullcap and a femur, this was one of the few facts that had formed an integral part of the image of the species, and had dictated its scientific name as well. While it is obvious that the major bones of the leg and foot must be adapted to bipedalism, the evolution of this new mode of locomotion also produced subtle changes in other parts of the body in order to maintain balance and equilibrium during bipedal walking or running. Put plainly, bipedalism is a precarious and difficult way to move around the world. Ask any infant. There is a good reason why many quadrupeds are able to get up and move like an adult within minutes of birth, while human babies take a good year or so to start toddling unsteadily about the world under their own steam. Any quadruped normally has at least two feet on the ground while the others move forward, whereas a biped must pivot over a single support while the other leg swings forward. From an engineering perspective, bipedalism is a ridiculous answer to the need for locomotion, posing problems akin to balancing an apple on top of a moving pencil.

One of the keys to habitually erect posture lies in the trunk, which plays a big role in the balancing act. It is the muscles of the torso, working on the skeletal framework of the vertebrae and ribs, that help keep us balanced over the supporting, or stance, leg during walking. The spinal column is especially crucial, so I asked my former student Carol Ward to study the vertebrae of the Nariokotome boy. She is an expert in this region of the body, having done a fine analysis of the anatomy of the lower back of a fossil ape for her Ph.D. She decided to collaborate with Bruce Latimer, who had analyzed the ribs with me,

and together they set about looking for changes from the primitive apelike condition. How the vertebral column had been reshaped in response to the demands of two-footedness would give us a new perspective on the extent of the boy's adaptations to upright posture.

Because apes, like gorillas and chimps, are quadrupedal most of the time, their vertebral column has a different task to perform than humans'. Our spine is weight-bearing; the double S-shaped curve in our vertebral column – curving forward through the neck, back through the thorax, and forward again through the lumbar region – helps absorb the impact of walking by acting like a spring. Because humans habitually walk and stand upright, the curvature also helps by balancing our body weight, with shoulders, hips, knees, and ankles in vertical alignment. This curvature is produced in part by the wedged shape of some of a human's vertebral bodies, the columnar portion of each vertebra that, along with the intervertebral disks, actually bears weight. If the upper and lower surfaces of the vertebral body were parallel, then the spinal column would be straight and vertical. However, in the thoracic region, the vertebral bodies are thinner at the front and thicker at the back, making a curvature that is concave when viewed from the front. In the lumbar region, the reverse is true; vertebral bodies are thicker toward the front of the body and thinner at the back, making a convex curvature when viewed from the front. The extent of wedging is measured as the angle between the upper and lower surfaces of the vertebral body. Because apes' spines do not carry the full weight of their bodies during normal locomotion, their vertebrae show a small amount of wedging only in the thoracic region; this produces a very mild curvature that is concave when viewed from the front.

Apes also normally differ from humans in the number of vertebrae. Roughly 96 percent of the human population has twelve thoracic vertebrae (one for each pair of ribs) and five lumbar vertebrae. The great apes (gorillas, chimps, pygmy chimps, and orang-utans) of Africa and Asia have thirteen thoracic vertebrae and three or four lumbar; the lesser apes of Asia, the gibbons and siamangs, have thirteen thoracic vertebrae and five lumbar. In Carol's previous work on the spine of *Proconsul*, an ape from Kenya that is about twenty million years old, she had found that it probably had six lumbar vertebrae. Since *Proconsul* can be taken as a reasonable model for the ancestor of modern apes and humans, Carol proposed that the primitive condition for those groups

was to have a high number of lumbar vertebrae. As might be expected, Old World monkeys like baboons and vervets also have many lumbar vertebrae, normally seven. Presumably, through the course of their evolution, different modern groups reduced the number of lumbar by different amounts. The greatest reduction evolved in great apes. This situation would increase the stability of their lower backs at the expense of flexibility. Lesser apes have retained a more primitive, and more flexible, configuration, as have modern humans, but both would have less flexibility and more stability than their ancestors. Humans, with their uniquely upright posture, have also evolved vertebral bodies with a large surface area, another adaptation for weight-bearing and stability.

Carol and Bruce wanted to discover the extent to which 15K showed the structural and mechanical adaptations to bipedal walking seen in modern humans. Although the vertebral column is not complete above the pelvis – there are parts of only nineteen vertebrae preserved, whereas humans usually have twenty-four – it is the most complete column known for an early hominid.

The wedged shapes of the vertebral bodies showed clearly that the boy's spinal column had a double S-shaped curve, just like our own. All the anatomical details of this adaptation to weight-bearing were also present. Yet Carol and Bruce noticed two fascinating differences from modern human anatomy. First of all, they confirmed my observation that parts of six, not five, lumbar vertebrae were preserved in the boy's skeleton. This is a more primitive arrangement, more like that seen in *Proconsul*, than they had expected, but a small number (fewer than 4 percent) of perfectly normal humans have six lumbar too. But when Carol and Bruce went to South Africa to study the few vertebrae from a specimen of the even more ancient hominid species, *Australopithecus africanus*, they confirmed for themselves that this specimen, too, had six lumbar, as John Robinson had reported. The chance that the only two specimens of early hominids that preserve the lower spinal column would both sample a very rare condition seems very slight.

Still in South Africa, my two colleagues also saw a third specimen in which the lumbar vertebrae are preserved, but the specimen was not then published (nor is it yet). This is a touchy situation. Professional ethics dictate that the right of first description or analysis belongs to the team who found the fossils or another scholar whom they designate. After all, the excavators have gone to the trouble of organizing an

expedition; obtaining funding and permits; and documenting, cleaning, and curating the specimen properly. To expect first access to the fossil as compensation for this enormous effort is only reasonable. But sometimes publications take years to appear, depending on the difficulty of the analysis and the other commitments of the scientists involved. As a courtesy, sometimes a visiting colleague (especially one who has traveled a long way) is permitted to examine unpublished material on the understanding that no public comment or publication will mention the material until it has been properly published. While waiting years to discuss a specimen that has altered your perspective crucially may be infuriating, such agreements are vital. Otherwise fossil finders are faced with the choice either of being secretive and refusing to allow colleagues access until a publication is out, or of running the risk of being scooped on their own material. Carol and Bruce, both of whom have excavated fossils themselves, understand this principle thoroughly, so they have been very circumspect about what they saw. But if this specimen, too, should have six rather than five lumbar vertebrae, it would push to the breaking point the probability that this is a rare condition. The conclusion would have to be that six lumbar vertebrae was the normal condition for early hominids, a dramatic discovery with interesting implications.

Carol and Bruce mapped out a scenario for the evolutionary reduction of the number of thoracic and lumbar vertebrae from the primitive condition of thirteen thoracics and five lumbar. As posture and locomotion changed in the hominid lineage, the lowest thoracic vertebra evolved into an additional lumbar vertebra; at the same time, the lumbar vertebrae began to develop the wedged shape that creates the lumbar curvature, which is called lordosis. Evolving a humanlike degree of lordosis improved the postural control of the torso in a habitually erect biped. Because early hominids had an extra vertebra in their lumbar series, the same lordosis could be produced with a smaller change in the shape of the body of each individual vertebra than would have been the case with only five vertebrae. Only the lordosis was present, so apparently the number of lumbar vertebrae was reduced further as selection favored additional stability.

The only other difference between the boy's vertebral column and that of modern humans is that the surface area of his vertebral bodies was unusually small for his weight. In this regard, he was more apelike,

but apes do not have to support their body weight through their vertebral column in all postures and movements. Again, Carol and Bruce found this same pattern in the South African specimen of *Australopithecus africanus*, so they concluded that this was a primitive characteristic that had been retained. At some later point in our evolutionary history, perhaps at the same time that the number of our lumbar vertebrae was reduced from six to five, selection for greater stiffness or stability of the torso must have acted to favor a broader weight-bearing surface.

At this point, I thought we had a balanced perspective on the adaptations of *Homo erectus* to bipedalism. We knew he was long-legged and slim-hipped, both adaptations that would improve the efficiency of bipedalism, and showed substantial changes in the shape and number of his vertebrae to favor stability of the back in an upright position. It was only in 1993, when I read the draft of the Ph.D. thesis of a young Dutch anatomist, Fred Spoor, that I realized there was another perspective I had overlooked.

