

COMMITTEE I
Unifying Principles in the Sciences

DRAFT - 10/15/86
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PSYCHOBIOLOGY OF SPACE AND TIME

by

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The Fifteenth International Conference on the Unity of the Sciences
Washington, D.C. November 27-30, 1986

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The attempt to discover a unified explanation for our universe has been a strong driving force in past philosophical thought. It constitutes one of the main challenges in modern science and is the central theme of our present conference.

Matter and energy, flowing through time with several particularities including symmetry and entropy are elements shared by most - or perhaps all - of existing reality. These elements and their related elaborations of the theory of relativity, quantum mechanics and the field theory are essential in order to make the world intelligible to the human mind. There is, however, a conceptual duality which should be clarified:

1) We are trying to reach an objective understanding of the material existence of the universe. For this purpose we design experiments and acquire knowledge about atoms, electrical charges, binding forces, DNA, the flow of materials, release of energy, natural laws, and many other aspects of reality. These elements certainly preceded the appearance of man. Cosmic cataclysms, melting rocks, the creation of stars and planets, and the beginning of life on earth were happenings totally unrelated to man's subsequent appearance. We may try to contemplate the objective reality of all these

events; we may consider the unifying principles of their interrelations; and perhaps we may attempt to surmise the reasons and purposes of the cosmos which persist with total independence of our existence. Our presence is very insignificant and will not modify the laws of nature.

2) Our understanding of the universe has an obvious ~~li~~mitation: the functional limitations of the brain, which is the organ capable of processing and understanding incoming information. When discussing concepts such as matter, energy, space, and time, the fact is often ignored that these terms and related ideas are the artificial creation of our working brains and are the neuronal interpretation of incoming signals. We certainly need sensory inputs and intelligence as bases of our understanding because the central nervous system must be reached with representations of matter and not with material reality. The stars do not penetrate our eyes: only a pattern of light enters. Time does not penetrate organisms: there is only a rushing of blood and metabolic activities which may have chronobiological patterns.

It is essential to be aware of the functional limits of the brain in order to evaluate our conceptual limitations. Attempts to explain reality only in materialistic terms, or only in ideological aspects, neglect their essential interrelation and especially the interdependence of methodology used and data obtained. Suppose that a Velazquez painting

is evaluated by an atomic scientist and by an experienced artist. The first could present us with an excellent account of orbiting electrons, electromagnetic forces, and perhaps the chemical composition of colors and canvas. All these technical data may be correct but the artist would shake his head, considering them meaningless information unrelated with artistic values of shapes and shades and taste. In a painting it is the human interpretation that counts - not the physical components. Perception of a painting also depends on the physiology of the observer: a blind man cannot see. A savage would lack the appropriate culture to evaluate what he saw.

The need to understand reality in its materialistic and mental duality has been emphasized by scientists and theologians. Reverend Moon, for example, has said that "The nature of human beings and that of the Universe have both internal and external aspects: the external aspect corresponds to the material, physical dimension; and the internal aspects correspond to the intuitive, spiritual dimension from which purpose and values are given."

In addition to the conceptual duality, there is an often neglected third element: the essentiality of patterns of information. Attempts to unify our understanding of the universe are centered on physical elements of matter and energy. It is true that life in general, and the brain in particular, have materials with an active exchange, but the

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role of these entities is only secondary and unspecific. Without oxygen, lacking glucose, or under hypothermia, the brain cannot function. No one, however, could maintain that metabolic or thermic regulations are the cause of thoughts or feelings. The neurons must function normally in order for mental processes to develop. We may investigate the behavioral consequences of metabolic alterations but material events are only the unspecific carriers of the mind. The wealth of information received, circulated, stored, and expressed by each individual constitutes the main elements of personal identity. A white sheet of paper, an unused computer, or an empty brain may become the material carriers of a wide variety of information but in the absence of messages, the paper, computer, and our neuronal network are useless.

By message I mean any kind of stimuli or information emitted by some material source and received by a person. The environment is full of messages, but only a very small amount will reach our sensory inputs and will be transmitted to the brain, where meaning may be perceived.

