New Light on Vision.*

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MAN alone among living creatures really sees the world in the sense that we usually associate with the verb 'to see'. The apes and monkeys are provided with eyes which are closely similar in structure to those of man and on the functional side are perhaps equally efficient dioptric instruments. Man's comprehension of what he sees, however, and his understanding of the world of things and actions revealed by his powers of visual discrimination, clearly transcend those of the apes, to which we have no reason to attribute the human quality of understanding what is revealed by sight, of appreciation of beauty, and the subtler forms of actions such as facial expression, or of possessing the initiative and skill that result from the wider vision.

Investigation of the comparative anatomy of the brain reveals the fact that within the natural order of mammals (Primates), to which man belongs, the cerebral connexions of the optic tracts have been so profoundly revolutionised that what is virtually a new instrument of vision has been evolved. The progressive cultivation of this 'new vision' (see *NATURE*, April 28, 1928, p. 680), eventually led to the emergence of those profound changes in the whole organism which transformed an ape into a human being and conferred upon him the distinctive attributes of mind and skill which are the outstanding tokens of his humanity.

The factors involved in the making of the mind fall into several distinct phases. The acquisition of definite representation for touch, vision and hearing in a newly evolved area (neopallium) of the cerebral hemisphere was responsible for the emergence of mammals. It conferred upon vision not only the possibility of closer integration with other kinds of sensory experience, but also a greater influence in the conscious control of behaviour. The birth of a new cortex created a new type of animal profoundly different in every part of its organism and especially in its potentialities. In particular the evolution of the neopallium involved the transference to the cerebral hemisphere of the control of voluntary movements and that led to far-reaching changes in the parts of the brain and spinal cord concerned with muscular activities. The new cortex established direct connexion with the spinal cord, new links with the cerebellum which provoked the evolution of a new element in that organ, and corresponding transformations of the cerebral and cerebellar connexions with all other parts of the central nervous system involved in the control and regulation of movement. This remaking of the brain involved the usurpation by the new cortex of many of the functions of the midbrain.

The next phase is displayed in the Primates, in which the increasing dominance of vision accentuated the process of transference to the neopallium

of the control of movement. The increasing concentration of visual functions in the cerebral cortex conferred upon vision a fuller participation not merely in the affairs of conscious life but also in the regulation of motor behaviour, and integrated visual, tactile, and motor experience with the kinæsthetic products of the animal's own movements, the consciousness of the postures and actions of its own body. The cortex came to play a part

FIG. 1.

in the control of posture, and this conscious activity eventually conferred upon man not only the erect attitude, but also that intimate integration of skill of hand and eye with the no less important factors we call balance, poise, and rhythm, which with perfection of timing are the essential elements in dexterity.

The nervous system was first called into being to facilitate the performance of rapid and precise movements. In the direction of these activities an important part has always been played by the eyes. Long before they were capable of true vision, such

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as the appreciation of images, they were instruments for recording movement in the outside world, and for guiding the animal's own movements. Throughout the whole of its subsequent history the refinement of muscular skill has been intimately associated with the progressive modification of the nervous

ments of the eyes, which in mammals are the essential preparation for the attainment of the fullest cultivation of binocular vision, the development of a macula and fovea, and the ability to see stereoscopically and so add a third dimension to spatial discrimination. In addition, the proprioceptive impulses from the eye muscles, as well as from the muscles and joints involved in any movement, add their quota to the integration and link the process of spatial appreciation with the personality of the individual. This coherence between vision and skill is the essential mechanism for the making of mind and for giving it its distinctive individuality as an intimate part of the personality. The practice of manipulation to satisfy visual curiosity, which is aroused in its most intense form when the macula is developed, necessarily led to the cultivation of tactile discrimination and stereognosis. Visual perception and conception are products of the integration of these factors with vision and as the result the progressive evolution of intelligence.

Bearing in mind these considerations, the facts of the comparative anatomy of the brain take on a new significance; and in turn features which hitherto have been overlooked can be detected in the brain when the fuller understanding of its working suggests the search for them.

In the human brain (Fig. 1) the fibres of the optic tract end for the most part (probably not less than

FIG. 2.

system. In its highest manifestation the making of the mind was in large measure due to manual dexterity, the exploration of space with hand and eye and the integration of the knowledge of the world acquired by vision with the intimate personal experience of the movements of our joints.

