

Brain and the Configuration of Conscious Experience

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Introduction

The Department of Psychology of the University of Vienna has an illustrious history of research on brain electrical activity recorded from humans. Beginning with Hubert Rohracher, continuing with Niels Birbaumer and currently with Herbert Bauer, major contributions to our knowledge of brain function have been made. Throughout this period, spanning most of the century, Giseler Guttman has played a decisive role in the guiding of and collaborating in the experimental work, in setting the context within which this work could flourish, and bringing the results to fruition. I feel honored, therefore, to contribute to this *festschrift* on the occasion of Giseler's 65th birthday.

The electrical activity recorded from the human scalp provides a window to view objectively the brain organization concomitant with an experience of the subject on whom the recording is made. Recently, but only recently, brain electrical recording has been joined by a variety of brain imaging techniques which are employed to a similar purpose. But even these new techniques cannot challenge the temporal resolution provided by the recording of electrical activity.

Ordinarily, we know of another's conscious experience mainly by way of his/her verbal report. However, this verbal report may not match the person's non-verbal behavior. Before the advent of clinical electroencephalography, I had a patient who was admitted to the hospital for bouts of episodic violence. The patient vociferously denied any such behavior. I thought „what a nice way to get out of going to jail.“ The patient died in status epilepticus that night. Electroencephalography would undoubtedly have shown a temporal lobe epileptic seizure.

What might be the difference between the organization of brain electrical activity over the rest of the head during his episodic seizure and that which characterized his brain between episodes? The question remains an open one today and would be worth pursuing.

How then are we to ask questions regarding the organization of brain electrical activity during different conscious states? Guttman et al. (1988) have shown dramatic differences in DC levels during sleep, wakefulness and trance. During sleep the DC level drops precipitously (a prediction made by Sigmund Freud in 1895 – see also Pribram & Gill [Chapter 5], 1976) while during trance the DC level gradually increases.

At the other end of the scale of the organization of brain electrical activity my colleagues and I have found that the squared maximum amplitude of the scalp recorded EEG leaps rapidly about (every 5 msec.) from place to place in the brain. Despite this, stable patterns of activity develop over seconds and minutes. These patterns are idiosyncratic for each individual subject and also for each task for that individual. The patterns can be recognized over months (Pribram, King, Pierce & Warren, 1996).

Figure 1.

