AMERICAN ANTHROPOLOGIST

VOL. 50 APRIL-JUNE, 1948 No. 2

THE EXTRAORGANIC

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TWO years ago the *American Anthropologist* published an article by me[1] in which some far-reaching statements were made concerning the relationship of the organic and the cultural. The chief thesis of that paper was that the manufacture and use of tools by the proto-human ancestors of man resulted in the evolutionary improvement of both brain and extraorganic implement in a recipro-causal manner. A closer examination since then of the literature on the evolution and development of the vertebrate nervous system has brought to my knowledge a process which provides a better factual basis for that conclusion than was given in that paper.[2]

The phenomenon of neurobiotaxis, with which the name of C. U. Ariëns Kappers is closely associated, is a physiological process by which the manufacture and use of extraorganic devices could have affected the primate brain in evolution. Neurobiotaxis is described as follows:[3]

> Comparative researches on the medulla oblongata and the mesencephalon (Ariëns Kappers, '07, '08a, '20) indicate that changes in position of the cell bodies are determined by a process of taxis or tropism, due to the stimulation of such cells and the bioelectric consequences of such stimulation which determine the selectivity of the neuronal connections and the differences between the dendrites and neuraxes, the so-called dynamic polarization of the neuron (compare with p. 79). By what means these processes are reproduced engrammatically under embryologic conditions, it is not possible to state at present. A similar statement applies to the entire ontogenetic development. Thus the formation of the extremities for walking and grasping can be explained only by use of engrammatic factors, the specific characters of which are unknown as yet. That the electrical potentials arising during evolution (Child, '21), the sequence of which may be determined by engrammatic factors, may play a part in this process is possible.

Differences in positions of cell groups attributed to neurobiotaxis are to be

[1] Greenman, 1945 (*See* Bibliography at end of article).

[2] Dr. C. Judson Herrick has read the present paper in manuscript form. I am indebted to him, and deeply grateful, for valuable criticisms and suggestions on a subject of which my own knowledge is based entirely upon the published literature.

[3] Ariëns Kappers, Huber, and Crosby, 1936, p. 76.

seen in the spinal cord, oblongata, midbrain and forebrain.[4] Under Résumé and Conclusions[5] is the following:

The phylogenetic differences in position of the cells of the motor nuclei suggest that the positions of the dendrites and the cell body are determined by the impulses which reach them. Further researches show that the determining influence is evident only in such cells as have a previous or indirect affinity for these impulses or lie in a region where these impulses accumulate. This affinity consists of simultaneous or successive states of action (stimulative correlation). Consequently a law governing nervous arrangement can be laid down. This law has long since been acknowledged to be one of the major laws governing the development of our mental capacities, that is, the law of mental association.

Herrick describes neurobiotaxis as

a principle which establishes that if in the nervous system, by a change in the mode of life of the species, a particular center receives its dominant stimuli from a new direction or by a different tract from the former connections there will be a tendency for the chief dendrites of the nerve cells of this center to be extended in the direction from which the new dominant nervous impulses are derived, and eventually the bodies of these neurons will migrate in the same direction. In the course of phylogeny many nuclei within the brain have changed their positions in accordance with this principle and the particular functional adaptations involved have been carefully investigated. . . . The applications of the principle of neurobiotaxis have been worked out in most detail in connection with the motor centers of the brain; but the principle applies equally elsewhere and many features of the nervous system, including the arrangements of correlation centers in the brain stem and the patterns of cortical localization of function, are believed to have arisen in accordance with it.[6]

The change during growth in the positions of motor neurons in relation to stimuli received by them is a process by which the use of extraorganic objects held in the hand can alter the structure of the brain, and it is likely that it played an important part in the passage of man's ancestors from a simian condition to that represented by Cro-Magnon and later types. This is hardly the selection of mutation, and it opens a door for a use-effect of a kind that is distinctive in neural evolution.

In the redistribution of neurons in each succeeding generation relative to stimuli received by them genes are not involved, for the stimuli are of a temporary nature and arise outside of the germ-plasm. Vertebrate evolution proceeds genetically by the building up of organic mechanisms through selection of small random variations[7] in the proper succession. One or more such small changes may bring new stimuli into the brain or send accustomed stimuli along

[4] *Ibid.*, p. 76.
[5] *Ibid.*, p. 92.
[6] Herrick, 1924, p. 196.
[7] Huxley, 1942, pp. 54–55, 115.

different pathways. It is obvious that if the positions of neurons are determined in successive ontogenies in relation to incoming stimuli, mutations involving changes in the structure of the organs of sense and movement could have influenced to an important extent the phylogenetic growth of the brains of animals throughout the whole period of organic evolution since the rise of the nervous system.