Messages and meanings do not occur spontaneously but are the products of cerebral activity. Language, arts, sciences, and all kinds of information are necessarily related to activities of the central nervous system. We should not fall into the dialectic trap of materialistic versus idealistic conceptions of reality but should reject the exclusivity of unilateral explanations in order to analyze some of the neurobiological aspects of our understanding of reality.

Environmental Stimuli

Sensory perception of the environment by any organism requires the reception of a threshold of energy. Lower

forms of life such as protozoa have localized receptors and their entire bodies react to heat, cold, gravity, and chemical and light stimuli. Higher forms of life, such as mammals, have specialized sensory organs which perceive specific types of energy. Visual receptors, for example, react only to a narrow band of radiant energy with a wave length of approximately 400 to 700 ^{nanometer (nm)} and a frequency range of 7×10^{14} to 4×10^{14} Hertz (Hz). This range represents a very small band of the spectrum of radiant energy which extends from electric waves (lengths of km to cm) down to X, gamma, and cosmic rays (lengths much lower than visible light, down to 10^{-6} nm).

Most natural sources of radiant energy emit wave lengths beyond the visible portion of the spectrum. We are therefore surrounded by an immense amount of stimuli which we are unable to detect because we lack suitable sensors. From a sensory point of view, we are very poor in a very rich environment.

Our situation is much worse when we consider that the energy of the stimuli must reach our sensory organs in order to be perceived. We are in touch with an infinitesimally small portion of the material universe. Environmental stimuli from most of the earth and the cosmos will never reach our eyes or ears. We are personally ignorant of the immense majority of physical reality. This is an unsurmountable

physiological limitation which must not be forgotten in our attempts to understand the environment..

Sensory Receptors

Ancient philosophers called the human senses "the windows of the soul" and today we may still accept that senses are the windows through which the brain perceives the surrounding world. In the absence of eyes, for example, the brain cannot have visual perceptions and the occipital cortex will not develop.

~~Genetic~~ Genetic determination is not enough for full development of neurons. Sensory inputs are essential, and will shape synaptic connections and nucleoproteic synthesis.

Aristotle indicated the existence of five senses: sight, hearing, smell, taste, and touch. His influence has been so enduring that many people still refer to their "five senses" as if no others existed. Today, however, we know that there are organs specialized for the sensory reception of cold, heat, pain, kinesthesia, gravity, acceleration, blood pressure, carbon dioxide content, hunger, thirst, and other elements. The reactivity of some of these receptors does not reach awareness, but originates unconscious reflexes for automatic cardiovascular regulations and for other autonomic functions.

Some of the most important and least known sensory receptors are in charge of the regulation of posture and motion. We know that, with our eyes closed, we are aware of the position and motion of our legs, arms, and body. The reason is that we receive continuous information through

sensory structures distributed in muscles, tendons, and joints, including neuromuscular spindles, Golgi tendon organs, and Rufini endings. This regulatory system is highly complex, being partly automatic and partly conscious. Spatial and temporal correlations, which are essential for the organization of movements, depend on signals originating in the kinesthetic organs.

The main function of sensory receptors is the transduction of energy and information received from the environment, initiating chemical and electrical signals suitable for circulation and for processing by the central nervous system.

Sensory activation requires a change in the codification of signals. While the original message is usually relayed, distortions and even gross mistakes may occur. Because of sensory specificity, the optic system provides only visual sensation[^] and the acoustic system only auditory signals. For this reason, the same mechanical stimulation may evoke the sensation of a flash when applied to the eye, whereas it may induce sound when applied to the ear. Thermal stimulation, applying heat to a cold skin receptor, will produce a frigid sensation. Sensory receptors have been divided in two groups: (a) Exteroceptors, which give us information about the outside world through the eye, ear, skin, tongue, and nose; and (b) Interoceptors and Propioceptors, which provide us with information of the inner

world of our body through sensors located in different organs. In general there is a multisensory reception with crosscorrelations among different senses. Thus interpretation of visual stimuli may frequently be influenced by vestibular proprioceptive and auditory stimuli. Through development, the organisms learn to expect specific correlations among different stimuli dimensions. Lack of correspondence may produce considerable alterations: for example, a lack of correspondence between visual and vestibular inputs may produce motion sickness.