The comparative anatomy of the brain reveals the fact that the progressive development of vision is strictly conditioned by the ability of the hands to be used as skilled instruments. It seems that manual dexterity is an implicit condition for the attainment of biological usefulness for the refinement of visual discrimination. Vision could not have extended the range of its powers and influence in the Primates if their hands had not escaped the specialisation which in other mammals restricted their power of adaptation.

The integration of vision and muscular skill is a complex process. The heightened powers of vision provide direction for the acquisition of skill—and the cultivation of skill involves not the hands only, but also the whole body, which is essential for the maintenance of the appropriate posture as well as for the performance of movements that contribute to the successful action of the part, such as the hand, upon which the visual attention is fixed. This participation of the whole organism in any act of skill contributes (in some way that we do not understand) to the development of the intricate co-ordinations involved in the conjugate move-

FIG. 3.

95 per cent) in the lateral geniculate body, where they transfer the impulses coming from the eyes to a new tract of fibres, the optic radiation, which carry them to the visual receptive area now commonly known as the 'area striata' (*Proc. Roy. Soc.*, p. 62; 1904). This almost exclusively cortical connexion of the pathway leading from the eyes is a token of the fact that in man vision is brought into the full light of consciousness. It had lost

most of those automatic and unconscious photo-static influences that are so obtrusive in most other living creatures. Vision is the foundation of intelligence and the chief source of our knowledge.

This distinction can be graphically displayed by means of three diagrams. In the reptilian ancestor of mammals (Fig. 2) the optic tract, in spite of the wide currency of Monakow's diagram, does not establish any connexion with the cerebral cortex. Most of its fibres end in the midbrain, from which tracts (*T*) proceed to the motor nuclei in the brain and spinal cord. In addition to this connexion, which automatically directs the movements of the animal, there is also a group of fibres (*X*), which forms part of the light-reflex mechanism, using the oculomotor nucleus (*III*) and the ciliary ganglion (*C*) to influence the iris and the size of the pupil.

Most of the fibres of the optic tract are functionally related to these unconscious activities. The number of fibres concerned with the conscious awareness of vision is small. They pass to the lateral geniculate body and from it to the thalamus.

In mammals (Fig. 3) the lateral geniculate body receives a larger proportion of the fibres of the optic tract and transmits some of the impulses (by means of the optic radiation) to the newly developed cortical area, neopallium, which affords a representation of vision (area striata) in the cerebral hemisphere. The transference to cortical control of functions previously performed by the midbrain necessitates the establishment of new connexions between the cerebral cortex and the midbrain, both (*A*) from the receptive visual area and (*B*) from the area which controls voluntary movements. For vision and movement are intimately interrelated. In addition, the assumption by the neopallium of the control of the movements of the whole body leads to a profound revolution in all the motor mechanisms in the brain and provides the visual area with opportunity to exercise a wider influence on behaviour.

In man (Fig. 4) all the midbrain connexions shown in Fig. 2 have been lost, excepting only the light-reflex arrangements (*X*). The visual pathway leads almost exclusively to the cerebral cortex, and more than half its fibres (*M* and *M'*) are new elements coming from the macula lutea of the retina. Only the monkeys, apes, and men among mammals have a macula and enjoy macular vision. The development of this sensitive spot on the retina was not evolved until the axes of the eyes were altered to permit them to look forward and their visual fields to overlap. A very complex and precise correlation between the movements of the two eyes is required (conjugate movements) to bring the two images of an object with certainty upon certain determined areas in the two retinæ. These areas become the maculae, the instruments which confer on vision greater powers of resolution and discrimination. The development of macular vision led to the progressive transformation of the brain and eventually to the making of the human mind. It conferred not only the ability to discriminate between the details of form, texture, and colour, but also led to an enhancement of the

knowledge which became accessible to a mind intent upon satisfying the curiosity awakened by such new revelations.

Binocular vision enriched by macular efficiency provided the conditions which made possible the attainment of stereoscopic powers, the conscious appreciation of a third dimension in space, the recognition of solidity and perspective. A vision of the world was thus revealed to man, with an appreciation of form, colour, size, and space, and a fuller understanding of distance and movement. The most significant enrichment of the sensory basis of the mind is conferred by the macula. To paraphrase the account given by the late Dr. Henry Watt, it "refines and distinguishes positions and forms, and, aided by the more precise accommodation which becomes evolved in association with it, it sharpens the objects of attention and dissipates the rest". "Stereoscopy adds a new character to a

FIG. 4.

group of forms that may persist for indefinite periods of observation; delicate skin gives greater sensitivity to variations of pressure, and the prehensile hand implies a very great refinement in the positions and forms of the derived articular sense. In the hand this becomes a fine mobile tridimensional sense which, like the stereoscopic eye, can go round and through things, so almost isolating them from their surroundings."

