CHAPTER 2

Technical invention in the Palaeolithic: What if the explanation comes from the cognitive and neuropsychological sciences?

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The evolution of the cerebral capacities of humans, from the first hominins to modern humans, is at the heart of our interrogations. How can we explain the fact that only hominins seem to have developed the capacity for technical invention, in contrast to our closest relatives, the great apes? The archaeological data allow us to observe this phenomenon, but offer very little in the way of a response to this question.

By examining the possible contributions of other disciplines, particularly in the cognitive and neuropsychological sciences, we can ask if there exists a cause-and-effect relationship between the following phenomena:

- the archaeological data, which indicate that technical inventions throughout prehistory are increasingly frequent and complex from the first hominins to modern humans;
- the cognitive perspective, which seems to indicate that the processes of analogical reasoning are increasingly frequent through time, either for "statistical" reasons (a greater population density leads to a greater probability of the meeting of two ideas) or for cognitive reasons; and
- the palaeoanthropological data, which show that current neurological conditions developed progressively, with the frontal lobes and prefrontal cortex becoming more and more accentuated from the first hominins to modern humans.

We will explore the possible contribution of a confrontation of these different disciplines.

Invention processes: The archaeological data

Through the study of a certain category of archaeological remains – stone tools that are not flint – I have shown that the invention of new tools and new actions seems to have resulted from a combination of preexisting elements, rather than from creations *ex nihilo*, or an accumulation of knowledge. They were made possible by the fusion of two different technical actions, by the combination of a familiar action with a tool traditionally used for other purposes, or by the combination of a familiar tool with a new worked material (de Beaune 2000, 2004, 2008). To briefly recapitulate this process, I will present some examples, the first of which comes from my own investigations of nonflint stone tools.

During the Neolithic period, the technique of polishing with a fixed polisher on bedrock was extensively used to polish ax blades. This technique could be the result of a fusion of the technique of polishing long objects with a small, generally grooved, hand polisher during the Upper Palaeolithic and Mesolithic, and the full back-and-forth grinding technique, generally realized with two hands, which appeared at the end of the Upper Palaeolithic or Epipalaeolithic and was first used to grind wild cereal grains (de Beaune 2000, 186–187).

Pottery seems to have resulted from a combination of the idea of a container (which already existed in the form of skin, vegetal fiber, bark, and wood containers) and the baked-clay technique. Baked clay was already used as a coating for walls and floors, and later as an internal facing of pit hearths as early as the second phase of Mureybet, and then to shape figurines starting in Mureybet Phase IIIA (Cauvin 1978, 101; 1994, 64).

Another much earlier example has been proposed by Despina Liolios in the context of antler-working techniques, which would have been transferred from wood to antler during the early Aurignacian period (Liolios 2003).

Much further back in time, we could include the first attempts at bone shaping during the Middle or Early Palaeolithic, which consisted of no more than knapping techniques transferred from flint to bone. The result was the crude bone bifaces or bone side scrapers found in several sites, such as Castel di Guido and Fontana Ranuccio in Italy and Bilzingsleben in Thüringen, Germany (Biddittu & Segre 1982; Pitti & Radmilli 1984; Mania 1995).

We thus see that from the Early Palaeolithic to the Neolithic, innovations or inventions seem to have resulted from the same process of technical transfer, meaning the combination of two already existing, but independent, technical ideas. These combinations did not arise from nothing, but rather from an association in the mind of things until then dissociated in experience.

In this way, the increase and diversification of inventions and innovations through time could simply have resulted from a demographic increase, which favored the opportunity for technical confrontations. However, we must keep in mind that the combination of two technical ideas is neither systematic nor necessary, and that it is possible for two ideas never to meet (for example, the idea of the wheel and that of the carriage for the ancient Mexicans).

In the same way, an "invention" can remain with no outcome if it is not adopted by the group, and in this case it is very unlikely that it would be recognized by archaeologists.

The term "exaptation" introduced by Stephen Jay Gould and Elizabeth Vrba (Gould & Vrba 1982) designates something that emerges from a context before its exploitation in another one. In other words, the word defines the choice in the present to use elements initially destined for other functions (or no function) for certain purposes. As an example, they cite the case of an African lizard whose extremely flat head constitutes an adaptation to life in crevices, but which also permits the animal to slide better.

Exaptation is in a way opposed to adaptation because, whereas adaptation implies a modification of a function to allow different uses, exaptation is the adoption of a character that had one use in an ancestral form and a new and different use in a descendant form.