Sensory inputs are the portals of entry of information sent to the brain, the first step being the acceptance or rejection of data. To analyze our personal awareness of the environment, we need to evaluate the succession of events that occur as data pass from external reality to internal consciousness.

Transduction of Information

Objects located in the environment, including trees, people, sunsets and stars, are not in physical contact with sensory organs. An amount of radiant energy^{per unit time}, called radiant flux and measured in watts or ergs per second, originates as a primary source in the object or is merely reflected as a secondary source, in either case reaching the appropriate sensory organ. Sensitivity is extraordinary in some instances: apparently a single photon is able to stimulate one visual cell. Greater energies, however, are necessary to trigger the

reactivity of other receptors.

The energy emitted by the objects has spatial and temporal characteristics which outline their main physical features. For example, a table will provide patterns of lines, angles, shapes, textures, lights, and shadows, forming altogether a coded pattern of information which will impinge on receptors of the retina. The actual table may be represented by drawing^A or pictures and, if the general pattern is preserved, it will be recognized as the original table. Obviously neither the table or its picture are introduced into the eye. The retina is reached by an amount of unspecific energy which carries a specific code of information.

By code I mean the symbolic representation of reality. A simplified abstraction which is necessary in order to speed up communication. For example the Morse code is made up with combinations of dots and lines representing letters, words and concepts. A tree may be drawn with a few lines, coding a by far more complex reality.

When codes of light stimulate visual cells in the retina, a new set of electrical and chemical activities is initiated and the optic code is transduced into a new electrochemical pattern of messages.

The use of microelectrodes in animal experimentation permits recordings from single cells or nerve fibers to detect action potentials related to optic stimulation.

In the retina as well as in other receptors, the initial response to a stimulus is a graded potential with its amplitude dependent upon the intensity of stimulation. The response is usually sustained during the time course of stimulation and probably originates in primary receptors! When this potential reaches a certain threshold, there is a depō-

larization of the cell membrane causing a repetitive spike discharge with a frequency related to the intensity of the stimulus. The spikes will then be propagated through the nerve fiber, conducting the output of the receptor cell. The pattern of firing will depend on the nature of stimulation and on the specific modality of the sensory organ. With this mechanism, the energy and the code sent by the environmental object is transduced into a different amount of nervous energy and a different code of electrical spikes.

The above description is very simplified because the process of transduction involves many complex reactions and the stimuli usually activate many sensory cells with interactive relations which will determine a variety of discharge frequencies including inhibition of spiking in some neurons. A highly complicated pattern is thus established in space and in time at the receptor site which will produce a compound action potential in the bundle of fibers transmitting information in response to sensory stimulation. These potentials have been recorded with gross electrodes, representing the summated activity of all components within the nervous bundle.

Neurophysiological details and many other related neurochemical phenomena must be investigated in order to understand the process of transduction, but for the present discussion the important fact is that energies and codes of

external information are changed at the receptor site into a new set of energy and codes.

Energy is unspecific and may be supplied by metabolic agents of the organism. Codes, however, carry specific information which must be preserved.

Circulation of Codes

When physical events occurring in the environment are transduced into membrane depolarization, release of chemical transmitters, and spike potentials, nothing is left of the original signals of lights, sounds, and whatever messages existed initially. This process of neural coding was well analyzed by Perkel and Bullock in 1968, who indicated that coding of incoming signals requires the intervention of many elements including:

(a) Stimulation of specific neurons with the activation of labelled lines of information. (b) The timing of the physical event influences the background of neuronal firing, and this fact is referred to as the doorbell code. (c) Additional coding is provided by increasing or decreasing the activity of single neurons. (d) Coding is modulated by neuronal responses to the intensity and duration of the stimulating event. (e) Spontaneous activity will continue undisturbed in neurons which have not been excited, indicating the absence of other local signals.

Transmission and circulation of all these neuronal

responses is further complicated because the speed of nerve conduction varies with axon diameter, degree of myelinization, temperature, and other factors. Conduction velocity slows at points of axonal branching and termination.