When in response to the visual curiosity excited by the new vision of the forms, textures, and colours of objects, the hand, under the guidance of the eyes, examines these objects, and explores their positions in space, not only is tactile information added to visual knowledge and integrated with it, but also the impulses from the joints, muscles, tendons, and in fact from the whole body, recording the effects upon the organism of the accomplishment of the action, are added to the visual, tactile, and motor sources of knowledge. Hence, as Dr. Watt expresses it, "the articular sense is the conscious correlate of action and of the individual's share in

his experiences". Thus "action enters into the data of sense to integrate with it and so build up psychical mind-stuff".

The consciousness of action makes possible "the integrations of percept and probably of concept that are the beginnings of intellect". It adds the essential personal element in the process of interaction of mind and mechanism, and the interpretation of the means whereby motor skill creates mind. For "the first purpose of the mind is to serve the ends of action. It is not merely a speculative instrument given to man that he may form for himself a disinterested knowledge of the world, create and enjoy works of art, and plan an elysium of happiness and love." It is primarily a means for seeking actively, under the guidance of attention and interest, the objects of its own desire, and for expressing in movement and other forms of behaviour the satisfaction of the impelling appetites. Vision and touch are closely integrated with movements and feelings and the affective results of such expressions of the mind's searching for satisfaction.

This brings us back once more to the essential fact one is trying to make clear in this discourse. Man's intellectual pre-eminence is based primarily on the evolution of macular vision in a Primate with adaptable hands which attained the erect attitude when the cerebral cortex under the conscious influence of vision came to control and regulate posture. The profound and widespread effects of this revolution upon the structure and functions of every part of the brain—cerebral hemisphere, cerebellum, red nucleus, substantia nigra, corpus

FIG. 5.

striatum, midbrain, and hindbrain—will not be discussed in this discourse. But attention must be directed to some of the obtrusive expressions of this new vision in the anatomy of the optic parts of the human brain.

The development of the macula was responsible for adding to the optic nerves and tracts as many

new fibres (Fig. 4) as the whole of the rest of the retina (peripheral) supplies. In the lateral geniculate body a new receptive nucleus of corresponding dimensions is provided to transmit macular im-

FIG. 6.

pulses to the cerebral cortex. For many years neurologists have been speculating on the nature of the representation of the macula in the cerebral cortex. During the War, Henschen's idea of the 'cortical retina' was revised and corrected by the observations made upon wounded soldiers by Sir William Lister, Dr. Gordon Homes, and many other physicians.

Recently (1928 and 1929) Prof. B. Brouwer and his collaborators, Drs. Van Heuven and Biemond, in Amsterdam, have introduced a new precision into the cortical localisation of the macula in monkeys. Studying preparations of the human brain in the light of their truly epoch-making investigations, one was able to detect with the naked eye a sudden change in the texture of the area striata at the place corresponding morphologically to where in monkeys Prof. Brouwer and his colleagues located the boundary between the peripheral and macular territories.

A drawing of the photograph (the negative) of a horizontal section through the posterior pole of a human cerebral hemisphere is reproduced in Fig. 5. The area striata, distinguished by the presence of an intracortical black line, is seen to undergo a sudden change in character as the peripheral part (P) on the medial surface is traced backward. At the point marked by the white arrow the thickness of the black line is reduced and the pale band on its inner side disappears. The macular cortex begins at this place and extends around the pole on to the lateral surface of the hemisphere to end (at M) at the lip of a deep furrow (lunate sulcus). As this lateral part of the area striata is much broader than the medial part (P) exact measurements reveal the fact that the macular part is at least as extensive as the whole peripheral part.