The insight that lay behind Fred's research is that another essential component in any locomotor pattern involves the organ of equilibrium, also known as the organ of balance. This organ literally provides your sense of balance regardless of the position you are in. It also controls an important ocular reflex that lets your eyes track as you move, so that the ground (or tree limb or any other substrate) is perceived as an unblurred, clear surface even while you move. This ocular reflex can be demonstrated by a simple experiment. If you jiggle the book you are reading rapidly, you can no longer hold the words in focus and read; the letters become an uninterpretable jumble. However, if you hold the book steady and wiggle your head rapidly, you can continue to read without much difficulty. This is because, as you move your head, the ocular reflex signals your brain, telling it exactly where your eyes should look so that it can interpret appropriately the information they send to the brain. The evolutionary point of this ocular reflex is not to make reading easier; it is to enable an organism to be quite sure where its feet are about to land even (or especially) when you are moving rapidly. Thus any change in locomotor pattern (and particularly in the rapidity and predictability of movement) must be accompanied by a change in the organ of equilibrium.

The hardware for the organ of equilibrium is a complex of

membrane, fluid, and nerves, known collectively as the vestibular system, that lies deep within the skull in the inner ear. The housing for this intricate structure — all that is preserved in fossils — is known as the bony labyrinth. Part of it is a snail-shaped structure known as the cochlea, which houses the organ of hearing. But the rest of the labyrinth is comprised of a chamber known as the vestibule and three tubes called the lateral, anterior, and posterior semicircular canals; these canals loop through the petrous bone of the skull. The semicircular canals are arranged at rough right angles to one another and are lined in life with a fluid-filled membrane. Special cells situated at the ends of the canals sense position and movement and are also the sensors for the ocular reflex. On theoretical grounds, it has been shown that the sensitivity of the vestibular system to posture or movement is tuned by the canals' dimensions, particularly by the radius of curvature of each canal. A somewhat obscure paper published early in the twentieth century confirmed this relationship between structure and function, showing that fast-flying birds had bigger canals than slow-flying or ground-dwelling birds. When Fred read this publication, he realized that the size of the semicircular canals might be used to deduce the habitual patterns of movement of extinct mammals, especially if the locomotor pattern were unusual. He decided to find out if the inner ear could reveal anything about the controversial matter of the timing and evolution of hominid bipedalism.

The bony labyrinth is not an easy subject to study. The entire structure of the inner ear is, in most mammals, less than an inch in size, and it lies within a particularly dense piece of bone known appropriately enough as the petrous, a name derived from the Greek *petra*, meaning 'stone' or 'rock.' It would be unrealistic to hope that fossil skulls would be broken so that the semicircular canals are visible and undamaged, and even more unrealistic to think that any curator would allow his or her precious fossils to be sliced up like a loaf of bread. (This procedure, known as serial sectioning, is the classic method for studying the inner ear of modern species.) But, with the help of an imaging expert, Frans Zonneveld, Fred was able to use computerized tomography, or CT scans, to examine fossil and modern primate skulls without inflicting any damage. CT scanning is an advanced technique for taking a series of X rays of a subject (usually a patient), gathering a series of radiographic slices that can be reconstructed into a three-dimensional whole with the aid of computers. Although the radiation dosage has to be adjusted

for scanning the skull from a monkey skeleton or a fossil hominid, rather than a living human, Fred was able to obtain exquisitely accurate information about the vestibular systems of his long-dead 'patients.'

As is often the case in innovative research, his first task was to build a frame of reference within which his results could be placed. Fred painstakingly scanned almost one hundred specimens of twenty different living primates. This reference set ranged from small bodied to large, from primitive prosimians like lemurs to monkeys, apes, and humans; it included species with a wide range of locomotor patterns. He was able to gather additional information from the literature to round out his sample. All of this preliminary work established that he could obtain accurate measurements from CT scans of this type and, as he had expected on theoretical grounds, that the different types of locomotion used by these various species are reflected in the dimensions of the semicircular canals. With such a varied reference sample, some differences in vestibular dimensions were simply an effect of variations in body size; these could be factored out mathematically. Once this correction had been applied, it was clear that fast-moving, agile species, like long-armed gibbons that swing through the trees, or big-eyed, fast-leaping tarsiers, have consistently larger semicircular canals than do slow-moving terrestrial or arboreal species. The data on humans stood out because we stand, walk, and run upright with a frequency matched by no other living primate. This locomotor peculiarity has shaped our vestibular system into a unique configuration. Relative to great apes like the chimpanzee or gorilla, humans have larger anterior and posterior canals and a smaller lateral canal, an arrangement well suited to monitoring movements that occur in a predominantly vertical plane.

Once Fred had perfected his methodology and analyzed his reference sample, he turned to the fossil record. Because he was pioneering a new approach to these questions, Fred didn't have enough time, money, and access to study every fossil hominid he might have wished for. He chose to examine a series of twenty hominid specimens mostly from South Africa, including *Australopithecus africanus*, *A. robustus*, *Homo habilis*, and *H. erectus*. His sample included skulls that many anthropologists would arrange in a single lineage: *Australopithecus africanus* to *Homo habilis* to *Homo erectus*, with specimens of *A. robustus* representing an evolutionary side-branch roughly contemporaneous with *A. africanus*. (My phylogeny is shown in Figure 5, on page 122.) A few parts of our ancestry

are fairly clear. I consider *Australopithecus afarensis* to be probably ancestral to all later species of australopithecines (but not necessarily to any species of *Homo*) and *Homo habilis* (whatever it may be) to be ancestral to *Homo erectus* and in turn to *Homo sapiens*. But the relationship between the two oldest and most recently discovered species, *Australopithecus anamensis* at about 4 million years and *Ardipithecus ramidus* at 4.4 million years, is very unclear at present, as is the relationship between these two early species and the later hominids. The obvious hypothesis, that *Ardipithecus* gave rise to *A. anamensis*, which in turn evolved into *A. afarensis*, and so on, is possible, and simplicity and chronology recommend it. Time will tell. However the species are arranged into lineages, the australopithecine specimens represent the vestibular apparatus in a genus some member of which gave rise to *Homo habilis*, *H. erectus* and ultimately, ourselves.

The first question was when the modern vestibular adaptations for full bipedalism had appeared in the evolutionary lineage from apelike ancestors to humans. The first answer was: *Homo erectus*. This was an enormously satisfying answer to me, since every analysis we had conducted on 15K suggested he was fully bipedal in a modern sense. Even though Fred has yet to scan the Nariokotome boy's skull, I am sure the results will confirm his findings on other specimens.

Learning that *Homo erectus* had a modern vestibular system was not as interesting to me as the result of Fred's scan of a specimen known as StW 53, a small skull attributed to *Homo habilis* because of its resemblances to OH 13 (Cindy) and 24 (Twiggy). It also seems very similar to OH 62, Don Johanson's partial skeleton of *Homo habilis*. Now I know Fred is a fairly conservative person, not one to relish the role of iconoclast unless he is quite sure of his information, so I listen carefully when he finds something unexpected or unusual. And the information his scans yielded about the inner ear of *Homo habilis* is certainly provocative in the context of an evolutionary sequence that starts with an australopithecine and ends with *Homo erectus*. I have already said that *Homo erectus* looked like a modern biped in terms of its inner ear anatomy. At the starting point of this sequence, the four individuals of *A. africanus* that he examined were rather similar to great apes in their size and morphology. So were the five specimens of *A. robustus*, although there were a few indications that both of these species had evolved in the human direction from an apelike condition. Because their bony labyrinths were

more apelike than human, this finding lends support to those who think that bipedalism in early hominids (before *Homo erectus*) was not fully modern. Although it has been argued that the anatomy of these species indicates a tree-climbing component to their locomotion, nothing about the size or shape of the vestibular apparatus reflects arboreality or terrestriality *per se*.

Although Fred might be criticized for not having scanned the earliest hominid species, neither *Ardipithecus ramidus* nor *Australopithecus anamensis* had been found at the time of Fred's study. Their omission makes the situation clearer in any case. If *ramidus* or one of the early australopithecines, *A. anamensis* or *A. afarensis*, has a rather apelike vestibular system, as you might expect, then the old argument about mosaic evolution can be raised. If one or all have an apelike bony labyrinth, then this may be nothing more than an evolutionary holdover, a trait retained until all parts of the body have time to 'catch up' to the new locomotor pattern, bipedalism. At this writing, the earliest certain biped was *A. anamensis* at about four million years. Since *A. africanus* and *A. robustus* lived more than one million years and maybe as many as two million years later than *anamensis*, sure enough time had passed for this new locomotor pattern to become established and for the organ of balance to evolve to accommodate it. No, the morphology of the inner ear of australopithecines is not an anatomical system 'in transit,' and the retention of an apelike morphology bespeaks the retention of an apelike component in the locomotor system.

