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The Brain and Subjective Experience: Question of Multilevel Role of Resonance

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Everything we experience and do as individuals is assumed to be a function of the nervous system. It is as though we were born with a total supply of algorithms for all given forms of psychic states and solutions for immediate or eventual actions. There is evidence that the forebrain is, so to speak, the central processor for psychic experience and psychologically directed behavior. Since information *itself* is immaterial, all forms of psychic experience represent immaterial emanations of the forebrain, including sensations, perceptions, drives, affects, thoughts, and the precisely measured, cold hard facts of science. But it is to be emphasized that there can be no manufacture or communication of information without the intermediary of behaving entities. Because of the immateriality of information and the Gödel-like problem of self-reference, a central question arises as to whether or not we can ever rely on the brain with its viscoelastic properties to achieve a reliable yardstick for measuring time and space and the general nature of things. Most needed at the present time is a refined picture of the anatomy and chemistry of the brain's circuitry accounting for its particular species of algorithms. Emphasis is given to the basic role of various proteins in generating subjective experience. Because of the role of resonance in contributing to the dynamical excitability of neural circuits, examples are given here of how it might play an algorithmic role at macroscopic, microscopic, molecular, and atomic levels. To describe this idea attention is focused on three evolutionary types of cortex that have developed in the triune evolution of the mammalian forebrain from the mammal-like reptiles (therapsids) to human beings.

To the best of our knowledge, the brain provides the rules for everything we do. If true, then in a sense we can never discover anything outside the brain because all the ingredients of cerebration, like those of a mathematician's

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formulas, are already in the brain. To say this is not to ignore the capacity for changes in size of dendritic and axonal fields in response to certain conditions. In his original expositions of Neurological Positivism, Vandervert referred to "science's erroneous placement of the world outside the skull" (1990, p. 9). He proposed that everything we know and do depends on the "algorithmic organization of the brain." Under this computational expression he included "any set of rules" for achieving solutions (1988, p. 321). In saying this, he does not deny the existence of a "world out there." Rather, he points out that all our experience is owing to what we realize by means of built-in algorithms of the brain. His use of the expression "algorithmic organization" is particularly provocative with respect to questions I will raise in regard to both classical cytoarchitecture and new developments in chemoarchitectonics as these topics pertain particularly to the role of various types of cerebral cortex in subjective experience.

But the problem of learning the cortical circuitry and chemistry will be as nothing compared with that of disclosing the origin of subjectivity. Elsewhere I have commented on the traditional scientific insistence of the objective approach in all scientific undertakings (MacLean 1975, 1990). This is indeed an ideal aim. At the same time there is a fundamental need to obtain insight into a situation that from many points of view undermines the objective method. This is because of the irony that everything observed and measured by our presumed instruments of precision must undergo subjective processing and interpretation by an introspective observer. Logically, there is no way of circumventing this or the other inescapable conclusion that the cold, hard facts of science, like the firm pavement under foot, represent informational transformations of a viscoelastic brain (MacLean, 1975, 1990) [viscoelastic is the scientific term for defining the physical properties of the brain]. As Wiener stated more succinctly than Berkeley or Hume, "Information is information, not matter or energy" (1948, p. 155). To be sure, the communication of information depends on its transmission by measurable physical entities. This might be called a law of communication. But the information itself is without substance. In terms of quantum mechanics, one could sum it up by an illustration used by Brian Cooney in relation to the currently favored philosophical term *qualia*. Excitation of the retina by measurable waves and particles would offer an explanation of how the visual system might be activated so as to generate the subjective impression of the color green. But Cooney notes, "Nothing in the materialist universe is green" (1991, p. 208).

If, however, we could learn the brain's limitations in deriving information, it might suggest changes in the direction of our observations and experimentation that would result in an entire alteration of our thinking. To cite an obvious example, the differences in the substance and speed of communication of our brain and of our instruments of precision are so extreme that, when added to the problem of self-reference, we might be led to re-evaluate both our everyday and scientific concepts of time and space.

For this article I want to focus on a few main points. After covering what I mean by subjective experience, I will then explain why, for purposes of illustration, I choose to focus on the evolution of three distinctive types of cortex that deserve more extensive research on their particular type of anatomy, chemistry, and circuitry. Then finally, I will select a few illustrations of factors that possibly could contribute to an understanding of the seemingly insoluble mystery of how the brain derives "immaterial" subjective information.

At this point I should explain a personal experience that led to the choice of the subtitle "Question of Multilevel Role of Resonance." In 1948 I visited Dr. James W. Papez, the well-known neuroanatomist and neurologist at Cornell University in Ithaca, New York. So as to answer some of my questions, he said he would like to perform a dissection of part of a human brain. During the quiet while he was exposing the temporal region, I broke the silence by musing aloud, "What is the origin of subjective experience?" Raising his head and looking at me as if I would know, he answered in a single word, "Resonance!" That word has been resonating in my memory ever since.

Subjective Experience

The topic referred to here is commonly discussed under the heading *consciousness* which can lead to as many ambiguous qualifications as there are authors. In more general terms, I have used the word "epistemics" to apply to the body of knowledge and collective disciplines concerned with clarifying the nature of the self and the subjective brain (MacLean, 1975, 1990). Since only we as individuals can experience subjective states, we must describe them on the basis of how we identify with the behavior and verbal expressions of others. Subjective experience represents various forms of psychic information. As far as we can tell, all psychic information is attended by the presence of some degree of awareness of wakefulness. The dreaming phase of sleep would be no exception because of an associated sense of awareness. Given the common denominator of awareness, there are five main psychic varieties of subjective experience that may be characterized as sensations, perceptions, "drives," affects, and thoughts. I use the word drives to include the mental states associated with routines, compulsions, and obsessions. Affects refer to feelings that we identify with the expression of emotional feelings in ourselves and others. The affects can be subdivided into three main types — basic, specific, and general (see MacLean, 1990, p. 426). Thoughts are products of various forms of conception. Under ordinary conditions, sensations and perceptions occur only during activation of sensory systems. On the contrary, subjective states associated with "drives," the general affects, and thoughts are not dependent on specific gateways to the sensorium but may occur and persist as the result of mentation.