It is possible also to identify the macular part of the area striata in many human brains by simple observation of the morphological features of the surface of the cerebral hemisphere. Looking at the

posterior aspect of the hemisphere (Fig. 6 represents the pole of the left hemisphere) three semilunar sulci—lunatus, polaris superior, and polaris inferior—may often be seen arranged in a trefoil or shamrock-leaf pattern (grouped around the calcarine sulci in the axis of the area striata). The rapid expansion of the lateral part of the area striata to afford cortical representation of the macula is responsible for the formation of opercula bounded by these three semilunar sulci. Hence the presence of this cortical shamrock-pattern affords definite evidence of the position and extent of the macular area. It is so situated in relation to the other cortical areas as easily to be linked up with them in the functions of wider vision, which involve the activities of the cerebral hemisphere as a whole—the process of mind-building upon the foundation of macular vision.

It is a matter of such vital importance not to overlook the part played by action in mind-making

that the argument may be emphasised once more, When under the guidance of vision some delicate manipulation is performed, in addition to the success or failure of the mechanical operation, and the emotions of satisfaction or disgust which the results of the attempt and the attendant circumstances excite, the action itself starts a series of impulses from the joints, muscles, tendons, and from other parts of the body, which integrate the whole process with the intimate texture of the individual's consciousness and personality. The appetites and feelings which prompt the action, no less than the discriminative experience and knowledge which play their part in determining whether it is worth doing and how to do it, become associated with the activities of the whole organism during the progress of the movement. It is no longer a mere matter of muscular contraction under visual control, but a complex process of integration of experience and of creating understanding and intellect.

Canadian Hydro-Electric Power Development during 1929.

By Dr. BRYSSON CUNNINGHAM.

THE recent issue of two reports¹ by the Canadian Government Water Power and Reclamation Service enables a survey to be made of the expansion which has taken place during the twelve months ended Dec. 31 last in the development of hydro-electric power in the Dominion. The review made in NATURE of July 27 last year, on the statistics then available, showed a very striking and rapid rate of progress. This progress has been substantially maintained and important activities are reported from practically every province. The total capacity of new installations brought into operation during 1929 amounts in round figures to 378,000 horse-power, bringing the aggregate for the whole Dominion to 5,727,162 horse-power, as compared with 550,000 h.p. and 5,349,232 h.p. respectively, for the year 1928.

Table 1 shows the available and developed water power of Canada as determined to Jan. 1, 1930. The available power is scheduled in columns 2 and 3 under two heads according to the period of availability. These figures are based on a computation of data relating to rapids, falls, and power sites generally, of which the actual fall or the possible head of concentration is definitely known, or, at least, well established. There are many other rapids and falls of greater or less capacity scattered up and down the country which are not yet included in the register and can only become available for tabulation when the necessary survey work has been undertaken and completed. This is particularly the case in the northern parts of the Dominion, where much exploration remains to be done. Moreover, there are possibilities of power concentration on rivers and streams of gradual gradient which have not been taken into account, except at such selected points as have been the objects of actual study and observation. Altogether, as a record of potential resources, the

figures in columns 2 and 3 may be looked upon as minimum values. Indeed, the basis of valuation itself is appreciably below the standard of development obtained in cases of actual installation by so

TABLE 1.—AVAILABLE AND DEVELOPED WATER POWER IN CANADA, JAN. 1, 1930.

Province.	Available 24-hour power at 80 per cent efficiency.		Turbine Installation (h.p.).
	At Ordinary Min. Flow (h.p.).	At Ordinary Six Months Flow (h.p.).	
British Columbia	1,931,000	5,103,500	559,792
Alberta . . .	390,000	1,049,500	70,532
Saskatchewan .	542,000	1,082,000	35
Manitoba . . .	3,309,000	5,344,500	311,925
Ontario . . .	5,330,000	6,940,000	1,952,055
Quebec . . .	8,459,000	13,064,000	2,595,430
New Brunswick .	68,600	169,100	112,631
Nova Scotia . .	20,800	128,300	109,124
Prince Edward Island . . .	3,000	5,300	2,439
Yukon and Northwest Terr. .	294,000	731,000	13,199
Canada . . .	20,347,400	33,617,200	5,727,162

much as 30 per cent. If the necessary correction be applied, it will be found that the present recorded water power resources of the Dominion will permit of turbine installations aggregating about 43,700,000 horse-power.

The actual installation to the end of 1929 in water wheels and turbines, as shown in column 4, amounted to 5,727,162 horse-power, representing slightly more than 13 per cent of the recorded potential resources.

The progressive development which has taken place since the beginning of the present century is best illustrated by a diagram, and the curve shown in Fig. 1 is remarkable not only for its continuous