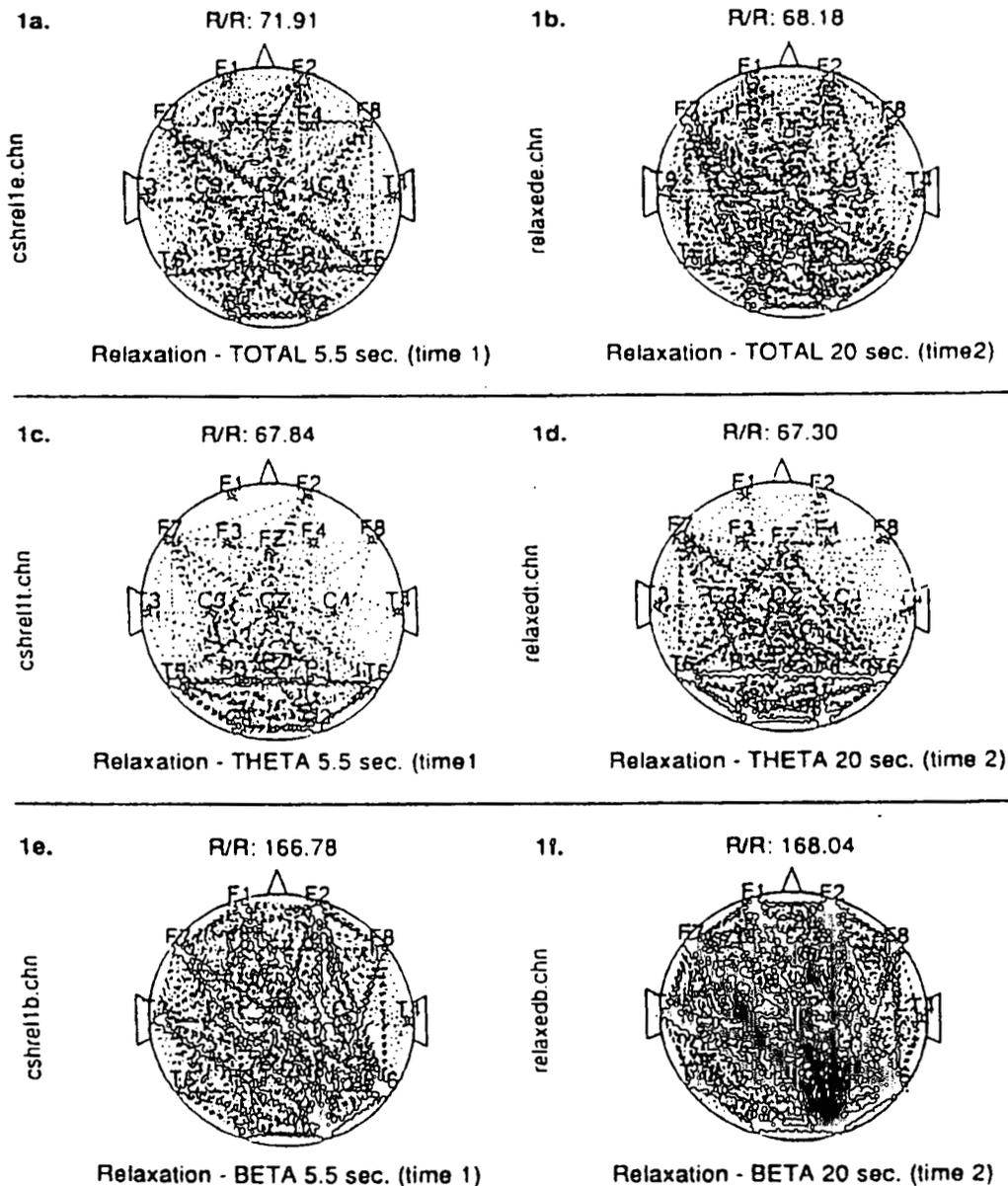


Figure 1: Scalar representation of two different portions (early and late) and two data set lengths (5.5 and 20.0 secs.) Of the baseline condition: Fig. 1a and 1b, total; 1c and 1d, theta; and 1e and 1f, beta.

Figure 2.