In ontogenetic development the new stimulus becomes reflected in neural structure and that structure is maintained as long as the new conditions in the adaptive organs last. The stimuli are temporary excitations in each ontogeny but their occurrence in each succeeding ontogeny maintains the related neuronal positions with a pseudo-genetic effect, until some further change arises through mutation in the organs from which the stimuli are ultimately received. Such a situation is recorded by Black for the teleosts, among which "the extreme specialization of any of the organs of special sense is followed by a corresponding amplification of the primary afferent nucleus or nuclei involved, together with a modification of the motor nuclear pattern in perfect harmony with the reflex needs of the animal."[8] The brain thus reflects the adaptations of animals, and the continual reaction between the neural and the adaptive mechanisms, the latter always following closely the requirements of the external world, played a large part in progressive evolution. It is to a considerable extent the *use* of the terminal organs that has produced in successive generations the neurobiotactical effects which are stabilized in the phylogenetic course. This is because the use of the volitional organs sets up proprioceptive sensations which return to the central nervous system with stimulative effect. "The enormous importance of these proprioceptive systems in the coordination and integration of bodily activities and as organic background of human behavior has only recently been fully appreciated."[9] Exteroceptive influences also reach the brain from the external organs of vision, touch, and balance, during the performance of discriminating manual acts, and these two types of stimuli become merged, with increasing complexity upward in the evolutionary scale, in the formation of the proper motor responses. The fact that instruments of human material culture are separate from the body is no barrier to the introduction of new stimuli into the central nervous system by their use. Objects of human material culture are extraorganic adaptations and have apparently interacted with the human brain in the same way as organic adaptations. None of the behavior patterns preceding the making and use of tools, in so far as we know them from observations on apes and monkeys, would have carried the brain beyond the simian level.

There is very little in the literature of genetics about neural changes which

[8] Black, 1917, p. 558.
[9] Herrick, 1924, p. 252.

arise through mutation or recombination. Huxley tends to regard the evolution of the central nervous system as allometric in character[10] and makes no reference to the genic control of neural structure. Dobzhansky, discussing types of changes produced by mutation, says that "Changes in the internal organs are observed mostly in connection with external changes; thus, the brain is changed in connection with the eye size and the presence or absence of the eyes."[11] I am indebted to the author for the information that this is a reference to recent work by Power, who was able to associate a mutational reduction in the eye of a fruit-fly with a diminution in size of the mass of unmyelinated fibers in the adjacent part of the brain and connected with the eye. This cannot be taken as an instance of a mutational change in the brain. Power's conclusion is as follows: "The data strongly indicate that the hypoplasia of the glomeruli is not a primary action upon the brain of the genetic factors studied but, rather, a secondary result of the ingrowth of a smaller number of centripetal fibers from the genetically reduced peripheral field (the eye discs)."[12] While the statement that the brain changes in connection with changes in external organs does not necessarily mean that it is changed in no other way, a caution must be entered that the literature of genetics offers no concrete evidence that the central nervous system, at least in its finer structure, is subject to mutation.

In the evolutionary advance of the animal form the gene has been the mechanism by which mutation and recombination have enabled living matter to adapt itself successively to water, land and air, and to all the minor conditions in each of those habitats down to the last ecological niche. Evolutionary progress has been largely a matter of continued improvement in the biomechanics of motion. The organism must act in relation to the external world, and this it does by movement, by avoidance or pursuit,[13] by the exercise of choice between the two according to the circumstances. Organic evolution is a pattern of exploitation of the environment by improvement of the implements of motion, of the body as a whole, and of its parts separately and in coordination. Parallel to this there has been a progressive widening of the patterns of volition, and on the evidence we are permitted to say that a living thing is as alive as its organic implements allow it to be. Its choice is as wide as its biomechanical ability, and the wider the choice, the greater the volition, the higher the intelligence. As Herrick has said: "Consciousness emerges within behavior as a new pattern of performance.[14]

Mutation and recombination have very obviously presented organisms

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[10] Huxley, 1942, p. 539.

[11] Dobzhansky, 1937, pp. 18–19.

[12] Power, 1943, p. 64.

[13] Hogben, 1940, p. 251.

[14] Personal communication.

with whatever they need in the way of tools for the kind of material they must work on. These changes, we are informed, are at random.[15] But there is nothing random about the evolution of a bird's wing from the forelimb of a reptile. It is the direction of mutations with which we are concerned, the manner in which for example, small graded genic changes could bring the horse from a small three-toed animal 18 inches high to one four times as high with the central toe become a hoof and the others vestigial, a change which also involved, among many others, replacement of the materials of the soft toe with the harder substance of which the hoof is made. Such adaptive changes are explained by modern genetics as due to organic plasticity.[16] Organisms choose or find themselves in a certain environment, adaptive mechanisms form in relation to that environment, and the organism survives as long as the external condition is maintained. When that condition is changed it becomes extinct or adapts itself if mutation and recombination produce the right modifications. Organic matter as a whole is in this view completely plastic. It is always changing, in all directions at once within the limits of each organism's capacity to do so, in the alternation from gene to soma. We see the useful products because they enabled their users to survive, and we do not see the useless ones because they did not get beyond the early stages in the serial piling up of mutations. Since however, organs degenerate and become vestigial, mutations are of two kinds, progressive and regressive, and the formula of evolutionary mechanics can be stated thus: Mutations with evolutionary significance are selected in small sequential steps in progressive or regressive directions concurrently in a single hereditary line in relation to use or disuse. That is what happened in the evolutionary history of the horse and the whale and man himself, with his hundred and eighty vestigial organs.[17]