At this point it is of interest to point out that at the beginning of the present century, there were psychologists of the so-called behaviorist school who sought to revive the spirit of the Helmholtz tradition and to make psychology an exact science on the same level as physics and related disciplines. As one of the chief proponents, J.B. Watson explained, "In 1912, the behaviorists [decided to drop from their] scientific vocabulary all subjective terms such as sensation, perception, image, desire, purpose, and even thinking and emotion . . . as subjectively defined" (1924, p. 6). To be consistent, they might also have decided to include themselves as subjective observers.

Evolution of Cerebral Cortex

In the three classes of terrestrial vertebrates (reptiles, birds, and mammals) experimentation has shown that psychologically directed behavior depends on the forebrain that consists of the cerebral hemispheres located above the midbrain. Comparative findings indicate that in the evolution of human beings and other advanced mammals the forebrain has expanded as a triune structure consisting of three neural assemblies with an anatomical organization and chemistry of three brain types that reflect an ancestral relationship, respectively, to reptiles, early mammals, and late mammals. Although extensively interconnected, there is evidence that each major component of this basically modular triune brain can operate somewhat independently.

Both birds and mammals are believed to have evolved from reptiles. But unlike mammals, birds have only a small area of poorly developed cortex resembling that of reptiles. Neurobehavioral studies, however, indicate that all three classes of these vertebrates engage in the same kinds of basic behavior involving the performance of the daily master routine and subroutines, as well as the orchestration of four main kinds of displays used in social communication. Neurobehavioral studies indicate that these basic forms of behavior are primarily dependent on large basal ganglia at the foremost part of the brainstem. In a comparative context I refer to these forebrain ganglia as the *R-complex* (MacLean, 1990, chapter 4).

One might speculate that the R-complex developed as a part of the brain for retaining the performance of forms of behavior that have proved to have survival value for countless generations, but is relatively deficient in learning to deal with new situations. The fossil record strongly indicates that mammals derive from mammal-like reptiles (the so-called therapsids) that were the predominant fauna throughout the one-continent world (Pangaea) some

250 million years ago (MacLean, 1990, chapter 5). About 180 million years ago, the evolutionary transition from therapsids to mammals led to a behavioral triad distinctive of mammals — namely, (1) nursing conjoined with maternal care; (2) audiovocal communication for maintaining mother–offspring contact; and (3) playful behavior (1990, chapter 17). These new developments apparently went hand in hand with a ballooning out and further differentiation of the primitive reptilian cortex which expanded to envelop a large convolution that the French physician Broca in 1878 called the great limbic lobe because it surrounds the upper brainstem. Broca also presented evidence that this lobe is found as a common denominator of the mammalian brain (1990, chapter 17). Although the limbic lobe has since been shown to derive information from all the internal and external sensory systems (1990, chapter 26), Broca placed particular emphasis on its connections with the olfactory apparatus. For this reason it became known as the rhinencephalon (olfactory brain). But in the last 50 years clinical and experimental findings have indicated that this part of the brain plays a major role in generating emotional feelings that guide behavior required for self-preservation and the preservation of the species. Hence as a means of de-emphasizing the functional implications of the term "rhinencephalon," I reverted to the use of Broca's descriptive word "limbic," and in a modular sense, referred to the limbic cortex and its primary connections with the brainstem as the *limbic system* (MacLean, 1952). Because of accumulating behavioral and biochemical findings, the history of the evolution of the limbic system might be described as the history of the evolution of mammals and their distinctive family way of life (MacLean, 1990, chapters 17–27).

In the progressive evolution of mammals a new and more complicated type of cortex expands beyond the limbic cortex and in the more advanced mammals leading up to, and culminating in human beings, balloons out above and around the limbic lobe. This exuberant growth apparently reflects an enhancement of the capacity of the three principal exteroceptive systems (visual, auditory, and somatic) for adaptation to the external environment. In human beings it accounts in addition for symbolic communication in words and numbers.

Cortical Areas and Subjective Experience

We are now in a position to focus on cortical areas with respect to subjective experience. As a first comment, let it be said that in this age of computers and interest in artificial intelligence, it is disappointing that the number of articles on artificial neural networks far exceeds those by neuroanatomists trying to extend the findings of workers of the last century who developed special stains to discover the connections of various nerve cells of cortex and other structures. One thinks first of all of Camillo Golgi (1843–1926) who in 1873 published his chrome–silver stain which for the first time made it possible to observe the entire structure of nerve cells. The disappointment expressed above is because within the past 30 years new histochemical techniques have been introduced that have greatly widened the scope of what can be accomplished in the study of neural networks. Hence today in addition to classical architectonics, one needs to place additional emphasis on "chemoarchitectonics." Immunocytochemical techniques promise to be an especial boon in this field (see below).