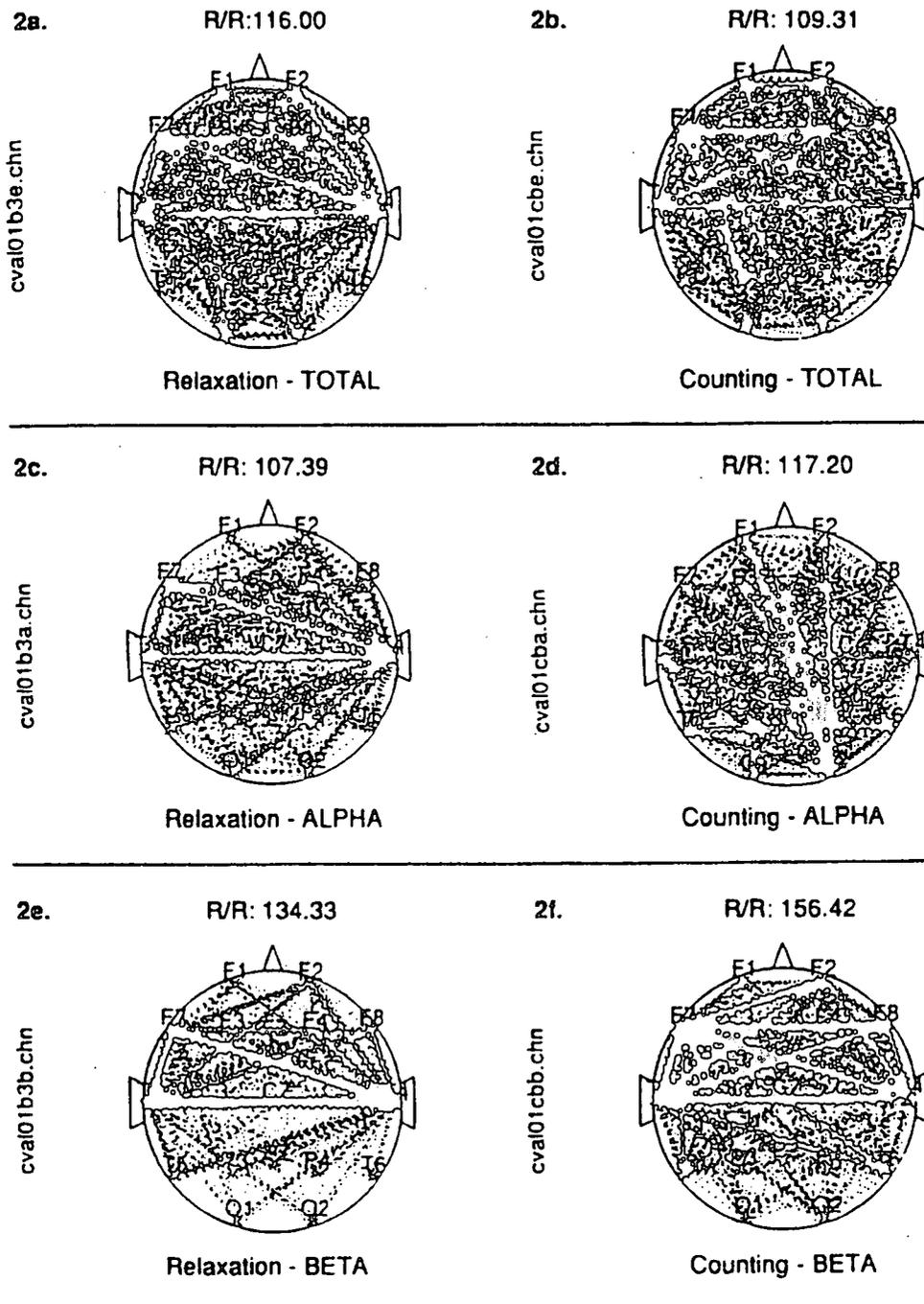


Figure 2: Scalar representations of recrudescence in total, alpha and beta EEG during resting and counting backwards.

Similar long-lasting, recognizable patterns have been found in Vienna relating to specific musical styles by Petsche and Etlinger (1998). Their patterns were obtained by calculating coherences among brain locations.

Currently my colleagues Tom Pierce, Joseph King, Todd Watson and I are comparing not only the rapidity of change in the maximum squared amplitude of the brain electrical activity but also its complexity as measured by factor

analytic and redundancy measures. In general, the older a subject the greater the complexity of his/her brain electrical activity recorded over 128 sites. This relative increase in complexity is manifest especially during the performance of a simple continuous-performance-with-oddball task.

The special utility of brain electrical recording has been tested by using Necker cubes and other reversible figures that induce subjective changes without any physical change in the stimulus itself. The change in configuration of brain activity when a change in subjective awareness occurs provides a key to understanding the brain organization that organizes the monitoring aspects of conscious awareness. Initial reports (Basar-Eroglu et al., 1996) have indicated that the anterior frontal cortex is critically involved. We are examining how that involvement influences the rest of the brain. What do all these research findings tell us about the configuration of conscious experience? First, that we need to distinguish between states of consciousness and the contents of experience, our perceptions. States are most probably determined neurochemically and can be accessed electrically by DC recordings. It is within a particular state that conscious experience becomes configured.

Second, the Petsche and Etlinger experiments indicate that perception, the contents of conscious experience, can be accessed by looking at the dynamics of patterns of coherence. I am especially interested in phase synchronization as this can tell us something about how the perceptual process becomes organized within the context of a particular state. Such work has been begun by Varela and his group in Paris (Rodriguez et al., 1999). Varela has shown phase synchronization to occur at the moment of face recognition in a situation where the stimulus is manipulated to show either a „moon“ or a face. This technique needs now to be explored in reversible figure experiments with the dense array of multiple electrodes.

Finally there is the monitoring aspect of conscious awareness: monitoring in terms of attention, intention and thought. Attention monitors current input; intention monitors prospective output (action); and thought monitors memory. These are all holding (lat. *tendere*) operations that impose delays between sensory input and motor output. When such delays are absent, behavior is automatic and not accompanied by conscious awareness (see Pribram, 1971, Chapter 6).