From the modern genetical viewpoint, in an evolutionary movement like that from a Dryopithecan or any other ancestor to Cro-Magnon, an almost inconceivable number of gene-controlled characters must have been involved, including the 14,000,000,000 nerve cells of the cortex. It meant that in every organ of this evolving succession of bodies there were changes in two directions, progressive and regressive in succeeding mutational, fragmentary and initially harmful[18] steps in the right order both ways so that each organ or specialized group of cells changed in relation to the modifications of every other in such a way that all were at a given time in precise adjustment to one another according to their functions. The brain must be in exact communication with the sense organs and the sensations of limb-movement, the lungs with the circulation of the blood; the relations must be maintained between simultaneous acti-

[15] Huxley, 1942, p. 22; Dobzhansky, 1937, p. 127.

[16] Huxley, 1942, p. 84; Dobzhansky, 1937, pp. 126, 127.

[17] Rogers, Hubbell, Byers, 1942, p. 312.

[18] Haldane, 1932, p. 187; Dobzhansky, 1937, p. 131; Huxley, 1942, p. 77.

vation and inhibition of muscles, and between tongue-movement and the tubercles anchoring the tongue muscles as speech developed. The focal distance of the eyes had to be held in proper adjustment to the distance of the hand from the body,[19] ability to discriminate sounds must keep pace with the increasing specificity of sound in the evolution of articulate speech, and whole groups of related readjustments had to be made as the body assumed the erect position and some parts became cumbersome or useless. If selection guides[20] random mutations into surviving forms we must suppose that the parts of one organ were changing at random independently of their functional connections with one another or with another organ. If progressive evolution takes place in this way it must be admitted that an almost unlimited number of groups of chance sequences are held in functional relationship to one another by chance, and that successful types were produced by selection of these small mutational steps even though individually they could hardly be important enough to be exposed to selection.[21]

The existence of such a process as neurobiotaxis would seem to obviate any need for mutational changes in the interneuronal connections, and it becomes a question of importance as to the manner in which neurobiotactical effects become incorporated into the germplasm, if in fact they do. The principles of orthogenesis[22] and organic selection[23] provide an acceptable answer if and when it is shown that mutation is the primary cause of change. If every member of a species for many successive generations acquires by neurobiotaxis a new adaptive structural pattern of nervous connections, the probability is enormously increased that a combination of mutations might appear which would perpetuate this structural pattern and stabilize it in the genetic organization of the species.

Neuroanatomists do not regard genetic effects within the central nervous system as sufficient by themselves to account for its evolution. Of neural evolution Tilney says "We may feel certain, however, that the progressive advances were due to the accumulation of slight changes which, modifying brain structure ever so little, ultimately made it more highly effective. Such changes in the different parts of the body are the result of a complex interplay of influences acting upon the animal as a whole."[24] In neurobiotaxis it is not necessary to resort to random mutation and selection though the gene may play a part in conferring through inheritance certain over-all morphological features of the brain based upon its past history. Herrick discusses the matter as follows:

The normal newborn child brings into the world an inherited form of body and brain

[19] Mott, 1907, p. 40.

[20] Huxley, 1942, p. 123.

[21] Robson and Richards, 1926, pp. 224, 316.

[22] Herrick, 1920, 1924, pp. 253, 308.

[23] Huxley, 1942, pp. 295–296.

[24] Tilney, 1930, p. 267.

and a complex web of nerve-cells and nerve-fibers which provide a fixed mechanism, common except for minor variations to all members of the race alike, for the performance of the reflex and instinctive actions. The pattern of this hereditary fabric can be changed only very slowly by the agency of selective matings and other strictly biological factors or by degenerations of a distinctly pathological sort. . . . But in addition to this hereditary organization the newborn child possesses the extensive associational tissues of the cortex with their vast and undetermined potencies, the exact form of whose internal organization is not wholly laid down at birth, but is in part shaped by each individual separately during the course of the growth period by the processes of education to which he is subjected, that is, by his experience.[25]

In any event the role played by the gene is not a simple one with respect to the nervous system. The concept of the gene, not as the vehicle of a character but as an element which initiates a unit process[26] is important, since not all the results that follow fertilization arise from the genes.[27] The physiological gradients and the organizers are active within the environment of the egg, and at a later stage the embryo develops within the environment of the body.[28] During these processes the nervous system becomes elaborated in relation to non-neural architecture,[29] and the same relation to the final environment is maintained to puberty and beyond. It would seem indisputable that the period from fertilization to puberty is the most important one in the understanding of vertebrate evolution, for the experiences of that period may through neurobiotaxis become permanent.