Special Significance of Cortical Areas

The cerebral cortex deserves special consideration with respect to subjective experience because certain areas are of primary importance in this regard. First of all, one might ask, why does cortex occur in layers with the number of layers ranging from two to seven according to its evolutionary age? Moreover, on the basis of differences in numbers of cells and fibers in respective layers various anatomists have subdivided the cortex of human beings and animals into several areas. The German neurologist K. Brodmann (1908), for example, identified more than 50 different areas in the human brain. If projected by themselves on a world globe, these areas might be imagined as a jig-saw puzzle of a country somewhat comparable to the United States. But in other respects there would be decided differences. In terms of population the inhabitants would consist of several billion nerve cells. According to the interpretation of the German anatomist M. Rose (1926), there were three main types of cortex which originate from basic two-, five-, and seven-layer embryonic stage. The two-stage type would correspond to the so-called archicortex (i.e., "first cortex") which, as mentioned above, occupies the inner part of the limbic lobe surrounding the brainstem. In terms of the jig-saw analogy, the cells would compare to the first settlers who occupied the land along the Atlantic seacoast.

Rose regarded the five-layer cortex as an intermediate, transitional form between the two-layer and seven-layer types — hence his alternate term "mesocortex." This mesocortex forms an outer circumferential band of the limbic lobe and borders upon the inner ring of limbic archicortex. *It is to be emphasized that the mesocortex appears for the first time in mammals* (Rose, 1926). In terms of our analogy, the migration of mesocortical settlers might be imagined as extending as far westward as the Mississippi valley (corresponding to Broca's limbic fissure).

The rest of the jig-saw pieces on our imaginary world globe would be representative of Rose's seven-layer type of cortex and in an evolutionary sense would rank as neocortex. On the world globe the migration of neocortical cells may be pictured as stopping at the coastline of the Pacific ocean.

Intercommunication Within and Among Cortical Areas

The jig-saw pieces representing the cortical areas might be regarded as somewhat like computer chips with inputs and outputs. In the case of cortical areas such as the olfactory or visual cortex where odors and things seen are generated, the great mystery with respect to the brain is where the viewers are seated. Figure 1 is an illustration of the kind of transitional or abrupt changes that demarcate various areas. The figure shows part of the hippocampal gyrus (limbic cortex) in the brain of the cat. It is a part of the brain clinically recognized to be involved in limbic epilepsy. Depending on the site of the focus, patients may experience a broad range of basic, special, and general affects. The general affects, which correspond to what we generally regard as "emotional feelings," include terror, fear, feelings of sadness and

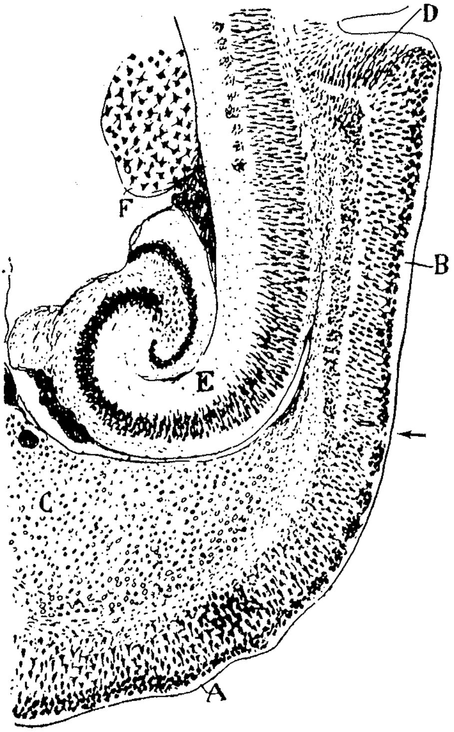

Figure 1: Illustration from a classical study by Cajal, showing the kind of abrupt or transitional changes that demarcate different cortical areas. A and B identify olfactory and entorhinal areas. Note transitional change in appearance of cortex between A and arrow, and the abrupt change where entorhinal cortex begins at arrow. See text for additional details. Other abbreviation: C, corpus striatum; E, hippocampal formation. From *Studies on the Cerebral Cortex (Limbic Structures)*, by S. Ramon y Cajal, 1901–02/1955, London: © Lloyd–Luke.

wanting to cry, and so on. Most important from an epistemic standpoint are the strong feelings of conviction and belief that what one is experiencing at the moment is of the utmost importance or is expressive of the absolute truth. Such feelings are free-floating and do not apply to anything in particular, but clinical findings indicate that they are generated in the non-lingual limbic brain and are of the kind that we attach to our beliefs regardless of whether they are true or false. Recently this region has attracted special interest because of brain imaging studies indicating its shrinkage in schizophrenia.

In the figure, Cajal has placed an A with a line leading to the typical olfactory cortex. I have added an arrow where there is an abrupt change in the layering of the cortex. From this arrow upwards to the sulcus denoted by D is the area 28 of Brodmann, more commonly referred to as the entorhinal area. This area has a distinctive layering of cells, with those in the second layer referred to as large star cells. Note how these cells, together with the deep layer without cells, mark an abrupt transition with the cortex below the arrow. The transitional cortex below the level of the arrow where the cells in layer 2 begin to cluster is sometimes mistakenly referred to in the human brain as part of the area just described.

Lorente de Nó (1933), one of Cajal's last students, declared his initial ambition to describe all areas of the limbic cortex together with special sensory and motor areas of the neocortex. He was desirous to obtain a detailed picture of the circuitry of various types of cortex as revealed by the Golgi stain. He said he was beginning with the entorhinal area because it represented the simplest type of cortex and showed the same basic organization in all mammals. In connection with the then current interest in "self-re-exciting chains" of neurons, he paid particular attentions to the Golgi type 2 cells with short axons and their relation to the Golgi type 1 pyramidal cells with long axons. Figure 2 shows a variety of short axon cells (numbers 1–4, 12) in different layers, as well as six pyramidal cells (numbers 5–9, 11), and a polygonal cell (number 10). The drawing in Figure 3 summarizes his conclusion as to where axons of Golgi type 2 cells terminate on different parts of a pyramidal cell. The long axons of pyramidal cells project to other cortical areas or to subcortical structures and may have collaterals innervating contiguous cortex.