The Deep Structure of Experience

How then, can we conceptualize the unconscious – conscious distinction? The easiest way, for me, derives from a distinction made by Chomsky regarding a deep *vs.* a surface structure of language. Take a person who is fluent in several languages. While speaking, say French, he/she is totally caught up in the „French frame of reference.“ He/she utilizes this frame to address a deep structure that „contains“ all he/she needs to know in order to cope. Now he/she

shifts to Chinese. Once again the „Chinese frame“ allows him/her to address that *same* deep structure.

From all we know about memory storage, this deep structure is more or less distributed over some extent within each brain system. It is composed of patches within a synaptodendritic processing web – patches that are organized by experience (see Alkon et. al, 1996 for review).

Nerve impulses on the one hand and on the other, graded potential changes (hyper- and depolarization) occurring within a dendritic web are two kinds of processes that can function reciprocally. A simple hypothesis would state that the more quickly the patterns of signals arriving at synapses are transduced into patterns departing from the web via axons, the shorter the duration of the design occupying the processing web. Once habit and habituation have occurred and a throughput has been established within the processing web, behavior becomes automatic. By contrast, the more persistent designs of graded polarizations are coordinated with awareness. The hypothesis carries a corollary: Nerve impulse patterns per se and the behavior they generate are unavailable to immediate awareness. Thus, even the production of speech is „unconscious“ at the moment the words are spoken.

Despite its importance, the distinction between neural circuits composed essentially of axons and processing in the web is rarely acknowledged. On the contrary, neurons are ordinarily conceived to be the computational units of the brain. Thus the majority of processing theories since the seminal contribution of McCulloch and Pitts (1943) have taken the axonal discharge of the neuron, the nerve impulse, as the currency of computation.

However, there is more to processing than these models indicate. Not only are axonal-dendritic synapses that connect neurons subject to local influences in these networks, but innumerable dendro-dendritic synapses provide an initially unconstrained high connectivity needed to account for the spatial and temporal richness of experience (Bishop, 1956; Pribram, 1960; 1971; Schmitt, Dev & Smith, 1976). Presynaptic dendrites are found in many locations in the sensory and central nervous system (see Table, p. 9, in Shepard, 1981). As summarized by Szentagothai (1985, p. 40):

The simple laws of histodynamically polarized neurons ... indicating the direction of flow of excitation ... came to an end when unfamiliar types of synapses between dendrites, cell bodies and dendrites, serial synapses etc. were found in infinite variety ...

Junctions (axodendritic and dendo-dendritic) between neurons in the form of chemical synapses, electrical ephapses, and tight junctions occur within overlapping dendritic arborizations. These junctions provide the possibility for processing within each neuronal circuit as opposed to the mere transmission of signals. The term neurotransmitters applied to chemicals acting at junctions is, therefore, somewhat misleading. Terms such as neuroregulator and neuromodulator convey more of the meaning of what actually transpires at synapses.

Nerve impulse conduction leads to a variety of junctional dendritic electrochemical microprocesses. When a nerve impulse courses down an axon it becomes attenuated both in amplitude and speed of conduction as the axon branches into teledendrons. This is because the amplitude and speed of conduction are proportional to fiber size diameter. Thus, when the nerve impulses arrive at synapses, presynaptic polarizations result. These are never solitary but, as noted, constitute arrival patterns. The patterns are constituted of sinusoidally fluctuating hyper- and depolarizations which are insufficiently large to immediately incite nerve impulse discharge. It is this delay that affords computational complexity and the opportunity for conscious experience.

Neurons are thresholding devices that sample the results of the dendritic microprocess. Discrete packets of nerve impulses are formed for communication and for control of other levels of processing. These packets are more resistant to degradation and interference than the graded microprocess. They constitute the channels of communication not the processing element. The following quotations from *Brain and Perception* (Pribram, 1991) and from Thatcher & John (1977) summarize what appears to be occurring:

The sub- and superneuronal aspect of the dendritic microprocess, its potential to extend beyond the single neuron, provides explanatory power for both older and recently accumulating evidence that brain processes coordinate with perception [and memory] are *distributed* (p. 10).