Evolution is not a simple matter of the production of new animal forms by the hereditary transmission of variations. Aside from selection a given biotype is the result of a great many factors, among the most important of which are the frequency of its mutations, its past history and its ontogeny.[30] In ontogeny the environment exerts an influence on the organism, which has to exist in a medium and develop and operate under its conditions. There are too many unknown variables in both genetics and the effects of use in ontogeny to justify exclusion of either from any particular observed change in anatomical structure. Ontogeny is a re-enactment of the main outlines of the evolutionary process, beginning with the single cell, in which the whole organism is created anew through the succession of different types of organization. Occurrences in ontogeny which are not yet completely understood are the regeneration of body-parts that have been severed, a phenomenon in which the nervous system plays a significant part;[31] the extent to which internal bone-structure and fiber-direc-

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[25] Herrick, 1931, pp. 373–374.

[26] Haldane, 1942, p. 21.

[27] Huxley, DeBeer, 1934, pp. 59, 413, 397; Child, 1924, pp. 211, 213.

[28] Huxley, DeBeer, 1934, pp. 12, 50, 59, 135, 140, 142, 397, 438, 439.

[29] *Ibid.*, pp. 390–393.

[30] Huxley, 1942, p. 555.

[31] Huxley, DeBeer, 1934, p. 420.

tions of tendons are the result of mechanical rather than genetic factors;[32] and the movement of the time of appearance of characters toward one or the other end of the life-cycle.[33] Embryonic growth is to some extent a process in which characters are formed which originally did not appear until late in the life cycle in ancestral generations, and which arose out of the relations of those earlier types to their external environment. The question may be asked whether the backward drift of a character into the embryonic stage might not have important effects on the development subsequent to its appearance, including the elaboration of the central nervous system. Neurobiotaxis takes place among such other phenomena as these, and is but one of many processes the sum total of which is evolution.

Despite the improbability that chance mutations are arranged in usable order by selection, that is the most plausible explanation of the changes in the animal form that has been given to date. Keeping in mind that it is the animal's mode of behavior as directed by its brain that determines the order in which one mutation is added to another to change the character of an adaptive organ, natural selection still would operate in reference to neurobiotactically produced types, among animals that use extraorganic implements and among those that do not, though with man its influence is diminished because of his insulation from the natural environment. Man is the only animal which has not undergone adaptive radiation.[34] Adaptation has taken place in the extraorganic instead. These two facts by themselves are sufficient evidence of the importance of the reciprocal relationship between organism and artifact.

The entry upon a terrestrial habitat by the simian ancestors of the human stock was probably a gradual process arising out of conditions upon which we can only speculate. But these animals found themselves more and more in a world of detached, movable, solid objects of all shapes and sizes, and of different kinds of materials. It was a quite different geometry than that in an arboreal life. The various physical and geometrical properties of objects came to have practical significance in relation to one another, over and above any immediate gustatory value. Flat surfaces were distinguished from round, points from edges, the angular from the circular, and the estimation of weight, dimension and balance were refined. The realization that things could be fastened together as well as separated into pieces, and the mental detachment of objects from a configuration[35] were things that were slowly and painfully learned through the application of natural objects to various kinds of needs. These objects were adaptable to many uses without modification, the chief of which must have been defense against those animals from whose superior

[32] *Ibid.*, pp. 433–434.
[33] Haldane, 1942, p. 23; Huxley, 1942, p. 531.
[34] Huxley, 1942, p. 561.
[35] Koffka, 1925, pp. 196–197.

powers they had been secure in the trees. The usable materials were sticks and stones, shells, the bones and skins of other animals, the outer crusts of fruits, bark, materials like grass that were easily detached from their moorings, and the earth under their feet. Such things formed the basis of all human material cultures up to the late Neolithic, and in using them without alteration these pre-humans simply adopted a type of behavior which ants and wasps had entered upon millions of years before[36] From the beginning of this process onward the young developed in an atmosphere of the manipulation of loose, portable objects. At first these were handled largely in an aimless manner or out of curiosity, but this interest became more purposeful as practical effects were accidentally produced. The difference in the life of an individual ape between such an experience and the lack of it was illustrated by one of Köhler's chimpanzees. Failing to solve a problem with sticks, the animal was successful in the same problem four months later after having become accustomed during that period to those materials.[37]

The implements by which entry onto the ground was made safe were sticks selected for use as clubs, spears or daggers, and stones that could be thrown, with increasing accuracy and with a better reason than rage.[38] The possession of a strong pole six or eight feet long, and its use with little more than anthropoid intelligence, trebled the defensive powers of the individual and imparted a confidence which allowed him on occasion to detach himself from the group, and the throwing of stones may have led directly to the discovery of the uses of flint flakes. From such unmodified implements were eventually derived those that were made.