At each synaptic junction there is a synaptic delay of 0.1 to 0.5 milliseconds. Synaptic relays have different ranges in different fibers of the same pathway. Postsynaptic neurons may introduce factors of phase lag or may alter the code of the presynaptic neuron.

In man some pathways, for example from the foot up to the brain, are longer than 1.5 meters. The existence of long paths increases the multiplicity of synaptic delays, the interaction of collaterals, and the possible intervention of many neural and chemical agents. Taking all these elements into consideration, it is obvious that conduction times will have considerable dispersion from their origin to their destination, spreading out further if their pathways are longer.

All these data are presented to explain the time distribution dispersal of nerve impulses and the modifications of the pattern of coding which occur during circulation of messages.

The surprising fact is that we can tap lips, finger, and foot simultaneously, and that we can perceive within 1 millisecond simultaneous stimulations which are applied to

different regions of the body. This accuracy in perception demonstrates the existence of neuronal mechanisms able to cope with distortion and with time dispersion in the circulation of incoming messages.

Unfortunately we know very little about the mechanisms involved in sensory integration, and apparently there are no central stations for the coordination of all attributes of perceiving and commanding. Perhaps, as stated by West in 1985, " any and all functions of the brain are distributed in space and time. .. The nervous system deals with ionic and molecular events that are remote from the outside world and that have spatial, temporal, and content representations radically different from what we think we understand as the physical universe."

Information Carried by Codes

Within the complexity of metabolites, neurotransmitters, membrane reactivity, ionic channels, ionic pumps, and many other intervening elements, information is relayed through different segments of neuronal pathways fully and exclusively as electrophysiological activity. The study of these spike-train codes may give us some idea about the mechanisms involved.

Codes in general are shaped by electrical impulses which are brief, discrete, and occur at irregular intervals with patterns which have special characteristics, capabilities

and limitations. Two main mechanisms may be distinguished:

(a) Labelled line coding carries an essential aspect of the information which is related to the specific fibers involved. This principle, described in 1838 by Müller, was expressed as the doctrine of "specific nerve energies," according to which the subjective quality of a sensation (the meaning of neuronal impulses) depends on the cerebral locus where the fibers terminate. For example, optic pathways start in the retina, go to the quiasma, geniculate body and superior colliculus, and end at the occipital cortex. Any stimulation, specific or unspecific, applied at any point of this pathway will produce only optic sensations - not smell, noise, or other effects. For this reason a mechanical blow to the eye is perceived as a flash of light.

(b) Frequency coding: Stimulus intensity is proportional to the frequency of spiking. As demonstrated by Adrian in 1928, the intensity of sensations is coded by the number of impulses arriving per unit of time. These impulses are identical, their rate being the carrier of information. For example, muscle stretch receptors will fire slowly during relaxation and fast during contraction, providing frequency coded information about muscle tension.

In addition, patterning of the neuronal firing rate seems to be very important for the coding of messages. Changes in the temporal structure of the trains include variation of

intervals, serial correlation of intervals, burst characteristics, number of intervals, duration, and temporal patterns.

Another mechanism of codification involves the multiplicity of channels of conduction. Thus a neuron may receive synaptic inputs from two or more excitatory or inhibitory sources. In this way, extremely individualized logic circuits may exist which establish an exquisite sensitivity to slight differences in spatial and temporal inputs. Statistical methods are used to describe the properties of spike trains, including interval histograms, autocorrelation histograms, and crosscorrelation histograms. In the last case, for example, it is possible to determine whether two neurons are functionally independent, in which case the crosscorrelation will be flat. In other instances, the histogram may have a special "signature" indicating functional interdependence.

Correlation histograms provide data in the time domain. With spectral analysis we may investigate relations in the frequency domain.

While the above discussion is based on the principle that information is coded in the form of trains of all-or-nothing nerve impulses, transmission of signals may possibly be based on analogue parameters of membrane potentials, although this mechanism appears far less important.

Material Traces of Codes Within Memory

Codes of information are stored within the brain,

structuring memory and providing the bases for personality, reactivity, and understanding of the environment.