The short axon cells considered above are generally regarded as having an inhibitory effect on other neurons. These cells show a progressive increase in number not only in conjunction with the evolution of the three main types of cortex, but also in the evolution of more advanced mammals. Cajal regarded the large number of these cells in the human neocortex as the anatomical expression of the delicacy of function of the human brain (see Lorente de Nó, 1938, p. 308). As dealt with below, the short axon cells have

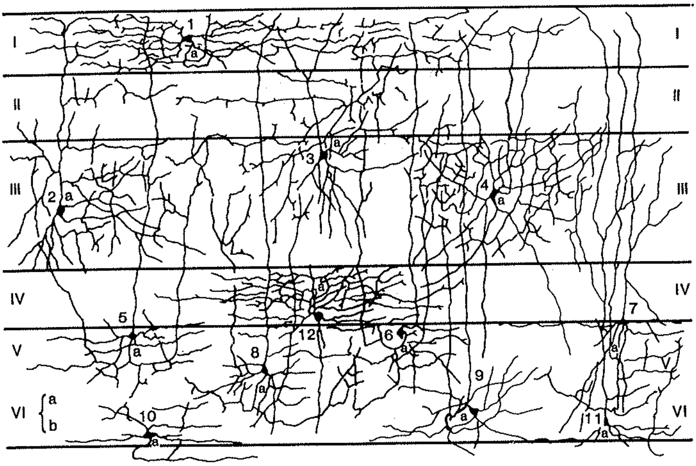

Figure 2: Lorente de Nó's depiction of various types of Golgi-stained cells of short axon and pyramidal cells in different layers of entorhinal cortex. See text for significance. Cortical layers are identified by roman numerals. Numbers 1–4 and 12 are located next to cells of short axon. Pyramidal cells are numbered 5–9 and 11. Number 10 identifies a single polygonal cell. From "Studies on the Structure of the Cerebral Cortex: I. The Area Entorhinalis," by R. Lorente de Nó, 1933, *Journal für Psychologie und Neurologie*, 45, 381–438.

become of great current interest because of neurochemical findings that they may belong to certain local circuits with a distinctive type of chemistry that affect neural transmission.

Figure 4 shows Marin–Pedilla's (1990) reconstruction of five types of circuit cells that he believes are implicated in the output of pyramidal cells in all mammals. He points out that "the pyramidal cell represents a mammalian innovation in cortical evolution" (p. 182), and is "the most distinctive neuron of the mammalian neocortex," comprising about "70–80% of all its neurons" (p. 181). The pyramidal cells are so named because of their pyramidal shape. Inspection of Figure 4 shows that they occur in layers 2, 3, and 5 and that they become progressively larger in size from above downwards. Contrary to past teaching, Marin–Padilla emphasizes that the dendrites of these cells grow downwards from layer 1, rather than upwards to it. This may reflect an evolutionary precedent because the older forms of cortex (archicortex and mesocortex) receive their major input from the outermost layer. In this layer the terminal branches of the apical dendrites of the pyramidal cells tend to orient themselves in the longitudinal direction of the incoming fibers. The question will arise later whether or not this arrangement and also the progression in size arrangement of the pyramids (suggest-

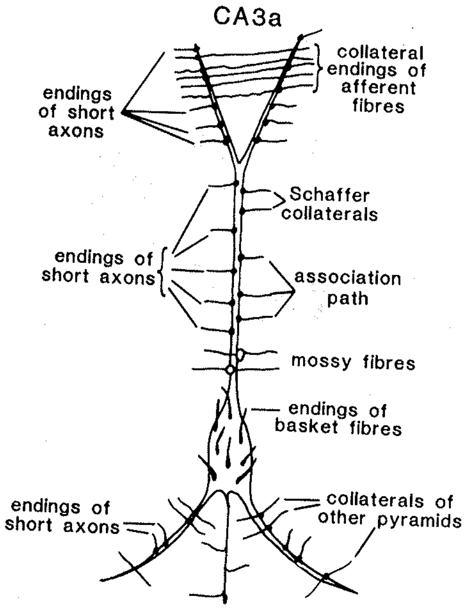

Figure 3: Drawing of a large pyramidal cell, summarizing Lorente de Nó's interpretation of sites of termination of different types of cells with short axon. From "Studies on the Structure of the Cerebral Cortex: II. Continuation of the Ammonic System," by R. Lorente de Nó, 1934, *Journal für Psychologie und Neurologie*, 46, 133–177.

ing somewhat the grouping of violins, cellos, and bass viols of an orchestra) has anything to so with mechanisms of neural resonance.

The question of resonance mechanisms will also arise in connection with neocortical sensory systems. It will be noted in Figure 4 that the motor cortex has no apparent layer 4. The so-called primary sensory areas and their neighboring association areas are characterized by distinctive layer 4 with closely packed, small granular cells, so named because their grain-like appearance. It was as though the evolutionary refinement of the visual, auditory, and somatic sensory systems required (in addition to a "ceiling" input from layer 1 to the cell layers underneath) a deeper layer with a "cellar" input directly from structures of the brainstem.