Fourier's theorem states that a pattern can be decomposed into components representing the relationships among sets of regular (i.e., periodic) oscillations each of which has been further decomposed into oscillations 90° out of phase. Components encode frequency, amplitude, and phase (the relations between oscillations). These components are quantified as Fourier coefficients. The ensemble of such coefficients, when embodied in physical form, becomes palpable as an optical hologram. When coefficients of identical value are connected as in a contour map, the resulting schema is what in the holonomic brain theory is called a holoscape. The contours forming such a holoscape are embodied in the microprocess of polarizations occurring in dendritic networks, thus constituting a sub- and transneuronal manifold. (Pribram, 1991, pp. 28-29)

The spatiotemporal patterning of these cooperative processes ... [involve] ionic shifts ... with extrusion of potassium ions and ionic binding on extracellular mucopolysaccharide filaments. If we focus our attention not on the membranes of single neurons, but upon charge density distributions in the tissue matrix of neurons, glial cells, and mucopolysaccharide processes, we can envisage a complex, three-dimensional volume of isopotential contours, topologically comprised of portions of cellular membranes and extracellular binding sites and constantly changing over time (Thatcher & John, 1977, pp. 305-306).

There is more. Dendrites are fitted with spines that resemble little cilia, or hairs, protruding perpendicularly from the dendritic fiber. These spines have bulbs at their endings, knoblike heads that make contact with teledendrons, the branches of axons and with other dendrites to form synapses. Activity in teledendrons and in dendrites such as those stemming from axonless neurons produce depolarizations and hyperpolarizations in the dendritic spines. The postsynaptic effects are ordinarily invoked chemically and can be modified by other chemicals that act as regulators and modulators (see Candace Pert, 1997 and Jibu, Yasue & Pribram, 1996). The following paragraphs to the end of this section are adapted from *Brain and Perception* (Pribram, 1991), pages 85-87:

Shepherd, Rall, Perkel, and their colleagues (see, e.g., Coss & Perkel, 1985; Perkel, 1982, 1983; Perkel & Perkel, 1985; Shepherd, Brayton, Miller, Segey, Rindsel, & Rall, 1985) modeled the process whereby these postsynaptic events occurring in spine heads interact. The issue is this: The stalks of the spines are narrow and therefore impose a high resistance to conduction (active or passive) toward the dendritic branch. Spine head depolarizations (as well as hyperpolarizations) must therefore interact with one another if they are to influence the action potentials generated at the axon hillock of the parent cell of the dendrite. The interactions (dromic and antidromic) among dendritic potentials (by means of which the signal becomes effective at the next stage of processing) thus depend on the simultaneous activation of both pre- and postsynaptic sites. According to Shepherd and colleagues (1985) several advantages accrue from this form of activation:

First the relative efficacy of distal dendritic inputs would be greatly enhanced. Second, ... the transients within the model spines and dendrites are rapid and do not have the slow, low amplitude time course of synaptic potentials recorded experimentally at a distance from the cell body. Within the distal dendrite, information might thus be processed through precise timing of specific inputs to different neighboring spines ... These precise interactions would greatly increase the complexity of information processing that can take place in distal dendrites. (p. 2194)

The activation of interacting polarizations occurs in parallel, is distributed and discontinuous: „Thus, the active propagation ... was discontinuous and resembled in this respect the saltatory conduction that takes place from node-to-node in myelinated nerve“ (Shepherd et al., 1985, p. 2193).

A prime virtue of this enhanced complexity is the potential for selectivity allowed by such a process:

... it has been shown that [post]synaptic polarization in a spine head can spread passively with only modest decrement into a neighboring spine head. If the neighboring spine is presynaptic, transmitter release could be evoked. (op. cit., p. 2192)

Thus effects on the presynaptic neuron can occur, effects critical to selectivity in learning (see e.g., Freud, 1895; Hebb, 1949, Stent, 1973).

Active spines appear to provide a basis not only for multiply contingent processing of synaptic inputs as outlined above but also for storage of information. The spine stem resistance as a parameter for varying the effectiveness of spine input to parent dendrite has been recognized as a locus for plasticity underlying learning and memory. (Shepherd et al., 1985, p. 2193)

And the spine stems have actually been seen to change their length and thickness under different processing conditions (Perkel & Perkel, 1985).