Exaptation could explain how complex physical characteristics can evolve from initial simple structures. In fact, the term better clarifies the technical invention process in question here.

Invention processes: The cognitive perspective

These few examples of technical inventions could result from the well-known cognitive capacity of analogy. To cite Le Ny from his preface to the book Analogie et Cognition, "analogy, in its broad sense, and its cousin, resemblance (or similarity), is probably the basis of many automatic cognitive activities, and I am not far from thinking that it is one of the fundamental determinants of cognitive functioning" (Le Ny 1999, x). More precisely, the functioning of analogy in problem solving, in the generation of scientific hypotheses, or in declarative knowledge attainment, as in many other cognitive domains, is always based on the capacity to perceive and use analogous facts. In other words, it is based on the capacity to establish a link between two domains and transfer a familiar procedure from one situation or class of situations to a new situation that is similar though not identical (Le Ny 1999, xiv).

The three following questions thus arise: What exactly is the process of analogical reasoning? Is it specific to humans? If so, when did it appear?

What is the analogical process?

The analogical process can easily be summarized as follows: When people are faced with a new situation or problem, they look for a similar problem or situation in their anterior experience for which they had found a good solution.

This strategy implies two types of mental representation: those stocked in the long-term memory, and transitory representations, meaning those used during information treatment that correspond to the working memory, including old representations reactivated in the moment of their treatment.

Although referential knowledge is essential, two other cognitive tools are also necessary for its utilization: abstraction and generalization (Gineste 1997, 86, 119).

Obviously, differences exist between a so-called expert, who has already confronted an analogous problem and who possesses structured and stabilized knowledge in the long-term memory, and a novice confronted with a new problem. The latter must establish a link between two domains and transfer a familiar procedure from one situation or class of situations to a new situation that is similar though not identical.

In spite of some minor theoretical differences, most cognitive psychologists agree on the manner in which the analogical process functions and its importance in the processes of invention and problem solving.

Is analogical reasoning specific to humans?

Chimpanzees occasionally use transfer to solve a problem or a situation. However, this capacity, known as competence transfer, has been observed only in captivity and uniquely among subjects educated in experimental-language training. This is the case with Sarah, studied by David Premack

(Premack & Woodruff 1978; Byrne 1995, 84–85), in the particular context of spatial competence.

The lack of inventiveness of chimpanzees could be explained as an absence or only minor development of their long-term memory. However, it is true that researchers have mostly studied the phenomenon of working-memory recognition, whereas studies concerning the recall of long-term memory have been neglected. This is perhaps because the latter is considered to be exclusively linked with linguistic information and thus inaccessible in the study of species lacking language (Vauclair 1992, 106). The only case of this type yet studied is that of Sarah.

If apes do have access to information stored in the long-term memory, their lack of "inventiveness" could be due to a lack of need for it in their natural environment, or a lack of social motivation. The chimpanzee Sultan, studied by Köhler, showed analogical reasoning. However, this remains an isolated and individual case and he did not transmit it to other members of the group (Köhler 1925). In other words, these aptitudes do not occur in nature because there is a lack of need or a lack of social connections between individuals.

When did analogical reasoning first appear among the hominins or first humans?

The degree of complexity required to realize a biface implies the capacity to preview and plan certain operational stages. It is obvious that working memory is not sufficient here and the recovery of long-term memory is necessary. We can thus conclude that *Homo erectus* was able to perform analogical reasoning.

Before this time, we can consider that the realization of choppers or chopping tools might depend only on the working memory. The capacity of this memory is weak – implying no more than 7 ± 2 units – and rapidly forgotten, in about 20 seconds, but it is sufficient to realize a cutting edge.

Meanwhile, the invention of stone knapping itself results from the technical transfer of an action to a different material. The percussion movement used to crack bone or hard fruit could have led to the use of percussion to obtain a cutting flake (de Beaune 2000, 176–179). This invention could have occurred in three stages.

The first stage corresponds to the use of cobbles or blocks to crack bones, hard fruits, or wood. An accidental flake is produced. The author of the action can store it – or not – to use it. This attitude, observed among modern chimpanzees, could have occurred among Australopithecines.

In the second stage, similar actions are employed but now the user focuses on accidental debris. Flakes serve as knives or scrapers to cut, scrape, slice, or saw animal or vegetable materials.

Though chimpanzees rarely act in this way, it is probable that the earliest Australopithecines used such flakes to scrape the buried parts of plants, for example. Among the activities that could have accidentally produced flakes, we can consider nut cracking, which is performed by some chimpanzees, or the cutting up of carcasses, unknown by chimpanzees, but perhaps practiced by some Australopithecines.