The purposeful alteration of natural objects for implementary use, something which no other animal had ever done with its hands, was of very great significance because new kinds of mechanical control and mental operations were involved. Using a stick or throwing a stone requires of the hand only a simple grasping ability quite similar to that necessary in the arboreal habitat, but in the actual making of implements in such processes as chipping flint and cutting with flake knives, the fingers came more and more to be used separately and the manipulative function was largely transferred to the finger tips, which acquired the high degree of sensitivity they now possess. If natural objects were cast aside after a brief use, artifacts, in consideration of the time and work expended upon them, came to be retained. They were present as models for the making of others, and different types of implements with which a group was equipped suggested combinations which resulted ultimately in the building up of a tool from different materials. Gradually, and very early,

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[36] Rau and Rau, 1918, pp. 214–216; Isles, 1907, p. 260; Houssay, 1893, pp. 51, 55; Forel, 1930, I, pp. 356–357.

[37] Köhler, 1925, p. 209.

[38] *Ibid.*, p. 90.

groups found themselves in possession of instruments that would cut, pierce, carve, chop, strike, scrape, saw, grind and bind. This was a more varied repertoire of tools than any individual living thing had ever before possessed. Their use affected the neural constitution in the same way as the bodily organs with which all organisms had previously worked. An example of the correspondence of the brain with an adaptive organ, an implement in the organic sense, can be seen in the ant-eater, in which the highly specialized tongue is the animal's means of obtaining food. This specialization

leads to a particularly great development of the lingual fibers and a consequent increase of this portion of the root and a close functional relationship of it with the visceral sensory centers of the tongue and the pharynx. As van Valkenburg ('11) pointed out, the variations in the position and shape of the descending root of the trigeminal are not to be regarded as chance conditions. They are due undoubtedly to the operation of neurobiotactic influences which tend to bring these fibers into closer relationships with the centers with which they are most intimately concerned, considered functionally.[39]

More complex effects upon the brain must result from visual, tactile and kinesthetic impulses arising from the use of a variety of tools, not necessarily upon the cranial nerves but especially upon the character of the association areas of the cortex, by which the human brain differs most markedly from those of the rest of the primates.[40] There is representation in the brain of the ant-eater of the movements of the tongue and of the entire jaw complex. But these movements are of a very simple nature as compared to those of the human hand, which can be applied to mechanically universal operations in fuller view of the eyes, giving rise to stimuli limited only by the geometrical and mechanical character of the objects themselves, and making necessary the ability to associate in the mind many recombinations of those conditions.

The motor cortex seems to possess, or to be in touch with, the small localized movements as separable units, and to supply great numbers of connecting processes between these, so as to associate them together in extremely varied combinations. The acquirement of skilled movements, though certainly a process involving far wider areas (cf. v. Monakow) of the cortex than the excitable zone itself, may be presumed to find in the motor cortex an organ whose synthetic properties are parts of the physiological basis which renders that acquirement possible.[41]

The effect of the progressive refinement of the use of the forelimbs is clear from the following statement:

Visual images are now (in the apes) always associated with impressions of the exploring hand, and the ideas of form, substance, extension, and qualities of objects are the

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[39] Ariëns Kappers, Huber, Crosby, 1936, pp. 396, 398.

[40] Herrick, 1931, p. 349.

[41] Leyton and Sherrington, 1917, pp. 179–180.

complex of the visual and tactile kinaesthetic images and capable of endless variations. This we may connect with the appearance in the zoological series of an occipital lobe, a line of Gennari visible to the naked eye, a deep layer of pyramids with a double layer of granules in the visuo-sensory striate area.[42]

The two foregoing quotations have to do with the relation between the brain and the effector organs. The cause of this precise functional connection arose chiefly out of the use of the latter. The cortical regions and layers mentioned in the second quotation did not arise first and cause animals to investigate the environment more thoroughly. The neural apparatus improved in response to the use of the effector organs in the slow testing out of the environment, and to the change of those organs through mutation wherein their efficiency increased. Black[43] says of the teleosts (the italics are inserted) that "the specialization of effectors of whatever nature is also *followed* by an adequate corresponding adjustment of the reflex connections of the sensory and motor neurones involved." As the neural apparatus improved in evolution it imparted new directions to the mutations in the effector organs. This reciprocal relationship is the logical consequence of neurobiotaxis.