It is this processing web that is conceived to compose the deep structure which becomes addressed by neuronal circuits that represent the surface organizations of various frames of reference described in the next section. And it is the substrate – the connectivity of this deep structure – that has evolved so dramatically in the human brain cortex:

Density of Neurons in the Cortex of Animals

Type of animal	Neuron density
Mouse	142.5
Rat	105.0
Guinea Pig	52.5
Rabbit	43.8
Cat	30.8
Dog	24.5
Monkey	21.5
Human	10.5
Elephant	6.9
Whale	6.8

Table 1: Neuronal densities in the motor cortex in various animals, based upon Tower and Elliot (1952) and Tower (1954). In Abeles, M. (1991), *Corticonics*. New York: Cambridge University Press, p. 50. *Note:* Neuronal densities are inversely proportional to the amount of connectivity (see Diamond, 1990).

Surface Structures

As noted in the introduction, there can be a dissociation between instrumental behavior and subjective awareness as expressed in verbal report.

Blindsight is such an instance. It occurs as a result of an occipital lesion, almost always limited to one hemisphere and presumably to the primary sensory receiving area of that hemisphere. Subjects with blindsight respond correctly by guessing the location and configuration of a pattern presented visually, but they cannot „see“ such a pattern when it is located in the „blind“ hemifield.

Of course, blindsight is not unique in such dissociations between patients' verbal reports of introspection and their behavior. Another such dissociation occurs after parietal lobe lesions and provides a somewhat clearer view of what patients experience when a still appropriately functioning limb contralateral to the lesion is excluded from awareness. Here is a case history presented by a student in my class who is experiencing such „neglect.“

From Mrs. C.:

I was doing laundry about mid-morning when I had a migraine. I felt a sharp pain in my left temple and my left arm felt funny. I finished my laundry towards mid-afternoon and called my neurologist. He told me to go to the emergency room. I packed a few things and drove about 85 miles

to the hospital where he is on staff (the nearest was 15 minutes away). In the E.R. the same thing happened again. And again, the next morning after I was hospitalized, only it was worse. The diagnosis of a stroke came as a complete surprise to me because I felt fine, and I didn't notice anything different about myself. I remember having no emotional response to the news. I felt annoyed and more concerned about getting home, because I was in the process of moving.

Not until several days later while I was in rehabilitation did I notice strange things happening to me. I was not frightened, angry or annoyed. I didn't feel anything-nothing at all. Fourteen days after I was admitted to the hospital, I became extremely dizzy, and I felt I was falling out of my wheelchair. The floor was tilting to my left and the wheelchair was sliding off the floor. Any stimulus on my left side or repetitive movement with my left arm caused a disturbance in my relationship with my environment. For instance, the room would tilt down to the left, and I felt my wheelchair sliding downhill of the floor, and I was falling out of my chair. I would become disoriented, could hardly speak, and my whole being seemed to enter a new dimension. When my left side was placed next to a wall or away from any stimuli, this disturbance would gradually disappear. During this period, the left hand would contract, and the arm would draw up next to my body. It didn't feel or look like it belonged to me. Harrison moved the left arm repeatedly with the same movement, and a similar behavior occurred, except I started crying. He asked me what was I feeling, and I said anger. In another test he started giving me a hard time until the same episode began to occur, and I began to cry. He asked me what I was feeling, and I said anger. Actually I didn't feel the anger inside but in my head when I began to cry. Not until I went back to school did I become aware of having no internal physical feelings.

I call that arm Alice (Alice doesn't live here anymore) – the arm I don't like. It doesn't look like my arm and doesn't feel like my arm. I think it's ugly, and I wish it would go away. Whenever things go wrong, I'll slap it and say, „Bad Alice“ or „It's Alice's fault.“ I never know what it's doing or where it is in space unless I am looking at it. I can use it, but I never do consciously because I'm unaware of having a left arm. I don't neglect my left side, just Alice. Whatever it does, it does on its own, and most of the time, I don't know it's doing it. I'll be doing homework and then I'll take a sip of coffee. The cup will be empty. I was drinking coffee with that hand and didn't know it. Yet I take classical guitar lessons. I don't feel the strings or frets. I don't know where my fingers are nor what they are doing, but still I play.

How do I live with an illness I'm not aware of having? How do I function when I'm not aware that I have deficits? How do I stay safe when I'm not aware of being in danger?