Finding that australopithecines were still apelike in their inner ear morphology creates the inevitable expectation that *Homo habilis* would be intermediate between the australopithecines' apelike condition and *Homo erectus*'s modern one. This 'in-between' position has always been assigned to *habilis* no matter what part of the anatomy was being discussed. Fred's research strongly reinforces the message of the analysis of *habilis* postcrania by Sigrid Hartwig-Scherer and Bob Martin in showing how inadequate this idea is. Fred's scans showed that the inner ear of *H. habilis* looks more like that of a gibbon or even a monkey than either a great ape or a human. 'It's very difficult to interpret,' Fred says of the enigmatic morphology of *Homo habilis*'s inner ear. 'The only thing that the labyrinth suggests is that it is less bipedally adapted than the australopithecines.' But he can see only two possibilities: 'Either this specimen is not *Homo habilis*,' despite its palatal resemblance to OH 13

and 24, 'or, if it is, *Homo habilis* is unlikely to be ancestral to *Homo erectus*.' I couldn't agree more.

Fred's work has been controversial, partly because people are always reluctant to endorse findings based on a new approach until they understand it thoroughly and partly because, I think, the concept of *Homo habilis* as the single intermediate species between australopithecines and *Homo erectus* is so appealingly neat and tidy. I don't think there can be much question that inner-ear morphology reflects locomotion, so I wouldn't doubt his results on that basis, nor can I fault them because they indicate that a good, well-known hominid isn't very hominidlike. I have long felt that *Homo habilis* was a poorly defined species that encompasses specimens with too great a range of morphology to be grouped together, and Fred's work adds yet another discrepancy.

One of the exciting things that is bound to happen in the next few years is that Fred will be able to scan additional specimens of fossil hominids. I predict that when Fred scans the skulls of large habilines, like 1470, he will find them different from and more human than those of at least some of the small habilines. The rare large-bodied and large-brained creatures like 1470 and 1590 look to me like something that could have been ancestral to the Nariokotome boy and other specimens of *erectus*. The false pretenders to the throne, I think, are those small-brained specimens like 1813, OH 13 and 24, and StW 53. Whatever these represent, it is a strange ape-bodied, hominid-headed species that probably went extinct without issue, like so many other early hominids. When we find out what those small habilines were truly like, I think we will be forced to wrestle anew with the enormous identity question.

What does it mean to be a hominid? What makes this one an ape, that one a human? It is not any huge genetic difference, that we know for sure. Identity must lie in the details, for we have the same number of arms, legs, fingers, toes, and teeth as apes; our bodies are built to a common plan. Yet neither I nor anyone else has much difficulty in telling apes from humans, alive or dead. It seems so simple. How big is your brain, how large your jaw, how complex your tools, how bipedal your adaptation? On one side of the divide stands the ape: furry, quadrupedal, smaller brained and bigger jawed, largely tool-less. On the other stands us and *Homo erectus*: hairless, upright, big brained and small faced, maker of lasting tools. But maybe there is no dichotomy at all, just one

long, labyrinthine continuum full of evolutionary experiments and unthought-of combinations of humanlike and apelike traits. In a real sense, the 'missing link' is an artificial construct and an unholy grail. I am not searching the Kenyan desert for some mythical chimera that lies between apes and humans. I am looking for the truth: about us, about them, and about our similarities and differences. I am striving to see the human animal in the right perspective.

CHAPTER 13

Rendered Speechless

These findings were fascinating, but I was feeling intellectually itchy, bothered by a nagging feeling that there was something big about the boy that we hadn't yet discovered. The idea hovered at the threshold of consciousness, an intuition that could neither be articulated nor dismissed. It was, I suppose, based on an observation I had made without even realizing it that nonetheless demanded explanation.

Even during those amazing days when we were excavating 15K's skeleton, I had noticed that his vertebrae were very odd in a way that lay outside of Carol and Bruce's purview in their study of adaptations to bipedalism. What I had seen was that the 'hole' through each vertebra, known as the vertebral foramen, was rather narrow. This is not a trivial anatomical detail. Since vertebrae rest one on top of the other, separated in life only by the intervertebral disks, the stack of 'holes' enclosed by the bony arches makes a bony tunnel, the vertebral canal, into which the spinal cord fits. The spinal cord is the home for the nerve fibers that control most of the body; many of the nerve cell bodies lie in the spinal cord too. If the canal is narrow, the spinal cord is small, meaning that the boy either received less information from his senses about the world around him or that he was less capable of a finely tuned response to that world. Anatomists designate these two types of information as either motor, impulses from the brain to the body that produce movements, or sensory, impulses that travel from the body to the brain to describe what has been encountered. A quick and dirty comparison showed that the canal in the highest of the boy's vertebrae that we possessed (one that came from the lower end of the neck) had only about one half the area of the canal at a corresponding point in a modern human skeleton. I was surprised momentarily, but then realized that I should have been able to predict this finding. After all, the brain and the spinal cord form an integrated unit, the central

nervous system, and I already knew that his brain was only about two thirds as big as that of modern humans; it was entirely consistent that the spinal cord would be small too. All I could deduce from this observation was that he must have been an awful klutz. As an afterthought, I wondered if this was why the Acheulian tool kit was so repetitive and simple; maybe he and other *Homo erectus* individuals were just not coordinated enough to make anything better.

I knew, though, that I needed an expert to tell me what this diminished spinal cord implied, so I called on Ann MacLarnon. Ann is a calm, competent biologist at the Roehampton Institute of Whitelands College in London; she is intelligent and insightful, and I knew she hadn't the temperament to go making any wild claims without a firm basis for doing so. Ann's main credential for this task was that when she had been a graduate student she had done an extremely thorough comparative study of the spinal cords of a whole series of different primates. She had a unique data base of measurements of vertebrae and spinal cords, down to estimates of the number of cell bodies of motor and sensory nerve cells in the spinal cord at different points. Ann was just the woman I needed to look at the boy's vertebral column as a whole and to tell me something about what he could and couldn't do.

With the help of a colleague, the next time I was in Nairobi I took the measurements Ann needed from 15K's vertebrae and sent them off to her. Then I settled back to wait for her results. I received a draft of a manuscript some months later, which I read through eagerly.

Ann's previous studies had shown that the dimensions of the vertebral canal are an excellent indicator of the width of the spinal cord itself, except at the pelvic end of the body, where the spinal cord peters out. In most primates, the dimensions of the spinal cord reflect the body size of the animal itself: big animals need more nerve tissue to maintain control over their bodies. Since all of that nerve tissue ultimately comes from or goes to the spinal cord, it is no wonder that big-bodied primates have big spinal cords and small-bodied ones have smaller ones. Ann had also discovered that the main difference between humans and all other primates was an enlargement of the human spinal cord in the region that controls the lower neck, arms, and thorax, which, fortuitously, was the very region that was best represented in the boy's remains.

Ann confirmed that the boy's spinal cord was genuinely small in the

thoracic region, as I had suspected. That made him anatomically like apes and monkeys and unlike humans. The lingering question was *why*, why humans developed this unique expansion of the spinal cord and what was implied about the boy's behavior by the fact that he didn't show a humanlike expansion. Typically, Ann took a very empirical approach to answering the question. She had dissected dozens of primates, including humans, and had studied the composition of the spinal cord in this region. Spinal cords contain two types of tissue, known as gray matter and white matter for their appearance. The parts of the spinal cord that house nerve cell bodies, where the nucleus resides, appear gray; the long nerve fibers, covered with fatty, myelinated sheaths, look white. Ann found that the enlargement of the spinal cord in the thoracic region of humans was due to an increase of gray matter, meaning that there were extra nerve cell bodies in that region. This made perfect sense; the extra cells showed that there were extra spinal nerves that left the spinal cord in this region. The surprise was that the location of the cell bodies told her that the spinal nerves were not for control of the muscles of the arms. (Although control of the arms is extremely important to us, it is just as crucial to nonhuman primates, who both manipulate objects habitually and use their forelimbs for locomotion.) These extra nerve cell bodies in humans reflected extra nerves to the abdominal and thoracic muscles. Ann's manuscript simply made this observation without drawing any further conclusions. I was dissatisfied and wrote back, pressing Ann to draw out the broader significance of her findings. What did it mean that humans had additional innervation of the thorax and abdomen? Why did we need it – and why didn't the boy need it?

She replied that she could think of only two interpretations of these data. The first is that *Homo erectus* was not yet fully adapted to bipedalism in terms of postural control of thoracic movements; by this she meant the twisting of the torso that inevitably accompanies walking, the characteristic movement that makes us swing the right arm forward with the left foot, or the left arm forward with the right foot, for balance. *I can't believe that, Ann*, I thought as I read her letter. She knew as well as I did that hominids had been walking for more than two million years by the time the boy was born. There was little chance that he and his conspecifics were still ill adapted to bipedalism so long after this mode of locomotion had evolved. Besides, the work that Carol and

Bruce had done showed that the vertebrae were almost fully adapted to weight-bearing. Since this is one of the most fundamental anatomical responses to bipedalism, I was incredulous that *erectus* could have adapted so fully to bipedalism in that respect – not to mention the reshaping of the pelvis, knee, foot, and (as Fred's work would later show) vestibular system – and yet still lack the nervous control of the muscles of the thorax. It made no sense to me.