Chemoarchitectonics

As mentioned, developments in molecular biology have provided new methods not only for revealing brain circuitry but also the chemistry involved in the neural transmission of specific circuits. Here I will cite just a

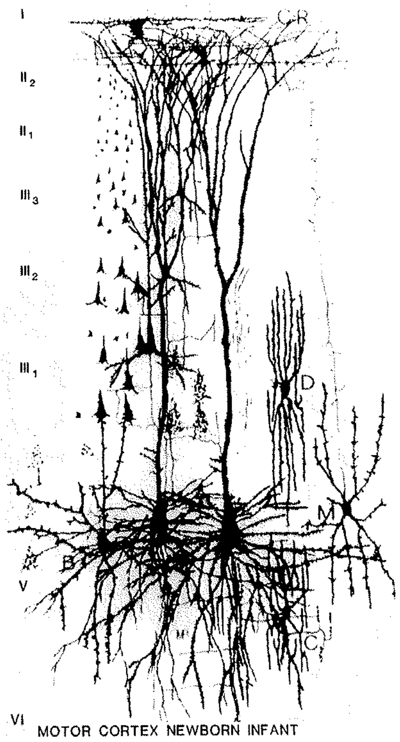

Figure 4: Marin–Padilla's schematic drawing of cells of the motor cortex of newborn infant, showing a pyramidal cell and its connected local circuit of cells with short axons that he believes is typical of the neocortex of the mammalian brain. See text for implications. Lettering identifies the five main types of circuit cells: C–R, Cajal–Retzius cell; B, basket cell; C, chandelier cell; D, double bouquet cell; M, Martinetti cell. From "The Pyramidal Cell and its Local-circuit Interneurons: A Hypotheical Unit of the Mammalian Cerebral Cortex," by M. Marin–Padilla, 1990, *Journal of Cognitive Neuroscience*, 2, p. 182. ©1990 by the Massachusetts Institute of Technology. Reprinted with permission.

few examples of how immunocytochemistry in particular has the capacity to differentiate types of cells and their chemistry. The so-called neuron specific enolase protein (NSE) makes it possible to differentiate nerve cells not only from the surrounding glia, but also from non-nervous cells outside the brain. Remarkably from a developmental standpoint, NSE does not become a marker until the cell is mature and has reached its final site of migration (Schmechel, Brightman, and Marangos, 1980).

In his "local-circuit" study described above, Marin–Padilla points out that basket cells establish inhibitory GABAergic axosomatic synapses with several pyramidal cells. As to further observations on local circuit cells, David Jacobowitz, a longtime neurochemical cartographer, has found in his investigations of calretinin and other calcium binding proteins that they serve as useful markers of different kinds of nerve cells. In a collaborative study of the prefrontal cortex of rhesus monkeys (Condé, Lund, Jacobowitz, Baimbridge, and Lewis, 1994), it was found that calretinin was a distinguishing marker for double bouquet cells (Figure 5), whereas calbindin singled out Martinotti cells, and parvalbumin revealed both chandelier cells and wide arbor (basket) cells.

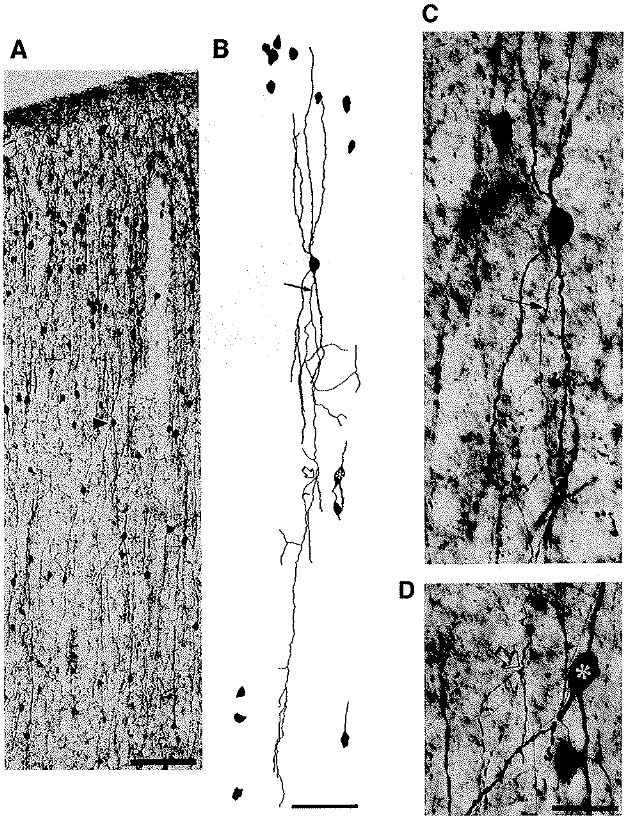

Figure 5: As explained in text, new developments in chemoarchitectonics promise to be a great boon in obtaining essential knowledge of the anatomy and chemistry of the brain's neural circuitry. As shown here (A, arrow), for example calretinin, one of the calcium binding proteins, appears to selectively differentiate double bouquet cells from other types of local circuits cells illustrated in the preceding figure. The section shown here came from the prefrontal cortex of a macaque monkey. See text for additional details. B, camera lucida drawing of cells indicated by arrow in A. C and D are photo enlargements. Asterisk identifies a neighboring cell in A, B, and D. From "Local Neural Circuit Neurons Immunoreactive for Calretinin, Calbindin D-28k or Parvalbumin in Monkey Prefrontal Cortex," by F. Condé, J. Lund, D. Jacobowitz, K. Baimbridge, and D. Lewis, 1994, *Journal of Comparative Neurology, 341*, p. 99. ©1994 by Wiley–Liss, Inc., a subsidiary of John Wiley and Sons, Inc. Reprinted with permission.