Ms. C. is obviously intelligent, attending lecture material, asking interesting questions. She is a widowed lady in her mid-fifties, enrolled in adult education, majoring in clinical psychology. She gets around splendidly despite Alice and despite a history of a temporary left hemi-paresis. The diagnosis was damage of the right temporal-parietal cortex confirmed by an abnormal EEG recorded from that location. The damage was not sufficiently extensive to show in a PET scan.

Placed in juxtaposition with blindsight, a simple conclusion can be reached: In humans, there are separate brain systems that organize allocentric (specifically, oculocentric) and egocentric (specifically, body centered) awareness. Damage to these systems „deletes“ awareness but minimally impairs instrumental behavior. When, however, additional brain damage occurs and „denial“ of the impairment in awareness is added, then behavior can become severely maladaptive: A driver of an automobile will run into a telephone pole because he/she is unaware of his/her hemianopic loss of awareness; a patient will inadvertently mutilate his/her neglected limb because he/she is unaware of the neglect. Denial ordinarily occurs when the brain lesion is more anterior and

medial to that which produces simple blindsight and neglect. More on this anon.

The Relation Between Allocentric and Egocentric Experience

Given a separate allocentric and egocentric awareness, how do these relate to each other? I once had a patient who, after a car accident, experienced the onset of sudden dizzy spells during which his visual world would rotate and end upside down. After 10-15 minutes another spell and his world was right side up once more. During the spells, he would brace himself against a wall or hold onto something solid. While his visual world was upside down he could navigate, but cautiously. The spells were becoming fewer and his main complaint was his annoyance that when he saw girls walking upside down, their skirts remained up/down.

I had no chance to examine this patient while his visual world had turned. But recently two undergraduate students undertook to experiment with ocular prisms that inverted the visual world. Following the work of Stratton (1896) and Ivo Köhler (1964) we expected it would take a week or so for the visual world to appear right side up once more after continuous wearing of the prisms. One of the two students became the guide for the one wearing the prisms. As expected, in about eight days, the visual world was „right side up“ for both the students even though the prisms inverted the ocular image for one of them.

What I wanted to know is where did the prism wearer's feet appear to him: within his oculocentric, allocentric space or within his egocentric experience? The answer was forthright: in his egocentric body space. The same with his hands. I then inserted my hand to match his within his egocentric awareness. No problem. But when I held my hand in exactly the same way beyond his reach, it was now upside-down from how it had been for him when „inside“ his egocentric frame. At the border of his reach, things became confused and he simply „couldn't tell“ Mountcastle et. al (1975) have shown in monkeys that cells in the parietal lobe will become active (fire) when a piece of food is displayed within the reach of the monkey even when he is prevented from reaching. When the food is presented beyond reach, no activation is recorded.

To summarize: separate brain systems organize an oculocentric, that is, allocentric „space“ and another, a body centered, egocentric „space.“ These two „spaces“ meet at the boundary of the person's reach. Injury to these systems allows a patient to behave appropriately to environmental circumstance, despite loss of awareness. Additional brain damage can, however, impair behavior. The damage is usually forward and medial to that which impairs awareness. In humans, such damage results in a denial of loss of awareness. In animals, instrumental behavior guided by allocentric or ego-centric cues becomes impaired. It is the „paradox“ – the fact that animals' and humans' instrumental *behavior remains intact despite damage to the „primary“ sensory re-*

ceiving systems and, further, that *behavior is disturbed by more forward lesions* – that led many eighteenth century neuroscientists to mislocate these primary systems (see the disputes between Ferrier, Goltz, Munk; reviewed by Ferrier, 1876).

Object Centered Frames of Reference

Allothetic and egocentric „spaces“ constitute frames of reference within which behavior becomes organized. These two are not the only frames for which separately localized brain systems can be identified. Another set of systems deals with the perception of entities. In vision these are e.g. objects and color; in audition they are e.g. phonemes and tones. Characteristic of entities is that they remain invariant over transformations. For example, object constancy derives from operations that can be described in terms of mathematical group theory (Hoffman, 1978; Pribram, 1991). Color constancy derives from operations on double opponens processing (DeValois & DeValois, 1993; Zeki, 1993).