The gradual accumulation of complexes of extraorganic implements placed groups possessing them into specialized relations to the environment which forced the maintenance of material culture from one generation to another, giving rise to a very different type of behavior, with radically different stimulation of the brain in the formative years, than among their cultureless ancestors. There is no physiological obstacle to the continuance of this influence beyond puberty, for growth, in the ontogenetic sense, goes on in attenuated form throughout life.[44] Implements improved and a premium was placed upon attention and memory as longer intervals were devoted to their manufacture and especially as this process was interrupted by the fall of night or other circumstances. The route between anticipation and consummation, over which attention came into existence[45] became longer and less direct. The environment slowly assumed an immaterial aspect of the relations between things, of ultimate but not immediate practical value. For a million years or more these processes introduced a constant stream of novel stimuli into the brain as implements were improved and as efficiency in their use and manufacture increased. The primate animal gradually entered a new medium of moving mechanisms and subtle forces, which widened the powers of volition and increased the range of awareness. It was an environment in the most precise sense even though an artificial one, and it was to exert an effect upon the bodies of its occupants just as previous environments had done. This environment moved,

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[42] Mott, 1907, p. 46.
[43] Black, 1917, p. 558.
[44] Huxley, De Beer, 1934, p. ix; Herrick, 1931, p. 350.
[45] Herrick, 1910, pp. 13–14.

through forces initiated in the body, but nevertheless out from and beyond the body as it employed the leverage obtained by the extraorganic. Two important forms of projectilism were specialized, sound as interorganic communication, and the thrown point. The effective use of a javelin demanded an increase in attention, exact calculation of distance, direction and weight, proper timing and coordination of vision and posture, and the consideration of some of these factors in making the implement. It gave rise to proprioceptive and exteroceptive impulses that brought new stimuli to the brain, with probable neurobiotactic results. An important cause of simian intelligence, as compared to that of other animals, was the habit of throwing their bodies from one branch to another.[46] Projectilism was never achieved with any accuracy by other animals and so it never left its mark on neural structure, but in man it was exploited to the utmost on an extraorganic level.

The use of sound as an implement of communication gave rise to articulate speech, which is the accomplishment of a highly specific effect at a distance from the body and therefore a form of projectilism. A spoken word is a projectile, and an implement quite as much as a knife. It is a physical thing made for a physical effect, the stimulation of the auditory apparatus with consequent action by the hearer. A spoken work is extraorganic, though interorganic in its use. In the rise of language, sounds made aimlessly or in response to affective states came to be selected for their effects, and articulation followed as the alteration of a sound for the purpose of making it more specific. The use of the various organs in altering the pitch, duration and terminal character of sounds was a manipulation of the raw product of the vocal cords. The whole process is identical with that in which sticks and stones were at first used in their natural conditions and later modified to become true artifacts. The essential mechanical identity and extraorganic nature of the two things is apparent in the fact that both have been subject to that process of differentiation through succession which we know as evolution.

Articulation involves the coordination of different organs and the muscles controlling them,—the vocal cords, lips, oral cavity, tongue, teeth, lungs, and the lower jaw. All of these factors partake in the production of sounds in rapid succession to form articulate words. Together they are a complex similar to the human hand, wherein the movement of the digits independently of one another in delicate manipulative operations involves rapidly successive and minutely balanced movements which are of the same grade of precision as those by which the various organs play their part in speech. In connection with the production both of articulate speech and artifacts proprioceptive stimuli were sent to the central nervous system, and the localized implementary fluidity they represented was far beyond that received from the same organs in a cultureless simian.

[46] Dorsey, 1925, p. 53; Huxley, 1942, p. 571.

Certain areas of cortex are differentiated for the neural control of speech in its various aspects, as is indicated by loss of those powers due to lesions of the areas controlling them. Lesions in Broca's area destroy the power to form words, which means only that that this region is concerned with the coordination of the muscles involved in word-formation. Understanding of the meanings of words is not involved.[47] In a similar manner the area of cortex connected with movements of the fingers has been mapped. The particular cortical point representing each digit of the human hand has been located, successively distant from the area for the hand as a whole, beginning with the little finger.[48] In a detailed study of this area in the chimpanzee, orang and gorilla the cortical points for independent movement of the digits of the hand were found to have an irregular distribution, with no such successive correspondence as that in the human cortex. Points were found for all digits except the ring finger in the chimpanzee, and the ring and little finger in the orang and gorilla. Out of a total of 448 of all kinds of movements elicitable by electrical stimulation, cortical points for 349 were found for the chimpanzee, 166 for gorilla and 117 for the orang.[49] A similar grading can be seen in the figures for the digits alone: chimpanzee 75, gorilla 31, orang 12.[50]

Though no areas for reading and writing have been localized on the cortex those abilities are among the phases of speech which can be lost through injury, when other aspects of speech remain normal.[51] This has interest in connection with the evolutionally recent invention of writing. Such cortical areas as these were formed as a result of the use of the various organs involved in speech, and of the fingers in the making and use of artifacts, through correlation of exteroceptive and proprioceptive impulses in the operation of neurobiotactical forces.[52]