Since the time of Aristotle, philosophers and scientists have speculated about the "seat of memory" which was often at parity with their interest in the seat of emotions and of the soul. Instead of intellectual fencing, contemporary investigators are providing an increasing amount of data based on ablations, stimulations, conditioning, electrical recordings, and other types of research which indicate that brain structures related to learning, memory, and recall include cortical association areas, the midbrain reticular formation, thalamus, hippocampus, and other areas located mainly in the limbic system. Many other cerebral areas seem to be excluded and are dispensable for memory functions. Most authorities emphasize that no brain structure has the exclusive privilege of remembering: there is no seat of memory; there are no specific memory neurons. The integrated activity of different brain structures probably provide the functional bases for memory.

In spite of our deficient knowledge, it is generally accepted that the establishment of a memory trace takes place in two stages: (a) Initially the information codes circulate, supported by material carriers of electrical and chemical phenomena. This first stage is evanescent and easily disrupted. Head injuries often determine loss of memory for

events that immediately preceded the injury. Electroshock produces unconsciousness and disrupts most of the neuronal circuits. Subsequently there is a differential loss of memory affecting the events immediately preceding shock therapy without disrupting the established older memory. (b) Initial memory traces are followed by a period of consolidation leading to the establishment of permanent memory. Retention of information apparently depends on protein synthesis because it is interfered with by agents which block RNA or stop the formation of proteins. The protein involved in retention requires less than one hour to complete synthesis. Long term memory storage, however, is a complex and little understood process.

Possible mechanisms of memory are widely debated but there is general agreement concerning the existence of material changes in the neurons related to long term memory.

The initial electrical codes of information may circulate as recurrent activity within reverberating circuits. According to Young (1951), the patterns of neuronal firing are set up by repeated stimulation of a pathway in the central nervous system. Permanent storage may require structural modifications in the synaptic junctions of the reverberating circuit.

Several investigators, including Hebb (1949), Milner (1957), and Eccles (1953), believe that individual

neurons are randomly connected but may be driven by sensory inputs to set up reverberating activity which outlasts the stimulus by minutes or hours. This persistent activity produces synaptic facilitation at points where different sensory systems interlace so that subsequent stimulation of one will induce activation of another.

Hydén (1961), Gaito (1963) and others have proposed a primary modification in RNA or DNA molecules as the main biochemical correlate of memory. According to this theory, the persistent passage of a particular electrical pattern may change the base sequence of RNA molecules. This new RNA would direct the synthesis of new proteins causing the release of transmitter substances at the synapse when the original bioelectric pattern of excitation recurs.

Anesthesia, hypothermia, coma, loss of consciousness, transitory blockage of metabolic and electric activities do not erase permanent memory. Its bases must therefore be anatomical, perhaps related to axonal spines, sprouting, synaptic changes, somatic neuronal modifications, or other little known mechanisms. Apparently there is a kind of order stating "print now" so that an experience in short term memory is transferred to permanent memory. Information carried by the codes is thus stored with a different code printed in the neuronal flesh.

Physiological Limitations of Information

The specific sensitivity of receptor organs represents a decisive limitation of our perception of the environment. The senses do not provide a balanced representation of reality which is perceived only through a very narrow window of inputs unable to feel the wealth of ultrasounds, ^{electro-} magnetic waves, cosmic rays, and many other stimuli in the universe. This fact is easy to understand: without eyes we cannot see light; without ^{sensory} receptors for atomic particles we may be unaware of the dangers of a radioactive cloud.

In addition to the limitations imposed by our senses, two other shortcomings should be mentioned:

(a) Habituation

Repetition of a stimulus considered of little value will produce neurophysiological responses of decreasing intensity. The tic-toc of a clock initially produces detectable auditory evoked potentials, but after a while the response disappears. Experience demonstrates that we lose awareness of repeated, unimportant sounds. In the process of habituation, the nervous system elaborates a succession of adjusting filters that are tuned to specific stimuli and circumstances. This is a defense mechanism which avoids overloading by filtering out bits of lesser importance. The neocortex cannot be habituated even after 6 hours of continuous stimulation, whereas the hippocampus habituates quickly

and rejects incoming impulses which are repetitive and meaningless. This is important because signals from all modalities converge in the hippocampus and it could easily be overloaded. Hippocampal neurons apparently modify portions of their membrane receptive surface to inhibit the entrance of unwanted signals.