Ann also offered an alternative explanation. 'I gave a seminar in my department covering a lot of spinal cord stuff, and the analyses I'd done on WT 15000 so far,' she wrote. 'A colleague, Gwen Hewitt, suggested that the increase in thoracic innervation in modern humans might be the result of increased breathing control associated with the evolution of speech.' In other words, the extra nerve cells controlled the intercostal and abdominal muscles of the thorax. I quickly reviewed in my mind what I know about these muscles. The intercostals are a set of muscles each of which runs between one rib and its neighboring (higher or lower) rib, in an arrangement that resembles the webbing between the toes of aquatic animals. These muscles help the rib cage work as a coordinated unit in breathing, so that all the ribs rise and fall, and move outward and inward, together. The intercostal muscles also contract every time you breathe in and out; they keep the wall of the chest firm so it doesn't balloon outward like an air mattress. Overall, then, the intercostal muscles function to coordinate and control inspiration (breathing in) and expiration (breathing out) very precisely. Abdominal muscles have a similar function of maintaining the integrity of the body wall during breathing. Because babies have such small chests, their abdominal muscles are used much more than the intercostals during breathing. Professionally trained singers usually breathe abdominally, too, as a means of increasing their lung capacity and increasing their fine control over expiration.

I considered the implications of Ann's (or Gwen's) idea. It is obvious that human speech is more than just making isolated sounds, which any animal can do. Humans have to get the intonation and the phrasing of the sentence right as well as the pronunciation of the words; otherwise that funny mechanical voice produced by computers emerges. If *Homo erectus* did not need the innervation to control breathing properly, that implied that the boy could not talk.

I told myself that this explanation could not be correct, either. We *knew* the boy could talk; he had a clear Broca's area. That was the bump

on his brain that formed the hollow on the left side of the braincase, the one into which I had placed Samira Leakey's finger that long-ago day in camp, when her mother and I were first gluing the skull together. Ann's answers left me restless. I could sense that something important was eluding us. For the next half hour, I pattered around my office distractedly and then went into the lab to interrupt all the students and ask them what they had learned that day. Nobody had discovered anything interesting enough to take my mind off Ann's work, so I explained her ideas to them. No one had a good idea about the intercostals or enlargement of the spinal cord, either.

I wandered out again, and as I passed the bulletin board in the hall, I scanned it as a matter of habit, looking for seminar and lecture notices. *Maybe I could go listen to someone else talk about something interesting and forget the Nariokotome boy for an hour*, I thought. I found what I was looking for, unconsciously: Marcus Raichle of Washington University at St. Louis was speaking in just a few minutes about positron emission tomography (PET) scanning. I am fascinated by new technologies, and I know new technology drives new ideas. Since I knew very little about PET scans, I went along happily.

PET scanning is a major new tool for learning about brain function. The patient is given a small dose of a very short-lived radioactive isotope into his or her bloodstream. While the isotope decays, the patient's head is scanned in a series of horizontal 'slices,' using a special sort of radiation detector. Raichle's group administered the isotope to normal medical-student volunteers and then gave them tasks to perform. As their brains worked, the blood flow was increased to the regions that were active; specific areas that commandeered a lot of blood showed up as bright white spots on the scan, while progressively less active areas were red, orange, yellow, green, and finally blue. Resting areas were black. The scans actually made the working of the brain visible as the task was performed over a matter of milliseconds. The work by Raichle and his colleagues was an elegant use of technology.

One of the first things Raichle's group decided to investigate was language. He exposed the students to a word, either by flashing it on a screen in front of their eyes or by pronouncing it over a sound system. The PET scans allowed him to trace the way in which words were taken in and processed and also to record the differences between hearing a word (auditory input) and reading a word (visual input). The

next task for the students was to read (or hear) a word and repeat it, thus highlighting the areas of the brain responsible for producing speech. According to traditional ideas, Broca's area in the left temporal region functions as a word-generator and should light up just before the word is repeated; this should be followed by the regions of motor cortex on both sides of the brain that are responsible for firing the muscles that move the parts of the tongue, lips, mouth, and throat in order to shape and produce words. Thus, the initial reaction to the input should be symmetrical, because the input is received by both ears if the input is auditory, or both eyes if it is visual. As the task of repeating the word is initiated, this symmetrical pattern on the PET scan should be followed by asymmetrical activity in Broca's area, which lies only on the left side of the brain. Once the word is generated, then the physical task of speaking the word should produce a new, symmetrical pattern of activity as muscles on both sides of the vocal apparatus work to create audible speech. The staggering fact, clearly visible on Raichle's slides, was that translating a word from thought into speech did not provoke asymmetrical brain activity. It is true that a part of the brain near Broca's area was activated in this experiment. Because Broca's area was initially recognized in the nineteenth century, when these sophisticated techniques were not dreamed of, perhaps this part 'near Broca's area' can be considered Broca's area itself. The important point is that both this newly defined Broca's area *and a corresponding area on the right side of the brain* lit up together. Another key finding was that this newly defined Broca's area lies deep within the brain. Like a cat lying under the bedclothes, it may make a superficial lump that is visible, but Broca's area itself cannot make a detectable impression on the interior surface of a skull.

This was exciting, but clearly the most important observation for me was the next set of experiments that answered the pressing question: So what does Broca's area *do*? A student was exposed to a word and asked to move his right hand. As expected, this task used the same input pathways; unexpectedly, it then lit up the newly expanded Broca's area. Since the left side of the brain controls the right side of the body, only an isolated, right-hand action produced this pattern of brain activation. (Moving the left hand in response to a word caused the right-brain area that corresponds to Broca's area to light up.) In other words, while the new Broca's area is active during speech, it is also active during other

complex activities that in no way produce language. After conducting these and many similar experiments, Raichle's group had concluded that Broca's area was associated with some higher-level control of motor programming, such as the coordination of complex actions involving the right side of the hand or vocal apparatus, *not* with the production of speech itself. Lesions or injuries to Broca's area itself produce stuttering and other motor problems with speaking, as Paul Broca had noticed in the nineteenth century, but only a defect to a much larger area causes aphasia, or loss of language.

This lecture made a staggering difference in my interpretation of the boy. If the presence of a Broca's area didn't automatically imply that the boy was capable of spoken language, it was time to rethink the whole issue of his communication abilities. Maybe Ann and her colleague Gwen were right. I was energized by this new information. I took a metaphorical deep breath and plunged into the contentious literature on language origins.

As never before, I began to appreciate the importance of language to humans. As long ago as 1863, Thomas Henry Huxley, Darwin's friend and defender, thought that language was the one feature that set the human apart from the animals. He described

that marvellous endowment of intelligible and rational speech, whereby . . . he has slowly accumulated and organised the experience which is almost wholly lost with the cessation of every individual life in other animals; so that, now, he stands raised upon it as on a mountain top, far above the level of his humbler fellows, and transfigured from his grosser nature by reflecting, here and there, a ray from the infinite source of truth.

Many others since Huxley have located human uniqueness in our command of language; to be fair, there has been a strong lobby opposing this view, and championing the ability of other animals to communicate. The resolution of this debate lies in the very nature of language.

In trying to understand what language is and how it functions, scholars have turned to three main sources. They have studied language capabilities among apes in order to deduce the minimal template for language: the basic ability that was presumably shared by the last common ancestors of apes and humans. They have also documented language acquisition – how infants learn language or how adults learn a new language – in an attempt to discover the underlying and

unconscious rules by which language is encoded in our brains. Finally, some researchers have focused on language difficulties or defects among those with impaired abilities, due to congenital or hereditary conditions or to injury. Knowing that an injury to a given area produces a given sort of language difficulty yields telling clues to the language functions of the brain. The results of defects can be extraordinarily specific, such as tiny strokes that cause the inability to retrieve the names of fruits or vegetables, or disturbingly general, such as the fluent but nonsensical 'word salad' produced by sufferers from some disorders.

In order to think productively about the origins of language, I had to resolve to my own satisfaction the question of how to define language. Spoken languages clearly dominate among humans; the very word we use, *language*, is derived from the same root as the French word for *tongue*, a term we also use sometimes to refer to a language. What a bizarre twist of evolution it was that a primate like ourselves evolved a reliance on *spoken* language. The zoological order known formally as the primates comprises monkeys, apes, and primitive prosimians like those I studied for my Ph.D. thesis: the galagos or bush babies, lemurs, and tarsiers. Primates are overwhelmingly manipulative animals – they are always handling, altering, and using objects with their hands – and, as a group, they are not especially verbal. If you had to guess at a modality in which primates would evolve an elaborate communications system, you would probably bet on a gestural modality. Nonetheless, humans have followed an evolutionary trajectory that has led primarily to spoken, not signed, language.