Apes of their own accord use implements held in their hands but they cannot be trained to form or use words, and it is likely that language arose in part at least as a result of the use of tools. Increase in content and complexity of the extraorganic must have provided a strong motive for the elaboration of the simplest sounds, and speech, once begun, followed the creations of the hand. Before natural objects were purposefully altered in the making of tools, each successive day in the life of the proto-human animal was a series of routine procedures always with the same beginning and in much the same order. There could have been no carry-over from the previous day. But as technical processes in tool-making necessitated search for the proper materials or termination of a project with the coming of night, the activities of the following day would

[47] Ariëns Kappers, Huber, Crosby, 1936, pp. 1657, 1658.
[48] Herrick, 1931, Fig. 136.
[49] Leyton and Sherrington, 1917, pp. 150–154.
[50] *Ibid.*, p. 150.
[51] Herrick, 1931, p. 351.
[52] Ariëns Kappers, Huber, Crosby, 1936, p. 1659.

necessarily begin at that point in the series. Attention was in this way fixed upon time, and one result could have been the introduction of the tenses into the simple linguistic arrangements that prevailed. In later stages language became indispensable to the manufacture of more complex instruments.

It was to a great extent the use of the primate hand that gave the primate brain its distinguishing power.[53] The importance of the hand as a mechanism through which impulses of increasing refinement passed from extraorganic implements to the brain has not been overlooked by neuroanatomists. The claims for human material culture set forth in the present paper and in the one of which it is a clarification are consistent with the wider interpretations that most neuroanatomists put upon their data. Many such authors could be quoted to the effect that neural structure is largely a reflection of the relationship of the organism to its environment, and that is the view of geneticists in respect to the evolution of the animal form.[54] One neuroanatomist has said that "The more diversified conditions of life on land appear to require far more complex centers of higher correlation than those possessed by any fish."[55] It is equally apparent that life in the midst of material culture requires a better brain than that of any ape or monkey.

The environment of material culture certainly stands in the same relationship to the human brain as the natural environment to the non-human brain, as for example, the arboreal habitat to the early primates which, as so many evolutionists believe,[56] could not have given rise to humans without that training in brachiation wherein the hand, at first able only to curl itself around a cylinder, as F. W. Jones has said, achieved the power to contain a sphere, with an eventual refinement of the tactile sense at the finger tips which put its owner into neural and biomechanical contact with a multitude of environmental facets never before experienced by any organism. The acceptance of brachiation as a cause of simian intelligence compels agreement with the major theme of this paper, that the human brain was formed by the use of extraorganic implements. This logical necessity arises out of the fact that in arboreal progression branches stand in the same relationship to the central nervous system as artifacts, so far as neurobiotactical effects are concerned. Swinging from the branch of a living tree is as much the use of an implement as striking or poking with a detached section of a branch. The difference is that in brachiation the implement, i.e., the branch, is fixed and stationary and the body moves in relation to it, while in the extraorganic environment it is the implement which moves. The implement moves in obedience to the will of the organism, the gross move-

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[53] Huxley, 1942, p. 570; 1941, pp. 243–244; Tilney, 1930, pp. 49–50; Herrick, 1926, p. 42; Jones, 1916, p. 162; 1942, p. 307; Dorsey, 1925, pp. 53, 70.

[54] Huxley, 1942, pp. 84, 206, 387; Dobzhansky, 1937, p. 13.

[55] Herrick, 1921, p. 452.

[56] Huxley, 1942, p. 571; Smith, 1912, p. 582; Jones, 1916, p. 179.

ments of whose body are thereby lessened and brought into coordination with more deliberate and particulate movements of the hands.

If the extraorganic did not bring about the passage from simian to human it would be the first time that a radically different environment was not the cause of the unique organism dominant within it.

At the proto-human level the mere manufacture of tools involved the coordination of sense impressions over and above use of the tools. But the secondary devices, chiefly of perishable materials and therefore unknown, must have had physiological and genetic effects. Fire and clothing enabled their discoverers to migrate into regions of lower temperature, with effects on population structure and the resultant differential gene distribution,[57] and the total material complex with the increased power over the environment given by it caused increase in population size with equally important genetic effect.[58] Fire and cutting implements complemented one another in the preparation of food and widened the choice of food materials. Clubs, daggers and spears gave them an advantage over other animals with which they had formerly competed at a disadvantage, and there can be little doubt that such early implements exerted a selective influence between members of the same group, and in intergroup warfare, with effects on mental and physical types and a related guarantee of the winning complex of weapons. Changes in the size of foraging groups and in the character of social organization are implied in the increased defensive power conferred by the simple spear or club, and by the tendency toward the establishment of a base of operations made necessary by the sheer bulk of a number of different kinds of implements. Such things as these accounted for early differentiation in physical type at the racial level, and for cultural variation, but neurobiotaxis was the directive mechanism that brought about the distinctly progressive evolutionary changes.