Filtering of impulses is certainly very useful for selection and rejection of specific types of information, but obviously it represents a sensory bias which modifies the quality and quantity of inputs.

(b) Feature Extracting Neurons

In most animals, the visual system has a limited repertoire of specific feature extracting neurons able to detect specific spatio-temporal patterns that represent important forms of stimuli. The retina of the frog has neuronal detectors for bugs, edges, and dimming light. The rabbit retina has specific cells to detect direction, orientation, uniformity, and other qualities. The visual cortices of cats and monkeys possess neurons to detect orientation, stereoscopic distance, and other factors.

The important fact for the present discussion is that some kinds of neuronal selectivity are not genetically determined but individually learned.

In the cat's visual cortex, located in the occipital lobe, all neurons respond to the orientation of the visual

stimulus. Each cell responds to a moving edge, or to a light or dark bar, of a particular orientation. Different neurons respond preferentially to specific orientations; for example, of a bar, but in the normal animal every orientation is equally represented.

In very young kittens without any visual experience, cortical cells respond very weakly and with rapid habituation when a visual stimulus (such as a bar) is presented. Most visual cells have no preference for any particular orientation of the bar. However, when newborn kittens were reared in a special box and exposed during the age period of 2 weeks to 5 months to 300 hours of vertical stripe stimuli, nearly all the cells of their visual cortex responded preferentially to vertical and not to horizontal bars. To the contrary, kittens exposed to horizontal bars responded specifically to them. This experiment demonstrated that cortical neurons may learn specific responses according to their early experience. Perhaps each visual neuron selects as its preferred stimulus the feature that it has seen most often. The physical changes that occur in the cortex during neuronal maturation may be driven by environmental situations.

Some properties of cortical cells such as binocularity and movement detection are determined genetically and built in at birth, while other properties develop or are modified by individual experiences during the first weeks

after birth.

Material Carriers and Transmaterial Information

The attempt to differentiate "objective" from "personal" reality has biological limitations of paramount importance. To feel, reason, understand, and behave depend necessarily on the anatomy and physiology of neuronal mechanisms which can deal only with codes, representing a reality which is artificial and distorted and must be interpreted through sensory transducers and according to the complexity of brain functions.

We can imagine, we may abstract, and we may propose theories and explanations, but all of them must always be linked to metabolic and neuronal processes. Without oxygen, consciousness is lost in seconds and both thoughts and feelings disappear. Obviously ideas cannot be equated with oxidation, but to think we certainly need a working brain with normal metabolic activities.

These facts indicate the convenience of separating the functional material carriers of neurons from the transmaterial information which may circulate through different carriers preserving its meaning (Delgado, 1969, 1979).

In order to correlate neuronal physicochemical events with psychological phenomena, three groups of brain functions should be considered:

1) Basic Metabolic Changes are necessary to maintain nerve cells alive, receptive, and reactive. These processes, which include ionic exchange, oxidation of chemicals, and consumption of energy, are absolutely necessary but are unspecific and not directly correlated with psychological responses. They permit transmission of signals independently of their quality.

2) A Material Carrier of coded signals is needed in order to circulate information through the central nervous system. This carrier is represented by chemical changes and electrical impulses which can be recorded, identified, and measured. The reception of information is impossible without senses, neural conductors, and basic metabolic activity, but these mechanisms are mostly unlearned and automatic. There is no understanding of messages at these levels and the signals must be decoded. A gross similarity may be found in a record player where the pickup cartridge transforms the irregular grooves in the record into electrical patterns passing through the electronic circuitry of the amplifier where they can be mixed, delayed, or changed in tonality. In this instance the material carrier is formed by electrical pulses with a measurable voltage and a pattern which can be identified in an oscilloscope even without knowing that the message is musical. A suitable decoding mechanism, in this case a loudspeaker, is needed in order to perceive the notes of the melody. One more

element is necessary to understand the musical sounds: a suitable sensor - a human being trained to recognize music.