In the third stage, the deliberate will to produce flakes by knapping a cobble with a hammerstone appears. The hammerstone thus becomes a basic tool that serves to produce flakes from a block or nodule, which is now transformed into a core. The artisans are now interested not only in the intentionally produced flakes, but also in the cobble or block with a sinuous edge on one of its extremities and a blunt surface for holding on the other. These are choppers. The most recent Australopithecines, *Paranthropus*, or the first humans were certainly the first actors in this third stage.

Marchant and McGrew have recently proposed a similar hypothesis (Marchant & McGrew 2005). If we accept such a scenario, we must admit that these first knapping tools provide some evidence for the capacity for analogical reasoning, but we do not yet know who among these first hominins possessed this capacity.

Invention processes: The neurological perspective

These data concerning the link between neuronal evolution and the evolution of cognitive capacities are contradictory. All researchers recognize that brain growth during hominization, which is shown by an increase in the thickness of the cerebral crust and in the size and ramification of neurons, would have led to a greater richness in the interneuronal connections, which itself would have led to a significant improvement in cognitive capacities, as shown in Figure 2.1 (also see Changeux 2000, 196).

The figure shows the topography of the meningeal vessels on the parietal bone of some hominins. This regulatory system, which is physiologically very important, is linked to the effective functioning of the brain. Known through endocranial casts, it shows a gradual increase in complexity during

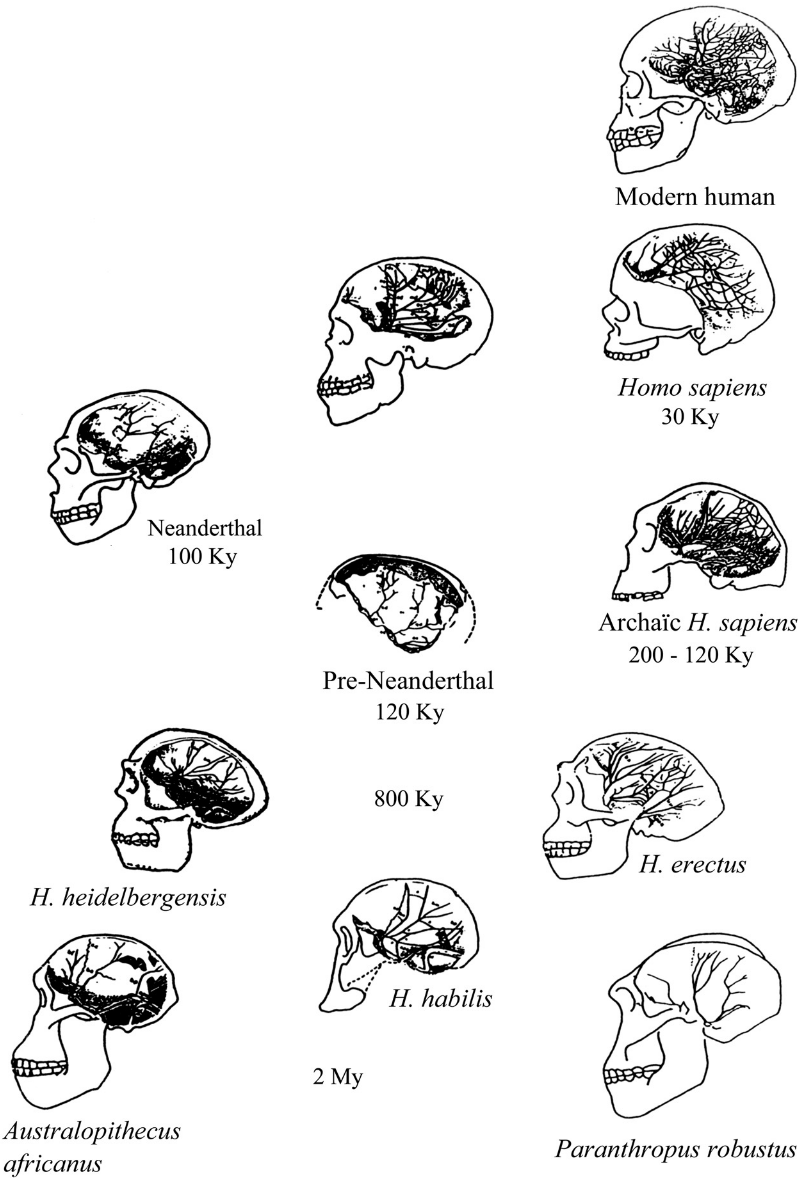

FIGURE 2.1. Topography of the meningeal vessels on the parietal bone of some hominins, adapted from Saban (1995). The possible filiations and hybridizations indicated by Saban by continuous or dashed lines are now outdated. (Courtesy of Elsevier Masson.)