Question of Multilevel Role of Resonance

In considering the question of the role of resonance with respect to the generation of subjective experience by cortical circuitry, it would seem a necessity to hypothesize both a receiving analyzer and a formulating emitter. The situation might be compared to the saying that "it takes two to tango." I am going to suggest that proteins play a key role in this process. It was as though we were required to return to Albrecht von Haller's question of "irritable tissue" and were asking, in a sense, "What makes matter cry out?"

Significance of Proteins

Of the countless proteins, there are 88 said to be common to all mammals (Graur, Duret, and Gouy, 1996). Several proteins are present in the brain in relatively large amounts, and "neurofilament proteins" has become a familiar expression. Twenty essential amino acids comprise the building blocks of protein, and electrical charge differences have long been recognized as implicated in the line-up and folding of proteins. Szent–Györgyi (1960), for example, cites an experiment in which the riboflavin and indole molecules could "be laid on top of one another in a way that positively charged C atoms come to lie opposite negatively charged ones" (p. 86). As a last "intriguing" observation, he refers to evidence indicating that in the case of nucleoproteins the density of unpaired electrons "is almost comparable to that found in metals, to which metals owe their conductivity" (p. 135). The so-called G-proteins are comprised of alpha, beta, gamma subunits that serve to transmit signals from the outside of cells to their interior (Gilman, 1987). In addition to participating in the transmembrane crossing of neurotransmitters and hormones, it is most important from the standpoint of the present topic that they are said to be involved in modulating psychic functions such as, for example, olfactory and visual perception.

Resonance

In physics, resonance is described as a reinforced vibration of a body exposed to another body vibrating at about the same frequency. Resonance is a highly efficient means of transferring energy and as exemplified by musical instruments serves to give amplification. Pendulums or tuning forks are used as favored objects to illustrate resonance mechanisms, but since later on I want to give emphasis to the harmonic aspects of resonance, I refer again to musical instruments. As familiar to musicians, plucking a full length string will give the fundamental tone (i.e., the lowest tone), together with a number of harmonic sounds that are multiple frequencies of the fundamental. As will be dealt with, harmonic resonance looms large in the consideration of subjectivity at the molecular and atomic levels both with respect to electrons ("matter particles") and photons ("electromagnetic particles") with their wave properties in relation to atoms. As one engineer commented to me, "Since we must test complex systems in search for conditions of harmonic resonance because mechanical and electrical systems tend to self-destruct in this state, I remain mystified as to how living systems can survive in this state instead." He was referring to the stabilizing effect of resonance at the submolecular level.

Keeping in mind our initial focus on the algorithmic functions of cortical areas in subjective experience, I will cite examples of the effects of resonance on the brain at four levels: (1) the macroscopic level; (2) the microscopic level; and the (3) molecular and (4) atomic levels.

Macroscopic Level

Granted that it is quite arbitrary where to draw the line between the macro and the microscopic levels, we do so here for reasons of exposition. Certain epileptic patients are subject to partial or generalized seizures when exposed to rhythmic or nearly rhythmic sensory stimulation. In giving a history a patient may report that a seizure sometimes occurs when driving past a woods in winter. The doctor will explain that the seizure may have been triggered by flickering light and advise the patient to avoid such conditions in the future. In a diagnostic seizure clinic, rhythmic stroboscopic stimulation at various frequencies may be tried as one of the tests. The literature contains photo documented case reports of patients rhythmically waving a hand back and forth in front of their eyes so as to obtain flickered light stimulation and induce seizures of a gratifying kind. Experimentally, it can be shown by plotting frequency–amperage curves that various responses elicited by brain stimulation of different structures can be obtained with the least amount of current when applied at an optimum frequency (e.g., MacLean, 1990, p. 365, Figure 20-6).

It would involve too much detail to describe differences in electrical excitability of the different types of cortex. But let it be said in passing that the limbic archicortex has the lowest seizure threshold, presumably because it has the fewest number of cells of short axon (see above). Electrically induced seizures show the tendency to spread in, and be confined to, the limbic system. If they do break into the neocortex, there is a high probability of a generalized convulsion. In considering resonance factors, it is important to keep in mind that the brain has its own natural rhythms — most notably the delta, theta, alpha and beta rhythms — that vary in their occurrence with sleep, dreaming, wakefulness, attentiveness and other states.

Finally, in this brief account, I would like to call attention to an overlooked, but potentially important aspect of resonance. Anyone who has spent part of a career recording brain potentials cannot help but be impressed by the great amount of apparent "slop" in the brain. It is enough to make one wonder how it is possible to add two and two and to come up each time with the same answer. A continuing puzzle to neurophysiologists is how the brain derives information from the same nerve stimulus that in each case excites an equal number of impulses, but in a different temporal pattern. What is the important factor: The number of impulses or the temporal pattern? Perhaps people with hearing aids could lend some insight into this problem. In a noisy environment they may recognize a momentary resonance each time it occurs at a certain rate.

Microscopic Level

Here the three main points to be covered apply to the microscopic observation described above under the heading Cortical Areas. Mention was made that the apical dendrites of the pyramidal cells of layers 2, 3 and 5 tend to be oriented in the direction of incoming fibers of layer 1 (the outermost layer). In Golgi-stained sections the distances between the terminal endings on the apical fibers are suggestive of the distances between the so-called miniature potentials that look like tiny blebs on baseline recordings with a microelectrodes. It would be of interest to learn whether or not these miniature potentials occur at any frequency that would tie in with others occurring elsewhere along the same or neighboring fibers.

In looking again at Marin–Padilla's illustration in Figure 4, one will note that in addition to the "progression-in-size" grouping of the pyramidal cells that was pointed out in orchestral terms, a vertical column of these cells has somewhat the appearance of a clarinet. Viewed in such a way, the question arises as to whether or not the pyramidal circuitry reflects any physical connection with resonance and amplification.