3) The Symbolic Meaning of a message is not intrinsic in the object or in the material carrier. Inborn brain mechanisms will not automatically comprehend data and recognition of messages must be learned, being related to individual personal experience. The visual sensory input of a pencil is transmitted via electrical signals through optic pathways in a monkey, savage, or cultured person. In all three cases the signals are probably similar while their interpretation will be different. For a monkey and a savage a pencil will appear to be only a small stick, while for a writer it has many uses and meaning and conveys a multitude of associations. Symbolism is not in the pencil or in the receptive brain but in their previous encounters and relations.

The difference between material carrier and symbolic meaning must be understood in order to appreciate the limitations inherent in electrophysiological brain research. The most sophisticated techniques for recording electrical codes of transmitted signals can only identify the carrier - not the meaning. The shape of a stick circulating in visual pathways might be identified, but not its history. The reference point of past experience must be known in order for symbolism to be deciphered. The frame of reference which must be studied to capture meaning is the individual experience

stored in the brain by means of special material carriers of information which are probably stereochemical combinations of amino acids and other substances which form the nucleoproteic structure of memory traces. Symbolism is found by recalling experience from memory storage and comparing it with the received inputs. Thus two events occur: comparative evaluation and temporal correlation which constitute the physiochemical basis of individual reactivity. According to definition these processes may be considered material (because essential material events are involved) or immaterial (because they depend on comparison and temporal correlation). It is more useful to comprehend the terms employed than to decide between definitions.

The brain in the newborn human infant has, among other qualities, the capacity to learn languages, abstract thinking, and moral judgement - but not to create them. Using the ideological information and initial training received in childhood, the adult brain may find new combinations and ideas, but only based on the frame of reference received from culture. Conscious or subconscious understanding of messages is probably dependent on progressive stages of chemical and electrical subcoding of sensory inputs which produce new material carriers and codes. These, in turn, activate new series of electrical and chemical phenomena involving constellations of specialized neurons. While these ideas are only

working hypotheses, they can be tested experimentally and should enhance our understanding of brain functions.

Whereas electrical recordings of brain activity provide information limited to the carriers, stimulation of neuronal fields should activate intracerebral processes related to both the initial material carriers and the subsequent subcarriers of symbolic meaning and past experiences stored in the brain. Thus we could differentiate between the cerebral mechanisms involved in simple transmission of inputs and those responsible for the cognitive processing of data. Although we still lack neurophysiological understanding of how we enjoy music or recognize a pencil, we do have methodologies and working hypotheses to investigate the problem, and we can already create hallucinatory musical and optic perceptions by direct stimulation of specific areas of the brain.

Personal Space and Time

Normal behavioral performance is based on the precise coordination of many muscles in space and in time. In the simple act of walking there are sequential contractions and relaxations of the leg muscles, compensatory movement of the arms, and maintenance of appropriate body posture.

At birth, human babies are unable to walk, demonstrating that unlike lambs and other animals, coordination of movements is not prewired in our brains, nor is it genetically determined. Each baby must learn through months of

trial and error to use his hands and body. Memories of experiences, sensory inputs and ideokinetic formulas of activity will slowly be acquired, leaving material traces within the neurons and contributing to the maturation of sensory-motor pathways. Awareness of space and time do not seem to exist in newborns and apparently are learned gradually through individual experience. This important fact indicates that spatio-temporal learning is influenced by environmental and cultural factors.

The cerebellum is one of the main structures for the processing of incoming signals, for sending orders to the motor cortex, and for the crosscorrelation of a huge amount of data. Refined skills, such as those involved in playing the piano, require very fast and complex integrations including visual and acoustic training to read, hear, and understand music; extraordinary precision in the control of finger movements; and a composite motor performance which will be modulated by technical training and also by the sensitivity and taste of each player. In a skilled performance the sense of space and timing is amazing: each finger must be placed independently in the correct position with a predetermined force and all ten fingers must follow unique but integrated sequences of notes creating a harmonious effect. While some people are 'gifted' with musical talent, without a piano, without training, this potential will not be realized.