The primacy of spoken language among humans is extraordinary. During the days of world exploration by Europeans, no people was ever encountered that lacked language. Indeed, this concept of perpetual speechlessness, of an inability to express language, is so alien that we have no common adjective to describe the condition. We have words with which to talk about written language and its possession; people are either literate or, if they lack written language, illiterate or preliterate. So, by extension, people with language might be described as *linguate* and those without spoken language must be something like *illinguate*, except there are no such words. In 1868, when Ernst Haeckel conjured up his hypothetical ape-man, *Pithecanthropus* – the archetypal missing link who was later embodied as *Homo erectus* – he gave it the trivial name *alalus*, meaning 'speechless' or 'without speech.' We have no

English equivalent. *Mute* does not suffice, of course, for it refers to individuals who cannot speak yet belong to a society and a population in which speech is a normal attribute; this term describes an individual's unusual condition rather than an attribute typical of a population or species. I find the lack of words to describe language capabilities fascinating. Other attributes shared by all normal humans have descriptors: we are bipeds; we are brainy or smart; we are relatively hairless or naked; we are upright; we are hearing; we are sighted; we are social. But there is no word in English to describe the ability to communicate through language; of all these important attributes, only language ability is so deeply embedded in our humanness that it is never remarked upon.

And yet it is not the ability to speak that makes us human. Language must not be confused with speech, for many people who do not or cannot speak are still linguists, communicating through sign languages. Of course, the sign languages used by the deaf or hearing impaired are full or true languages. They are often largely or wholly independent of the dominant spoken language of the region; thus, for example, American Sign Language is not a manual translation of English. Its syntax, grammar, and vocabulary do not coincide with that of English. American Sign Language is simply a language unto itself, used by non-hearing (or hearing-impaired) people who function in a dominantly hearing and speaking world.

There is another, telling proof that language is not the same thing as speech. In a recent study of deaf children born into signing families, Laura Petitto and her colleagues at McGill University showed that, even as normal babies begin to speak by babbling, deaf babies begin to 'speak' by babbling *with their hands*. These babies repeated signs or partial signs – the manual equivalent of nonsense syllables like 'la-la-la' or 'mum-mum-mum' – over and over again. As a hearing baby will, these deaf babies tried to join in the conversation by making utterances (signing nonsense words or syllables) at the appropriate points, enacting the rhythm of a dialogue before they have mastered its content. As Petitto observed, the fact that deaf infants babble shows that language is an innate capacity in humans; it is the mode of expression, not the ability itself, that is learned. Or, to use the felicitous phrase of Steven Pinker, a linguist at MIT, there is a 'language instinct' hard-wired into the human brain.

Learning a language is a tricky business for a child. There appears to

be a critical period during a child's development in which he or she learns how to express language, a transient window of opportunity that, once missed, cannot be regained. Children who are deprived of human contact during this crucial period are not able to learn full language later. A well-documented example is the child known as Genie, who from eighteen months until thirteen years of age was imprisoned alone in a bedroom by her father. Once she entered the outside world in 1970, she was found to have normal intelligence and received intensive instruction in language. Sadly, she never acquired full language. Like other such children, Genie acquired a limited vocabulary (and responded to a much broader one) and simple patterns of grammar and syntax, but she never mastered language. Her usual utterances were remarks such as 'Want milk' or 'Paint picture.' Her most complex utterances were sentences like 'I want Curtiss play piano.'

The record of Genie's speech demonstrates some crucial distinctions between verbal utterances and full language. Language is much more than a capability to learn and express the abstract symbols for entities or concepts that we call 'words.' Language is a system of communication, one that implies the existence of at least two individuals who share a common set of conventions and symbols; it is an inherently social activity. This is why someone like Genie, who was socially deprived but not intellectually impaired, did not learn language. At the age at which most children are learning language, Genie had no one to talk to, or to talk to her. These appalling circumstances caused a dreadful stunting of her humanity from which she could never recover fully. Not only the general ability to communicate through language but also the mechanics of any particular language – the specific words or symbols used to refer to an entity (such as *cat* or *gato* or *paka* in English, Spanish, Kiswahili, respectively) – are transmitted culturally. Without culture, without society, there can be no language. Language is also fundamentally both symbolic and arbitrary, because words are symbols that have no consistent or overt relationship to the item to which they refer. Language has what Sue Savage-Rumbaugh, a well-known researcher in ape language, calls displaced referents; that is, words can and do act as symbols referring to subjects that are not actually present. Thus, we can talk about clouds whether or not there are any visible in the sky; we can even talk about referents that have never existed in the real world, such as blue dragons. Because of this attribute, language is also productive;

new words can be created to refer to new ideas or experiences, the meanings of words may alter over time, and words may even acquire two or more meanings in ways that allow for joking, punning, and other complex wordplays.

Genie's speech has most of these attributes, and here her command of language goes well beyond that of any animal that has been observed. Animal language works through rather limited vocabularies of calls, postures, and sometimes scents that appear to convey concrete meanings: 'Danger! Leopard' or 'I am sexually receptive.' Konrad Lorenz, the great ethologist, has paraphrased the most universal animal signal as, 'I am here; where are you?' Animals clearly remember the past and sometimes plot elaborately to manipulate the behavior of others in their social group. Monkeys have been observed to give an alarm call, indicating that a predator is near when it is not, in order to distract other monkeys from a favorite food source. Still, nonhuman animals apparently cannot discuss the distant past, the remote future, or abstract or hypothetical ideas.

True or full language must also include two specific categories of words, according to linguist Derek Bickerton, whose book, *Language and Species*, was one of the most provocative I have read. First there are those words that refer to concrete objects (nouns like *table*, *toy*, or *dog*), perceptible attributes (adjectives like *green* or *noisy*), and real actions (verbs like *run*, *hug*, or *give*) – what linguists call lexical items. This category can be extended to include words that express constructs or abstract ideas (*loneliness* or *absence*). Genie, and at least some animals, clearly use lexical items in their language. In addition, true or full language includes a number of words or partial words that are primarily relational (*in*, *of*, the *'s* that indicates possession), numerical (*any*, *many*, *some*), referential (*that*, *a*, *this*), temporal (*before*, *until*, or endings that indicate tense such as *-ed* or *-ing*), directional (*to*, *at*, *from*), and so on – which linguists call grammatical items. It is the grammatical items that allow us to express complex thoughts in a single sentence without confusing our listeners; they eliminate ambiguities or, as linguists say, they disambiguate our utterances. These grammatical items transform a sentence like Genie's 'Applesauce buy store' into one of its several possible meanings: 'I want some applesauce; let's buy it at the store' or 'Applesauce is what we always buy at the store' (a more familiar phrasing would be 'We always buy applesauce at the store') or

'Applesauce is what we bought at the store.' Less obvious interpretations of Genie's sentence might include the meaning that a person named Applesauce bought a store or the statement that the food, applesauce, could be used to buy a store in an apple-loving society. The grammatical items that are missing from Genie's remarks are decoders of meaning and unscramblers of reference. In fact, one of the awkward linguistic habits of American scientists is to omit many of these grammatical items from their writings, for which a substantial cost is paid in terms of clarity.

In contrast to full language, small children, individuals like Genie who have missed the opportunity to learn language normally, and apes who have undergone considerable training all use a much simplified form of language. There is usually only one tense, the present tense. The structure of the utterances or sentences is very simple – 'Me up' or 'Give me banana me banana me' – and contains few or no clauses. In these circumstances, part of the 'sentence' is often gestural: 'Open' accompanied by a fixed look at a cupboard and then a fixed look at the trainer (to convey 'I want you to open this cupboard for me'). In fact, my cat is adept at conveying exactly the same message without bothering to verbalize. More to the point, grammatical items are rudimentary or, often, completely absent.

This restricted or bare-bones language is what Bickerton calls proto-language. He believes it is the first means of verbal communication that we learn as children and is probably a fair approximation of the first means of verbal communication that we developed evolutionarily too. It is the form of language that we share with a few talented and trained apes. Bickerton suggests that proto-language is a robust if limited means of communication that survives even horrendous deprivation like that meted out to Genie or those who suffer particular types of neurological injuries. It is the fallback rudimentary type of language also used by people fully adept in one language who are trying to communicate in another; thus, proto-language lies at the root of pidgin languages. Proto-language is the sort of language we can readily envision as developing by small increments from the extant oral and gestural utterances of many social species.