As will be later illustrated at the submolecular level, proximity is a most important factor in the efficient transfer of various forms of energy by resonance. At the microscopic level the question arises with particular interest in regard to the closely abutting granular cells of layer 4 of the neocortex and the more densely packed cells of the dentate part of the archicortex (hippocampal formation), as well as the wide granular layer of the retrosplenial mesocortex. I remember the neuroanatomist Grant Rasmussen's speculations that such cells might be particularly important in sensory and mnemonic functions. Is it possible that the close proximity typical of granule cells reflects a physical arrangement conducive to the resonant transmission of electrical potentials? In the preceding section we mentioned the capacity of momentary resonance to be detected in presence of background noise. Resonance might also be a factor in a search for temporarily forgotten words when we say it is so close to the tip of my tongue that I can almost taste it. Then suddenly when one's thoughts are elsewhere, the word or name will jump into your mind. This recalls the experience of a mechanism of quite a different sort. Patients who do exercises for correcting double vision are often aware that as they try to bring their eyes together, the double image of what they are looking at will suddenly jump together like iron to a magnet and appear three dimensional.

The cortex of the auditory receiving area (the so-called Heschl's gyrus) has quite a different appearance from other sensory areas of the neocortex. Here parts of the receptive cortex give the appearance of overlapping shingles, a physical arrangement that would also favor resonant transmission.

If it weren't for the vagus nerve — the great visceral nerve — carrying messages to the brain from an essentially two-layered nervous system in the gut, one would be inclined to give priority to the olfactory sense as the place to start in an investigation of the origin of subjective experience. As Helen Keller said, in effect, "smell is *in the organ*; touch is in the object." The question of the neurochemistry and function of smell is much too involved to go into here, but apropos of resonance I would like to emphasize the prolonged burst and slow decline of rhythmic potentials elicited in the limbic piriform cortex by olfactory stimulation. Under special conditions gustatory and noxious stimulation induce the same kind of rhythmically recurring potentials (MacLean, 1990, pp. 468–469, Figure 26-1; see also Freeman, this volume).

Molecular and Atomic Levels

A most important lead to the wave–particle theory of quantum mechanics began in 1911 when the New Zealander, Ernest Rutherford, discovered the nuclear nature of the atom. In his studies on radioactivity, he found that the positive charge and mass of the atom are in the nucleus and accounted for the so-called alpha waves. The alpha waves proved to be helium atoms that had lost two electrons, identified as beta waves, whereas the high energy photons were called gamma waves (Hey and Walters, 1987). During a postdoctoral year in England the Danish physicist Niels Bohr became associated for a while with Rutherford and developed a great interest in the question of what made the atom stable. It is at this point that the word harmonics enters the picture. Classical physics provides no explanation of why electrons given off by excited atoms should result in perfectly ordered spectral lines in harmonic patterns (Bernstein, 1991, pp. 28–29). Bohr derived his so-called planetary theory (familiarly referred to as "Bohr's orbits") from his calculations of spectral lines associated with hydrogen. This gave him the idea that electrons circulating around the atom can occupy only certain orbits, with the outermost orbit being at the lowest energy level or so-called "ground state." The nearer the orbit is to the proton, the greater is the energy of a circulating electron. The energy loss with each orbital "step-down" is associated with the emission of a photon.

A new phase in quantum mechanics began in 1923 when Prince Louis de Broglie of Paris proposed in his doctoral dissertation a wave theory for electrons in orbit. He calculated that "electron waves would have wavelengths something like a thousand times smaller that those of visible light" and that the circumferences of Bohr orbits "were just large enough that whole number of electron wavelengths would fit into a given circumference" (Bernstein, 1991, pp. 30–31). He suggested that his wave proposal was subject to experimental testing by diffraction methods. And so it was that his speculations proved to be correct.

In 1925 Werner Heisenberg, dissatisfied with Bohr's scheme[1] of orbits, decided to focus on the atomic spectra resulting from electrons' loss of energy and invented his own brand of matrix mechanics for calculating the associated wavelengths. Then in 1926 Erwin Schrödinger published his wave equation that, as Bernstein points out, "became the heart and soul of quantum theory" and "the basic tool of the modern theoretical physicist, to say nothing of chemist and electrical engineer" (1991, p. 33).

In chemistry the classical example of resonance is Kekulé's famous benzene ring and his introduction of the idea of oscillation in regard to the oscillation of the valences of the six carbon atoms. Further clarification of the structure of benzene is said to have been given by Linus Pauling in 1931 with his introduction of the concept of hybrid orbits. In his influential book *The Nature of the Chemical Bond*, Pauling (1960) credits Heisenberg (his paper of 1926) as responsible for introducing the "concept of resonance" into quantum mechanics and then points out the value of the concept in discussing problems of chemistry. In regard to living systems, Pauling used the theory of resonance to help explain anesthesia, memory, and other conditions.

Szent–Györgyi's (1960) short book, *Introduction to a Submolecular Biology*, is an interesting reference for getting a feel of how quantum mechanics influenced the development of molecular biology. Szent–Györgyi had a special interest in quantum mechanics from the standpoint of electron spin resonance (ESR) as it applies to a transfer of energy in molecular oxygen-reduction mechanisms — oxygenation representing a gain of electrons and reduction a loss. At the molecular level he cited experiments showing that

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[1] Since this paper was written, a commentary has appeared telling of new findings on Rydberg (giant) atoms that indicate that Bohr's orbits may continue to merit consideration (see Amato, 1996).

resonance can make itself expressed at a distance of 17 angstroms. In terms of orbits, the Pauli exclusion principle requires that no more that two electrons can occupy the same orbit. But in addition, the spectral lines indicated a missing factor that could be accounted for if each electron had a spin in opposite directions. Such a spinning electron might be conceived of as a tiny magnet, thereby providing a mechanism for neutralizing forces on two electrons in the same orbit. Commenting that ESR provides "one of the most powerful tools" available to biology (p. 70), Szent–Györgyi gives several molecular examples of how it might help to explain how electrons jump up or down from one orbit to another.