If, through neurobiotaxis, the use of tools increased the power of the brain in the passage from simian to human, that organ was brought into constantly better positions to exert its directive function upon the extraorganic constructions themselves, and material culture underwent an evolution of its own. Morgan says the same thing in respect to mutation which, once occurring, will, if followed by another in the same direction, have "a better chance of producing a further advance since all individuals are now on a higher level than before."[59] Morgan is not here talking specifically about the brain but his remark applies to that organ, in respect to neurobiotactically determined changes in animals as well as in man, and in relation both to the improvement of organic and extraorganic adaptations. Among animals there is a correspondence between the forebrain index and the type of limb termination,[60] a condition which

[57] Dobzhansky, 1937, pp. 13, 14, 185; Huxley, 1942, p. 61.
[58] Dobzhansky, 1937, pp. 131–134.
[59] Morgan, 1925, p. 148.
[60] Tilney, 1928, pp. 941–942.

may have been brought about by neurobiotaxis. In human history there is a correspondence between the evolution of the brain and that of the extraorganic limb terminations.[61] There is no reason to believe that the cause of this condition was different for humans than for other animals. Unless this correspondence is without meaning, human culture could not have become improved through the lower paleolithic complexes to the Aurignacian and following types. If, for example, Pithecanthropus was able to use a pointed stick as a weapon he could not, in this interpretation, have been trained to the skilful use of a bow and arrow, nor in the construction of such a mechanism. It was no sheer autonomous creative faculty that produced more complex and efficient tools, but a much simpler ability, that of perceiving the possibilities of combining objects or processes seen in accidental adjacency or juxtaposition[62] in the proper context. This ability is possessed by insects[63] and birds.[64] It formed the basis of many of Köhler's experiments with apes,[65] and human behavior often depends upon it.[66] The acquisition and evolution of human material culture cannot be satisfactorily explained as simply a direct result of any autonomous expansion of the powers of the brain. Neurobiotaxis gives a rational explanation of the directive trend of neural improvement.

If it was the extraorganic that was responsible for the evolution of simian to human, it is important to the understanding of the nature of human life. Evidence in favor of that view has been presented in detail. By way of summary and simplification the process of reasoning involved may now be stated in its main outlines.

It is improbable that evolutionary changes in the vertebrate nervous system result from random mutations apart from other contributing factors.

The nervous system does undergo evolutionary changes through neurobiotaxis.

The most significant anatomical difference between humans and the other primates is in the brain.

It was necessarily a physiological process that made possible the change from the simian to the human brain.

Neurobiotaxis is a physiological mechanism by which the effects of the use of tools may alter the neural structure of all members of the human community. This structure may be maintained by the external conditions indefinitely, and provide the basis for further changes arising through the operation of neurobiotaxis; or, it may provide favorable conditions for the preservation of

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[61] Greenman, 1945, p. 219.
[62] *Ibid.*, pp. 212, 215.
[63] Rau and Rau, 1918, pp. 214–216.
[64] Skutch, 1945, p. 366.
[65] Köhler, 1925, pp. 130–133.
[66] *Ibid.*, pp. 196–197.

useful combinations of mutations and so stabilize the behavior in question in the genetic organization.

In its general thesis this paper is concerned only with the differentiation of the human stock from the rest of the primates. It is another matter whether, once humanity was achieved, there was any further improvement of the central nervous system in correlation with each new refinement of the extraorganic means of living. While there is no reason to believe that neurobiotaxis has ceased to be a decisive factor in human evolution it is not necessary to suppose that it has been as important in relation to material culture since the paleolithic as it was previous to and during that period. Evolution has in the past operated in different ways at different times, and it is likely that the principle of neurobiotaxis is at present playing a directive role, if at all, in relation to social rather than technical behavior. At the same time it may still account for the maintenance of neural structure which is not transmitted genetically, by responding to constant features of the cultural environment. Current thinking on the nature of human culture must take into account the fact that it is not in itself a unitary thing, and not the same in its operation at all times during evolution. The conclusion may be drawn from the facts presented in this paper that in the early stages of human evolution material culture cannot be regarded as on a different level and largely independent of the human organism. The relation to the organic of those departments of human behavior called non-material, and just what things belong in that category, are more obscure.

The existence of the social sciences is but a reflection at the research level of the pre-occupation of human beings with one another, a very ancient interest. The human organism itself has been the instrument *par excellence* ever since one individual found himself with the means of effective control over the behavior of others. A great part of human culture has been built up around that means of power, and that part has the organic both as origin and goal. On the other hand the human body itself has in the past thirty thousand years become increasingly a cultural product, a development which was accelerated upon the advent of agriculture and, in more recent times, by advances in medicine and surgery. These and other considerations tend to lessen the gap between the cultural and the organic when they are viewed against the background of evolution.

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