Bickerton argues that proto-language and true or full language are two systems separated not only by their modes of expression but also by their evolutionary genesis. In his view, proto-language and true

language evolved independently to serve different purposes, and they probably have different neurological bases. This is why proto-language does not become full language as the speaker matures or learns more. Genie (or a trained ape) does not suffer from arrested development of language; she has fully developed proto-language and has failed entirely to develop the other system that is true language. Under normal conditions, proto-language is supplemented and eventually supplanted by full language in humans.

Why have apes failed to learn full language? It is not because they are physically ill adapted for speech (which they are) nor is it because they cannot grasp the use of symbols. Experiments conducted by Allen and Beatrice Gardner, working with the chimpanzee called Washoe, by Penny Patterson with the gorilla Koko, and by Sue Savage-Rumbaugh with the pygmy chimp named Kanzi have all demonstrated that apes have an impressive ability to learn symbols and icons. Because her protocol involves a computerized board with lexigrams or arbitrary symbols on it, Savage-Rumbaugh's work with Kanzi has effectively demolished the criticism that ape language was a product of wishful thinking on the researchers' parts. Clearly apes exposed to appropriate linguistic opportunities learn to combine symbols into multiword utterances and to participate in meaningful dialogues. The problem, according to Bickerton, is that apes do not have the elaborate representational system that humans possess and so they never progress from proto-language to full language. There is an absolute limit to the complexity of their utterances, a limit that is both grammatical and conceptual.

Bickerton hypothesizes that proto-language developed as a communication system, based on the neurological template that we share with apes. In contrast, he believes that the neurological basis for full language evolved as a complex system for taking in sensory information about the environment, processing it, storing it, and perhaps evaluating it as a basis for future actions. The basis for full language, argues Bickerton, was a sort of mapping function, a means of representing the world internally. While all creatures map their world to some extent – trout have exquisitely accurate templates of the shape, size, and behavior of suitable prey, which is what makes fly fishing so challenging – humans have evolved a stunningly intricate representational system that far exceeds that of other organisms in complexity and subtlety. The more complex this internal or mental representational system is – the more

categories we can create for classifying the infinite number of items, sensations, and actions that we sense or think about – then the more distanced we are from the reality before us. In other words, in order to make a highly detailed and accurate map, one that changes minute by minute as new information is added, we interpose a tremendous amount of mental processing between the experience and our mental representation of it. This distance has the advantage of freeing us from the tyranny of the present: it permits us to think about circumstances or events that are not occurring and may never occur. And, Bickerton notes, in order to achieve consciousness – in order to 'stand outside yourself' and look at (or think about) yourself – there must be somewhere else to stand. Without a detailed mental symbol that represents yourself, you cannot think about yourself in any complex way. Apes seem to have only a rudimentary sense of self and a limited degree of consciousness, but they simply lack the elaborate representational system that would enable them to develop truly complex thoughts and full language.

What did this mean for the Nariokotome boy? His vertebral anatomy suggested to Ann that he had no facility for verbal language; it rendered him speechless, in fact. But was Ann's suggestion correct? Would other analyses confirm it? And if they did, how would it change my image of this boy I thought I knew so well?

Finding Links, Missing Links

My foray into the literature on language origins gave me several specific ideas to think about. Language is predominantly spoken, meaning that the anatomical capacity for speech has to exist, but it also reflects particular mental abilities. These include the ability to map, categorize, and analyze the world in a complex fashion. Language also requires the use and understanding of symbols (or displaced referents), the capacity to create novel symbols (i.e., to be linguistically productive), and the habitual practice of using both lexical and grammatical symbols. Language capability is developed through social interactions, and the vocabulary, grammar, and syntax of any particular language are culturally transmitted. Derek Bickerton's work, in particular, had given me the idea that language might evolve in two stages, through two separate routes. The challenge now was to detect the origin of these attributes in the fossil record.

Anatomical capability was one topic I knew something about. Now that Broca's area was effectively eliminated as ironclad evidence of speech, what was left? For some years, several researchers had been trying to establish the shape and size of the vocal apparatus in different types of early hominids. Because the vocal tract itself is composed of soft tissues, which do not fossilize, the only clues from fossils are the hyoid and the subtle markings and shapes of the base of the skull, which can be ambiguous. The hyoid is a small and fragile bone that anchors the tongue muscles; it is rarely preserved and is unknown in the fossil hominid record until Neandertals appear about 1.5 million years after 15K lived. This leaves only the anatomy of the base of the skull as the basis for reconstructions of the vocal tract.

The first, groundbreaking attempt at such work was started by Phillip Lieberman and Edmund Crelin in 1971, with a project aimed at determining the speech capacities of Neandertals. Lieberman, a speech analyst,

and Crelin, a gross anatomist, reconstructed the vocal tract of a particular specimen, known as the Old Man of La Chapelle-aux-Saints. They worked from a cast of the skull that was commercially available, but they were unfortunately unaware that the base of the skull had been broken away and inexpertly reconstructed before the casts were made. However excellent a cast of a fossil is, I know that the details always must be checked, to ensure that the original is faithfully portrayed. But neither Lieberman nor Crelin is a paleoanthropologist and they were oblivious to this pitfall. Their idea was a good one, but the anatomy they used as their starting point was open to serious dispute and their work was severely criticized in the anthropological literature. Their conclusion, that Neandertals may have talked but would have had a greatly restricted range of vowel sounds, was not generally accepted.

But an anatomist/anthropologist of the next generation, Jeff Laitman, persisted, introducing new methods and bringing greater rigor into the attempt to reconstruct ancient vocal tracts. He developed measurements that showed the relationship between the increasing flexion of the base of the skull and the development of a more and more human vocal tract, with a larynx placed low in the neck. Laitman showed that, as hominids evolved from apelike forms to australopithecines, *Homo habilis*, *Homo erectus*, Neandertals, and finally modern humans, cranial flexion went from nonexistent in australopithecines and *habilis* to substantial in *erectus*. Cranial flexion was full blown in Neandertals some 300,000 years ago. A series of careful analyses convinced Laitman that the earliest hominids, like the australopithecines and habilines, were anatomically unable to talk; like me, he had read Raichle's work and knew that having a Broca's area did not mean that these species had language. But Laitman's studies left the case for language in *erectus* equivocal, for 15K's larynx probably rested in a position very similar to that of a young modern human child. Toddlers speak proto-language, so the boy's ability to vocalize might have been developed to a similar degree.

If *erectus* was anatomically capable of some kind of speech, did that make the boy and his colleagues linguists? Possibly, but confirming evidence of the other attributes of language were needed before I could endorse such a conclusion. The next criterion would be evidence of the regular use of symbols or icons. When I started to examine the record of human behavior – the archaeological remains left behind by different hominids – searching for clear symbols, I was walking on

well-trodden intellectual ground. Previous attempts to identify symbolic behaviors in the archaeological record had produced two widely divergent answers.

Historically, the first answer was that the manufacture of stone tools shared many of the features of the cognitive processes needed for language. Productivity was shown by the variable forms of artifacts, which are manufactured by combining a basic 'vocabulary' of motor operations in the same way that words are combined into phrases or sentences. Arbitrariness or symbolic content was seen in the imposition of a predetermined form upon a raw material. In other words, hominids seemingly had in their minds the standardized shape of a particular tool, such as a teardrop-shaped hand ax, and altered lumps of rock until they conformed to this shape. Cultural transmission of symbols was read into the repeated creation of a similar set or industry of tools by the same evolving population over time, but other aspects of language could not be detected or could not be analogized with stone tool manufacture. If making stone tools in regular shapes does correspond analytically to the processes used in creating language, then the origins of language may go back to a period about 1.4 million years ago. That is the point at which some hominid – it is generally believed to be *Homo erectus*, but no one knows for sure – began making hand axes and the consistent flakes that are struck off of them. Before 1.4 million years ago, stone tools were made, but their shapes are inconsistent and highly variable.

The 'language written in stone' idea was first expressed by Ralph Holloway of Columbia University in the late 1960s and has been elaborated upon or challenged many times since. Research subsequent to Holloway's initial publication has revealed a new view of stone tool manufacture that suggests flaws in this analogy. It is now clear that the form of an artifact, and the sequence of motor operations needed to produce it, are largely dictated by the raw material itself. Instead of a hominid's 'deciding' to make a hand ax, for example, we now understand that it is the size, shape, and fracture properties of the chunk of raw material at hand that determine whether or not a hand ax will be made. This means that the location of a toolmaker on the landscape relative to sources of various raw materials may be the overriding determinant of the components of that hominid's tool kit. The persistence of a characteristic suite of tools in one area over time is not necessarily evidence of cultural transmission of tool types and technological skills,

as was long believed; the tool kit may simply reflect what can be done with the quantities and types of stone that are found in that region. Some tools can be made of large pieces of stone, others of small; some tools must be made of fine-grained rock, others are less demanding; and so on. Technological breakthroughs – inventing or learning new ways of shaping stone – may increase the options of what can be made with a given raw material, but the limitations are imposed by the material, not the toolmaker.