hominization. This topography was compared by Saban with those of young modern children during their development. It is remarkable to observe that the topography of the meningeal vessels of *Paranthropus robustus* (cranial capacity: 520 cc) resembles that of a modern newborn; that the distribution of the vessels of early humans (*Homo habilis*, cranial capacity: 700 cc) is close to that of a 40-day-old modern child, and that of *Homo erectus* from Java (cranial capacity: 1,000 cc) resembles that of a 1-year-old modern child.

Moreover, researchers agree that brain growth primarily concerns the neocortex, and, more precisely, the frontal lobe, which is very important in human beings because it represents nearly one third of the cerebral volume. This aspect developed considerably during hominization, the earlier hominins having a supraorbital torus that blocked the development of the skullcap above the forehead.

But here is where the unanimity of opinion stops. For a precise understanding of the link between human cognitive capacities and cerebral organization, there exist two main, and rival, theses: localizationism and connectionism.

Localizationism

Supporters of localizationism, known as localizationists, suppose the existence of a correlation between mental functions and specific areas of the brain. Arising at the beginning of the nineteenth century, this theory was greatly developed following the creation of a cerebral map. More recent cerebral imagery seems to point in the same direction.

The frontal lobe, which is of specific interest to us here because it is the one that developed the most during hominization, seems to be the center of reflexive conscience and upper psychism. It is here that intentions seem to arise and where programming, initialization, and control of voluntary behaviors seem to occur. In any case, researchers agree that certain complex apprenticeships, such as the solving of algebraic equations, multiple language learning, or motor abilities, take place in the prefrontal associative zones.

Moreover, analysis by positron emission tomography has been used to examine brain activation during experimental stone toolmaking (Stout et al. 2000). Experiments show that the main areas activated by an experienced modern knapper (neocortex and cerebellum) are exactly those that underwent the greatest expansion in hominid evolution. Therefore, some palaeoanthropologists are certain that the enlargement of the frontal lobe during hominization is related to cognitive abilities and language (e.g., Bradshaw 1997; Gärdenfors 2004).

Many neurophysiologists remain skeptical, however, concerning an excessive localizationism. Renowned French surgeon and anthropologist Paul Broca himself pointed out that a functional deficit resulting from the deterioration of a specific area, far from providing evidence for the role of that area, could also prove that a nervous circuit removed from the actual center of the function involved had been interrupted (Cocude & Jouhaneau 1993, 411).

Connectionism

This brings us to the second thesis: connectionism. According to this theory, the cortex would be organized according to a certain homogeneity based on the notion of a nervous system network: modular units would be interconnected with a similar structure and function. In other words, different functions would be assumed by particular cortical areas, but largely distributed among the cerebral tissue. Each cortical area would thus be more or less implicated in different functions.

Long-term memory, for example, does not seem to have a precise localization and appears to be registered at the level of synaptic connections in both hemispheres with no precise anchoring. Each event would thus be stored at a large number of points in the form of traces dispersed throughout the brain (Cocude & Jouhaneau 1993, 407).

The brain would act statistically, each cerebral area participating in all the mental operations, but with varying degrees of implication according to the operations (E. R. John, cited by Cocude & Jouhaneau 1993, 411). This supposes a weak functional specialization of cortical neurons and tremendous brain plasticity, which could explain the apprenticeship ability and modification faculty dependent on experience. Plasticity also explains why a function that was previously assumed by a destroyed area could be taken over by another area (adjoining or homologous in the other hemisphere) after a lesion at a particular point. At the neuronal level, this would be reflected by a biochemical modification corresponding to mnesic traces left by experience and liable to be patterned again.

In addition, neuronal circuits are not unique, but redundant, thousands of cells having identical tasks in parallel. The best proof of this redundancy is that the daily death of many neurons that are never replaced does not result in any apparent malfunction. This shows that the same memory is coded in many parts of the cortex and not localized in a unique network.

A compromise between localizationism and connectionism?