The existence of a kind of intrinsic biological clock, providing a neuronal timing mechanism, has been postulated by several investigators. Old clocks were based on the tic-toc of a pendulum or of a tiny balanced wheel. Continuous recurrence of cyclic activities constitutes a suitable method for estimation of the passage of time. Cycles of day and night, the reliable movements in our solar system, and more recently the high precision of electrical cycles and atomic changes have been used for time keeping.

Living organisms have a rhythmicity in their respiratory movements and heart beats which give a certain temporal sensation, and it is well known that people can calculate the occurrence of some events with surprising accuracy. The brain must have a role for this temporal perception and the existence of normal, spontaneous neuronal rhythms has been investigated. We know that the electrical activity of the brain has frequency cycles up to 100 per second, and the alfa, beta, theta and other frequencies in the 3 to 30 Hertz range are particularly clear. Of all these, the theta rhythm in the septum and hippocampus has been postulated as a time keeping mechanism. Each theta cycle may be like the tic-toc of a watch, modulating the excitability of neurons related to motility and posture (Garcia Austt and Buño, 1981). This biological clock has a setting possibility, returning to zero when triggered by

special sensory inputs in order to start counting and to send orders triggering a motor sequence.

The motoneurons are the segmentary centers for organization of movements and they receive information from the cerebral motor cortex via the reticular formation. This last structure is influenced by the rhythmic activity of the septal-hippocampal system which has a powerful influence on the temporal organization of motor orders. A feedback is established from peripheral sensors to the reticular formation and septum, resetting their rhythms and frequencies. In this way, the timing originating in the septum and hippocampus is essential for the integration of motor performance.

It should be emphasized that the spatio-temporal timing of neuronal activities is performed through patterns of codified signals. In the same way as reception of signals by sensory organs is limited to a narrow band of stimuli, all the reception, elaboration, and expression of intracerebral information, including spatial and temporal elements, are determined and limited by the codes carrying messages through cells and pathways of the brain.

Decoding the Codes

Studies about the physiology of the visual system indicate that the "sustained" and the "transient" ganglion cells in the retina are the sites for the separate processing of spatial and temporal features of visual stimuli. Informa-

tion is transmitted through separate pathways and the detection of space and time is performed by different neuronal populations (Wright and Ikeda, 1974).

The questions still remain of how we perceive space and time; where is personal awareness; how we know that a color is "blue;" how we understand the meaning of words; how can we understand the universe ?

The brain deals only with codes of information carrying the transmaterial meaning supported by material processes of neuronal spikes, special transmitters, and neurochemical phenomena. According to Wolfe (1983), visual experience is composed of a series of specialized subsystems that act more or less independently and are responsible for processes of which the viewer is normally unaware.

One problem is that research methodology can discover only the material substratum - not the message. If we analyse a video tape we may learn everything about its structure and the position of magnetized elements. When we record the electrical activity of the optic nerve, we may detect release of transmitters and firing of spikes. None of this "material" information will tell us about the hidden message or about psychological sensations. For this purpose we need decoding mechanisms. It is even more important to understand how and why we feel and know. Awareness of ourselves and of reality is a general experience for which we

have no explanation. We may postulate, however, that it requires a first step of decoding the circulating codes of information and that this process is related to the existence of a frame of reference stored in memory and acquired by personal experience.

Language provides a good example: written words and sounds are the material carriers of messages. Words may be written in sand, on paper, or in the sky; they can be said by telephone or sent in Morse code - their transmaterial meaning is preserved. Understanding messages requires learning the specific language in order to decode the information and compare it with previously stored data. If we do not know the code, we cannot decipher meaning: arabic and chinese writings are totally uncomprehensible to untrained people from other cultures.

In a similar way, values are not genetically determined but must be acquired by individual experience. Recognition of this fact is essential in order to understand the physiological relativity of our personal perception of the universe and our responsibility for overseeing adequate structuring of children's brains. Just as infants must be given warmth, food and care, they also require sensory stimuli - messages and values - to structure their growing neurons and establish the frames of reference which are the bases of their personality.

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