Another problem that came to light after Holloway made his initial suggestion can be stated as a simple question: If toolmaking indicates the possession of the cognitive faculties necessary for language, how is it that chimps can and do make and use tools (in the wild and in captivity) and yet never master full language, even with intensive training?

Other analyses have suggested that language was a very late acquisition indeed; this made more sense to me from my new perspective. Two anthropologists at the University of New England in Australia, William Noble and Iain Davidson, have emphasized the symbolic nature of language as its most readily visible and perhaps the most important attribute. To them – to me too – the earliest, unequivocal evidence for the repeated use of symbols occurs very late. This evidence occurs at different times in different parts of the world, perhaps reflecting the spread of modern humans. Nowhere do undoubted symbols appear earlier than about 125,000 years ago, when anatomically modern humans first evolved; in much of the world, symbolism appears a mere 30,000–50,000 years ago. (While some people think of 50,000 years ago as very ancient, to me it is a negligible span of time that is smaller than the dating error of the fossils I work on.) Noble and Davidson point to abundant evidence from the Upper Paleolithic, a period that began around 35,000 years ago in Europe coincident with the appearance of anatomically modern humans. Although there are a few cases of apparently symbolic behavior in Europe earlier than this, they are isolated instances and thus not fully convincing. But unmistakably symbolic signs occur, repeatedly, from the beginning of the Upper Paleolithic onward.

Among the earliest known symbolic expressions are the beautiful little stone carvings from Vogelherd, Germany, a site dated to about 32,000 years ago that yielded caches of carved horses, humans, and other figures associated with arbitrary signs. Similar symbolic and

arbitrary expressions abound in the Dordogne region of southwestern France, in the spectacular painted caves such as Lascaux or in the less well known but equally stunning rock shelters filled with bas-relief sculpture, elaborately carved bone and ivory objects, and engravings. The animal depictions are amazingly beautiful and powerful, as well as being readily recognizable. Less well known (but not less common) are the geometric or linear symbols – odd grids, repeatedly used angular constructs, rows of dots, zigzags, V-shapes, and the like – that accompany the animals. The meaning of these geometric figures (or, for that matter, the meaning of the animal representations to the original artist) is so opaque as to defy analysis. Some items have been suggested to be arrows or traps, others to be ‘female symbols,’ still others to be artists’ signatures. Some may convey no more than ‘I am here.’

Yet without doubt all of these images are symbols and all of them are meaningful, even if we are today uncertain of the message. They were made with great care and considerable effort on the part of the artists. The sites where they were created are not always easily accessible; the pigments had to be gathered, ground, and carefully prepared; scaffoldings and lights were needed in many locales (and their traces have been found). Huge bas-relief carvings, as in the rock shelter known as Cap Blanc, or elaborate paintings, as in Lascaux, probably took days or even weeks of effort. The creation of the paintings, sculptures, and engravings seems likely to have been a ceremonial occasion, perhaps accompanied by music or song, according to studies of cave acoustics and the placement of artworks. These artistic expressions were much more than idle doodling or scribbling; they were deeply important to the artists, and I believe they are deeply important still. Almost certainly these are not the earliest symbolic (and hence linguistic) behaviors in the human lineage; they are simply the convincing earliest *evidence* of manifestly symbolic behaviors. In evolution, new behaviors routinely precede the appearance of concrete adaptations that facilitate those behaviors.

There are hints that symbolic behavior may have occurred earlier than the origin of modern humans. For example, our predecessors in Europe, the Neandertals, buried their dead; we find whole skeletons in deliberately dug trenches, sometimes associated with lumps of red ocher, or a tool or two, or a segment of an animal’s leg. The dead are sometimes arranged in artificial postures known as flexed or crouch burials, with the knees drawn up tightly; bodies were certainly

manipulated and may have been bound with some sort of fiber to achieve this position. Some archaeologists have argued, perhaps too fervently, that this mortuary ritual is clear evidence of a spiritual belief in an afterlife for which the dead person had to be prepared and equipped. While that interpretation leans too heavily on Western religious beliefs to persuade me, I think these burials are at the least evidence of some careful housekeeping and respectful treatment of individuals who are no longer alive. Is burial of the dead a symbolic act? The Upper Paleolithic behavior leaves no room for doubt, for the most spectacular of Upper Paleolithic burials have all the attributes of Neandertal burials and much more: intense patches of red ocher that must have been scattered over or painted onto the bodies; caps or cloaks covered in beads made of animal teeth or shells; carved bracelets, pendants, and other personal adornments; tools; and in one case, two pairs of mammoth tusks. These elaborate grave goods and body treatments unquestionably reflect symbolic behaviors. The difference between Neandertal and Upper Paleolithic burials is the difference between a burgeoning ability and one that is so fully developed as to be unmistakable. It may also be the difference between proto-language and true language.

If this interpretation is correct, then the advantages of more sophisticated and precise communication with others may be exemplified in the results of studies conducted by Olga Soffer, an archaeologist at the University of Illinois at Urbana-Champaign. She has looked at the differences in settlement patterns between earlier, Middle Paleolithic sites of northern Eurasia, presumably made by Neandertals, and those of later sites of the Upper Paleolithic in the same region, presumably made by modern humans. Earlier sites are smaller in area, suggesting people lived in smaller social units, and the sites’ contents suggest their residents used strictly local resources. Earlier sites are also geographically or ecologically restricted, occurring and recurring in the same areas. In contrast, Upper Paleolithic sites are very different: they are larger, they contain items derived from more widely scattered resources, and they are located in more diverse habitats. Skeletal remains from these periods reflect differences between Middle and Upper Paleolithic lives. The Neandertals from the earlier sites were subjected to more physical stress and died younger than anatomically modern humans, who survived weaning and childhood in greater numbers and enjoyed better health. Soffer concludes that the transition reflects ‘a dramatic change in

economic and social relationships' that coincided with the appearance of anatomically modern humans. To me, this change appears to be the aftermath of the development of true language, with its consequent improvement in planning and in the sharing of information.

Another way of looking at the origin of language is to ask what language is *for*. It is, according to Bickerton, a sophisticated system for representing the world that has secondarily been usurped for communication. Minimally, language, even proto-language, implies the existence of two individuals, a speaker and a listener. It is *about* social interaction and the exchange of information, which implies that the speaker and the listener do not share all knowledge in common. We might ask, then, when it becomes clear in the fossil record that groups of hominids began encountering other groups of hominids who were sufficiently foreign to make the exchange of information an important adaptive mechanism. Once again, the answer points to the Upper Paleolithic. This was the period when objects of personal adornment first began to appear regularly. As Randall White of New York University has observed, clothing, jewelry, and makeup or body paint are all means of projecting an identity. Then, as now, personal adornments almost certainly symbolized both individual identity and that individual's allegiance or membership in some larger group. What clothes or jewelry you wore, your style of body paint or scarification, or your haircut was a symbolic way of telling others who you were. There was no need for personal adornment as long as everyone was familiar; as in a small village, everyone would know everyone else from birth. The lack of personal adornments attests to a small social world, restricted perhaps to a few wandering bands who encountered one another regularly. The rise of personal adornments in the Upper Paleolithic, the greater density and larger size of archaeological sites, and the contents of those sites show clearly that people traveled substantial distances to congregate (at least periodically) into much larger groups. This new pattern of living meant that suddenly there was both a need and an occasion for demonstrating visually that you were part of this group and distinct from that. Lines were drawn between us and them; ethnicity was born.

It is easy to envision that these periodic gatherings would also have been occasion for important exchanges: of potential mates and of information. Margaret Conkey, a Berkeley anthropologist, has argued that the symbolic art of the Upper Paleolithic was a means of encoding

information. Art was in some sense an aide-mémoire, needed because new, richer, and more diverse information was now available through communication with others. Art and ceremonies not only created images, they created memorable occasions, experiences that evoked strong emotions that would embed the information firmly in the mind of the participants.

We can only imagine what was communicated: places to hunt; new sorts of traps; locations of water, good caves, or outcrops of stone good for making tools; the location of plants or herbs that might be edible or might heal illnesses; techniques for making tools, traps, or snares; information about the behavior of animals; tales about the weather and climate; or ways to make and keep fire. Mixed in with all of these topics, and probably others we cannot imagine, would surely have been those most human of all interests, personal gossip and stories. Knowledge of places, resources, events, and people would be valuable and precious information. Symbols were one means of remembering this information, of mapping the world permanently.