In discussing the action of drugs, Szent–Györgyi placed emphasis on their effectiveness being dependent on their capacity as electron donors. Pursuing this line of research, Snyder and Merril (1965) performed molecular orbital calculations. They were motivated by the recognition that the two classes of hallucinogens have a structural resemblance to tryptamine and to phenyethylamine which in turn are structurally similar to the cerebral neurohumors serotonin and epinephrine. They found a close correlation between the index of electron donation and hallucinogenic potency.

In the discussion of these matters, one finds little or no mention of harmonic frequencies. In the above introductory description of resonance, reference was made to a single string instrument with its fundamental tone and accompanying harmonics. In the light of Pauling's "hybrid orbits" a more apt analogy for what follows might be the keyboard of a piano with its white keys for the standard scale and the black keys for the sharps and flats of other scales. Granted the complexity of the problem, and with all the current emphasis on receptors, would it be naïve to ask, at the subjective level, how a hallucinogenic agent competing off key with the normal harmonics of a naturally occurring substance might result in distortions of perception and other alien symptoms? In terms of our metaphorical piano keyboard, how might the sharps and flats of mood altering drugs affect the ups and downs, say, of manic–depressive illness.

Discussion

In a sense, quantum mechanics has given us a "trialectical" ladder as a replacement for a dialectical ladder in our climb to achieve knowledge. Formerly, in terms of classical physics, the dialectical ladder was constructed of matter and immaterial information. In this respect it was more like a fireman's pole than a ladder. Instead, quantum mechanics has provided us a ladder having two sides, with one side comprised of matter (i.e., particles) and the other side of measurable waves of energy, with immaterial information for rungs in between. A report of the essence of what Niels Bohr said in an ongoing discussion with Einstein would come close to defining the immaterial crystallization of information: "A particle in *reality* has *neither* a position nor momentum. It has only the *potential* to manifest these complementary properties" (Bernstein, 1991, p. 48). In the word "potential" we hear echoes both of Aristotle's "form" (information) and his optimistic philosophy of striving to achieve a higher actuality of being.

Speaking above of Wiener's dictum that "information is information, not matter or energy," I emphasized at the same time that there can be no communication of information without the intermediary of behaving entities. When one includes, as I do, the emanations of the psyche as immaterial information, it is understandable why many people find it upsetting because certain kinds of psychic information can deliver the most powerful punches that can be imagined. It is for this reason that special emphasis must be given to the correlative statement that there can be no manufacture or transmission of information without the expenditure of energy.

As far as the immaterial qualia are concerned, it is really a misinterpretation to state that they do not exist in the entire universe. To say so is to deny the universe in our own brains that Vandervert (1990) had reference to when speaking of "science's erroneous placement of the world outside the skull" (p. 9). To be sure "it would be hard to imagine a more isolated and lonely creature than a human being with the subjective brain imprisoned in its bony shell. The totality of experience is confined within those prison walls. No one else can ever enter or leave that cell" (MacLean, 1992, p. 324). This means that if there is anything about which we can be sure, it is our subjective existence and all we experience. What we gather from our communication with others in the perceived world "out there" is that if something like colors do not actually exist as such in the entire cosmos, they are generated so as to be experienced as such in our viscoelastic brains. And we hypothesize that proteins, the primitive stuff of life with their variegated chemistry and irritable nature provide the essential ingredients and contribute to a neural and partially resonating circuitry that gives them a feeling of reality. Granted that color is only a form of information, we now read in textbooks of genes that code the protein moiety of rhodopsin located in the retinal cones so that a single molecular change gives us the capacity to distinguish red from green.

Finally, in recalling Vandervert's expression about the algorithmic functioning of the brain, it would seem likely that the brain has built into it its total supply of algorithms that can be counted upon for arriving at various solutions. This is of particular interest in regard to mathematics, sometimes referred to as the "queen" of the sciences. The brain seems to have a genetic supply of algorithms for putting everything in the world together right down to subatomic levels. One could not say that math is isomorphic with nature, but it might be close to refer to it as *isoresonant* with nature, recalling some lines form an article by Bryan Bergson (1992):

> Imaginary numbers [draw] the line of demarcation between systems science and reductionist science because imaginary numbers predict the resonant harmonics of systems. In the resonant harmonic mode, systems are open, selectively absorbing energy and information from their environment. The whole is greater than the sum of its parts in this mode, causing emergent phenomena . . . . On the other hand, real numbers characterize closed systems in which the whole is equal to the sum of its parts, constituting the basis of reductionist sciences. (p. 88)

Whether or not mathematicians are born with a greater and different supply of algorithms than other people cannot be known at the present time, but somewhat like musicians they can be imagined as being finely tuned to listen to the music of their equations. But given the seemingly limitless capacity of algorithms to provide solutions, no amount of "listening" will supplant the basic hard work of obtaining a well defined picture of the anatomy and chemistry of the brain's circuitry accounting for its particular species of algorithms. A vital thing lacking, it seems, is an irrefutable frame of reference, by which to measure and judge the nature things. And this brings us back to our focal question as to whether or not the brain can ever become bright enough to recognize its own limitations and not overreach itself with its viscoelastic tentacles.

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