How then can we explain the observation that certain lesions seem to correspond to particular areas, which are also visible through cerebral imagery? It is possible that the two explanations – localizationism and connectionism – are not necessarily contradictory. Lambert was of this opinion: "Plasticity involves a balance between stability and further modeling, if not, without invariants, the brain would always be destructured and memory of an extreme lability" (Lambert 2006, 52). Moreover, Lambert and Rezsöhazy show that this plasticity is not limited to synaptic plasticity but rather concerns many biological domains, emphasizing the astonishing coexistence between "a coherence that is maintained and a correlative ability to distort itself in order to adapt to conditions that are susceptible to change" (Lambert & Rezsöhazy 2004, 287).

In addition, cerebral plasticity seems to be more developed during infancy when a child is in the process of development and the neurons and synapses are being organized. Adult plasticity diminishes as a result of the number of acquisitions they already have (Bradshaw 1997). This explains why children recover and compensate more easily and more quickly than adults in the case of cerebral lesions.

Therefore, the two theses would be viable. As Changeux suggests, "Functional specialization of cortical areas indeed exist . . . but these areas are very largely interconnected. They can group in very large and much more global functional units" (Changeux 2000, 49).

Although all cerebral areas can be concerned by a particular cerebral activity, there exists a certain hierarchy: the more sensory objects concern abstract and general concepts, behavior rules, and relations between oneself and others, the more the contribution of the frontal and prefrontal areas becomes important. Concrete images mobilize essentially sensorial primary and secondary areas when concepts have a larger connectivity. The increase in the hierarchy from the perceptual to the conceptual is accompanied by a progressive mobilization of primary somatosensory cortex, association cortex, and prefrontal areas. There thus exists a sort of geography of comprehension in our cerebral cortex (Changeux 2000, 115).

Returning to hominization and the evolution of the neuronal capacities of humans over thousands of years, we can propose some preliminary conclusions.

1. If cognitive abilities are in fact localized, we must admit that an enlargement of the frontal lobe plays a prominent role in psychic, cultural, and technical human evolution, probably by allowing humans to innovate and adapt their knowledge. Whereas long-term memory seems to concern whole cortex territories, the short-term or working memory seems closely related to the frontal cortex. However, we see that the latter is essential to analogical reasoning.
2. Although the brain is highly plastic and possesses significant capacities for self-modification, we have seen that this adaptive function would be related to the neuronal networks that follow variable paths. However, the larger the cortical surface, the more numerous are the networks. The cortical surface of cerebral circumvolutions is much larger in humans than in other hominids (64% of the cortical surface is hidden in the cerebral recesses, versus only 7% for primitive monkeys). Therefore, even without information concerning the precise localization of cerebral abilities, we can conclude that the exponential increase of hominin brain volume must be related to the increase of cognitive abilities.
3. If a comprehension geography indeed exists in the cortex, with a hierarchy from the perceptual to the conceptual, we saw that prefrontal areas are in this case implied in the most abstract operations and those concerning relations between oneself and the other; this point confirms the link between the increase of the prefrontal cortex and abstraction or planning operations, or, in other words, the analogical reasoning conditions that permit technical invention.

Conclusion

What can we conclude from this confrontation of different disciplines? I would be tempted to link the three phenomena exposed at the beginning of this chapter: first, there is an exponential frequency and increasing complexity of the toolkit and other productions, material or not; second, the analogical reasoning process appeared as early as the beginnings of hominization; and third, the development of the cortical surface and prefrontal cortex involving mnesic traces favors stocking, which permits the analogical reasoning that could lead to invention.

Though this parallelism could seem commonplace, it shows that the conditions of technical invention were present much earlier than we could have imagined a priori: as early as the appearance of the first knapped-stone tools. Furthermore, though technical inventions seem to increase and diversify according to an exponential rhythm during prehistory, it is possible that this is not due to an improvement of neuronal or cognitive conditions already acquired but to external circumstances such as a greater population size, which would have increased the probability of meetings between two ideas or two techniques.

The investigations of Stanislas Dehaene (cognitive neuroimagery specialist) concerning the neurological processes employed during reading apprenticeship seem to point in nearly the same direction, showing that neurophysiologic constraints could play an important role during the birth of cultural inventions. These inventions would be adopted only when they invade cerebral areas initially devoted to sufficiently similar functions. This means that “the cultural variations that mankind can produce are not unlimited” and “are strictly constrained by representations and cerebral mechanisms inherited from evolution and which define our human nature” (Dehaene 2003, 198). In this way, the instantaneous success, or, in contrast, the difficult apprenticeship, of a cultural object could be explained by its greater or lesser appropriateness with the representations shaped by our brain. We rejoin here the idea of exaptation developed by Stephen Jay Gould.