There are other sorts of evidence that suggest advanced cognitive skills on the part of early modern humans. The ability to colonize new continents, especially Australia, also bespeaks considerable cognitive sophistication on the part of our ancestors, even if there are no archaeological remains that directly demonstrate arbitrary, symbolic behavior. Greater Australia (a region that includes the continent of Australia and several adjacent islands that were then part of the same landmass) was colonized at least 40,000 years ago and maybe as many as 60,000 years ago, according to the oldest known skeletal evidence and archaeological sites. Archaeologist Sandra Bowdler of the University of Western Australia sees the colonization of Greater Australia as the culmination of a series of waves of territorial expansion that brought significant numbers of humans into southeast Asia for the first time since *Homo erectus*. In any case, this island continent could not have been reached from the mainland without boats; to reach Greater Australia required a trip across some 200 kilometers (125 miles) of open sea, heading toward a landmass that could not be seen from the shore. The trip must have been repeated many times, for the archaeological evidence shows that the continent was populated too rapidly for the colonizers to have been a single boatload of people and their offspring.

The difficulty of colonizing Greater Australia was not over once the

first colonists had survived the trip. Bowdler believes that the colonizers were tropical rain forest peoples with a strong set of adaptations for the exploitation of coastal or aquatic resources. They may have followed the shoreline and rivers down the eastern shore of Australia, where rain forests persisted. Yet many things about the new continent were different and difficult. None of the animals the colonizers knew and hunted were there, and indigenous Australian species took the place of many of the familiar rain forest plants. Many aspects of their previous adaptations to life needed to be altered, particularly as they came to drier areas or highland regions of Australia. Most of the desert interior of Australia was simply unsuitable for human habitation, as many have discovered at their peril. Considering the complexity of the problems that had to be solved to build suitable ships, accomplish such voyages, and survive, reproduce, and populate a new continent – problems that caused high death rates among English immigrants and deportees who tried to recolonize Australia in the nineteenth century – I find it hard to imagine that the people who first colonized Australia lacked full language.

Inspecting the archaeological record is not the only means of investigating the origins of human language. An entirely different type of evidence was gathered by Luigi Cavalli-Sforza, a prominent human geneticist at Stanford University, and his Italian colleagues. They collected blood samples from forty-two different human populations around the world: Mbuti Pygmies, Lapps, North African Berbers, Sardinians, Eskimos, Melanesians, Indian groups from North and South America, Europeans, Tibetans, Maoris, and many others. The team analyzed these samples for information about the distribution of 120 alleles, or genetic alternatives. Using complicated statistical techniques, they grouped the results into phylogenetic trees that reflected the genetic resemblances among the human populations. These trees provide not only an estimate of relationships but also a sequence of branching that can be assumed to represent the path of evolution.

Their results led to some striking conclusions. Reassuringly, the genetic data from different populations cluster into groups that correspond to geographic realities: Africans with Africans; Asians with Asians; Australians with other Pacific peoples; and so on. Analysis of these clusters and the distances among them supports the idea that all modern humans shared an African origin. The greatest genetic distance

lies between the African populations and all other groups combined, implying that the Africans separated first from the other groups, giving Africans the longest time over which to evolve independently. Cavalli-Sforza concludes that the first split occurred when the initial, single population divided into an African and an Asian group; then Australians broke away from the Asians; and finally the Europeans separated from the Asians. This branching pattern would fit well with a model of migratory waves of modern humans spreading across the Old World, starting from an African origin. Cavalli-Sforza sees a congruence between the genetic distance data and the fossil evidence for the spread of anatomically modern humans into various parts of the world. Modern human remains are about 125,000 years old in Africa, about 50,000 to 60,000 years old in Asia, about 40,000 years old in Australia, about 35,000 years old in western Europe, and only 15,000 years old (with contested evidence up to about 35,000 years) in the Americas.

Cavalli-Sforza's argument becomes compelling when he compares his branching phylogenetic tree, based on genetic data, with one produced by a group of linguists trying to reconstruct the 'evolution' of modern languages. The two trees – one linguistic, one genetic – are amazingly similar, so similar that the two seem highly likely to reflect the same historical events. Of course, the language you speak is not genetically determined but culturally transmitted. There are many well-documented instances of peoples who have lost their original language and adopted that of a socially dominant group. In fact, a language is more easily replaced than (in most cases) genes are; languages change easily while it seems relatively rare that the genetic makeup of one population is swamped by an influx of new genes from another. Thus Hungarians speak a Uralic language originally imposed on them by the Magyars who conquered Hungary in the Middle Ages; nonetheless, genetically, Hungarians are predominantly European, with only slight traces of Magyar genes.

Genes, though, can move surprisingly quickly. Cavalli-Sforza gives an example closer to home for many of us: African Americans today have a gene pool that is on average about 30 percent European, yet African slaves and their descendants have been in America for no more than two hundred years (and often less). One way in which this admixture could occur in such a short span of time, Cavalli-Sforza calculates, is if 5 percent of all children born to African Americans in each generation

(since the institution of slavery) had one European and one African parent and if all of those offspring were considered to be ethnically black.

Although languages evolve more rapidly than genes and move more freely among peoples, there are only about five thousand languages in the world today. Of course, the number of individual languages is only a general reflection of the antiquity of language as a capability; you can't calculate the time of the origin of all languages from such information. But surely if humans had had language since the origin of the genus *Homo*, back almost two and a half million years ago, the number of languages would be far greater and the diversity of tongues broader.

Cavalli-Sforza makes one final, telling observation about the link between anatomically modern humans and full language. Neandertals disappeared and were rapidly replaced by modern humans, an event that may have taken only a few thousand years in some parts of Europe. He finds the strong dominance of modern humans easier to understand if Neandertals were not fully linguinate, 'if they were biologically provided with a speech of more modest quality than modern humans,' as he puts it.

In our society [Cavalli-Sforza writes], until 100-150 years ago, deaf-mute people had very little chance of reproducing because of strong adverse social selection. . . . Even if interfertility was potentially complete and there was little or no impingement, Neanderthals must have been at a substantial disadvantage at both the between- and the within-population level.

In my mind, these varied lines of evidence - anatomy, archaeology, and genetics - all point to a single conclusion. True language seems to me to have been a very recent acquisition, one that just precedes and enables the evolution of anatomically modern humans and fully modern behaviors. It would seem that, once again, Haeckel's unfounded guess about the attributes of the missing link was correct: *Homo erectus* was speechless, illinguate. Not only does this conclusion contradict the accepted wisdom that language acquisition demarcates the origin of the genus *Homo*, it leaves me with a haunting and novel image of the Nariokotome boy.

Here was a young man, tall, black, lean, and muscled, thoroughly adapted to his environment. He made tools that, although crude, represented a substantial advance over those of his predecessors and he made

these tools according to a distinct and repetitive plan, using deliberate techniques. He lived in a group with strong social ties, one that nurtured helpless infants and nourished their mothers. He and his kind were very successful in obtaining high-quality foods, almost certainly by hunting, so successful that the evolution of big brains and large bodies could occur. The boy's species, *Homo erectus*, was perhaps the cleverest that had yet walked the face of the earth. Long-legged and immensely strong, this species strode out of Africa. They were such effective predators that they could invade and colonize most of the Old World at a rate that appears virtually instantaneous to our modern dating techniques: less than a hundred thousand years to get from Africa to Java, not by deliberate migration but by simple population expansion, year after year.

All of this looks and sounds so human, and yet . . . and yet the boy could not talk and he could not think as we do. For all of his human physique and physiology, the boy was still an animal - a clever one, a large one, a successful one - but an animal nonetheless.

This final discovery of the boy's speechlessness had an enormous emotional impact on me. Over the years that had passed since Richard, Kamoya, and I had first excavated his bones, I had thought I was growing to know the boy, to understand him, to speak his language, metaphorically. I grew fond of his form; his face took on the familiarity of a member of the family or an old friend. I could almost see him moving around the harshly beautiful Turkana landscape, at a distance looking enough like the Turkana people to be mistaken for human. *He did this*, I would think, *he knelt there to scoop up water or crouched behind a bush like this one to stalk an antelope*. But then, as I approached him closely, preparing mentally to hail him and at last make his acquaintance in person, it was as if he turned and looked at me. In his eyes was not the expectant reserve of a stranger but that deadly unknowing I have seen in a lion's blank yellow eyes. He may have been our ancestor, but there was no human consciousness within that human body. He was not one of us.