When we performed an experiment on size constancy, Ungerleider, Ganz and Pribram (1977) showed that monkeys who had their peri- and prestriate cortical systems removed responded to the retinal image size of a pattern (a square) and failed to take the distance of the pattern into account. Extrapolating to object constancy, one would expect that a person would fail to recognize an object when its perspective changed. Turnbull (Turnbull & McCarthy, 1996; Turnbull, 1997; Turnbull, Carey & McCarthy, 1997) describe just such a patient. For this patient, every perspective of an entity entailed its own „meaning“: its separate potential usefulness and relationship to other perspectives.

Other Reference Frames and the Relations Between Them

Taken a step further, other frames of reference can be identified. A categorical and a propositional frame are the most obvious. Just as perspectives are grouped to construct invariances that are identified as entities, so entities can become grouped into categories. Eleanor Rosch (1975) has performed a series of experiments showing how categories are constructed around a kernel, a prototype. And Martha Wilson (1987) has shown, with monkeys, that with respect to visual entities, the inferotemporal cortex is critical to the formation of prototypes. Furthermore, she has provided a model for the operation of this prototype system (see also the review by Pribram, 1991, Lecture 7).

Edelman (1989) has constructed his theory of consciousness around the operations that produce categories. Others (e.g. Freud, 1895; Eccles, 1958) have invoked propositional utterances as the basis of conscious experience. A propositional frame of reference uses entities and categories to construct pro-

posals, naming entities and categories and predicating their relationship to one another.

At this propositional level of experience we can go back and identify the distinction between allocentric and egocentric frames and suggest that this distinction underlies Brentano's (1973) conceptualization of „intentional inexistence“ or as it is usually called, „intentionality.“ Intentionality is the experiencing of aboutness - experiencing the distinction between self and other, where both experiences are about entities, an egocentric me and an allocentric other. Note that when operating in the propositional frame, the ego and allocentric frames are embedded - but note also that the embedding is reciprocal and interpenetrating, not just hierarchical.

This reciprocal embedding can be accounted for by a multidimensional model where dimensions are extended into a more encompassing domain. Hertz named such operations holonomic (*holos*, whole; *nomos*, law), What I have in mind is a shift much as occurs from a representation in Euclidian geometry to Riemannian, or from viewing a scene in two-dimensions to viewing it in three. Essays into such hyperspaces are being explored (see e.g. *Hyperspace*, by Michio Kaku, 1994) in physics but as yet have not been applied to understanding the variety of frames of reference in our conscious perceptual experience and their relation to one another. I believe this to be a most fruitful direction to pursue in consciousness research and wish I had the mathematical and intellectual tools to do so myself. However, this much appears to be necessary: In a massively parallel system, each of the variables (dimensions) can be encoded in its own synaptodendritic domain (or segment of the network) and the entire ensemble scanned simultaneously. Any significant change in any one or in several of the dimensions would change the profile of the ensemble and thus the output to the scanner which determines the frame of reference.

Earlier I noted that with deeper brain damage, a failure in awareness of a loss of awareness results. Such denials can become complex in that they are often situation dependent. Ramachandran (1995) has described in detail such complexities. These context (situation) dependent second order impairments of conscious experience are dispositions that lead to meta-consciousnesses. At the same time, when unimpaired, such dispositions operate outside of awareness and therefore partake of unconscious processing. For that matter, the processing that allows us to experience entities and frames - e.g., allo- or egocentrically, categorically, or propositionally - is always unconscious. We experience only the result of processing as the contents of consciousness. And even these escape intentionality, aboutness, under most circumstances when processing has become automatic. Only when a situation is new as when we are learning to drive, or when automaticity is disrupted do we need to „pay“ attention and become consciously aware that we are processing the contents of consciousness.

Episodic Experience

The brain systems involved in processing novelty and distracting disruption of automaticity are located, in a sense, at the opposite „end“ of the brain from those that process reference frames. These anterior and medially placed systems include the anterior poles of the frontal and temporal lobes and the limbic formations on the medial part of the cerebral hemispheres that connect the two poles (Kaada, Pribram and Epstein, 1949; Pribram 1961). Whereas the posterior convexal systems organize our experience within a complex of reference frames, these frontolimbic systems organize our experience into a „narrative“ composed of episodes and events that occur within these episodes. Again a case history highlights the issues:

TK [an eight-year old boy] had an agenesis of the corpus callosum with a midline cyst at birth. During the first six months of his life, two surgical procedures were carried out to drain the cyst. Recently performed Magnetic Resonance Imaging (MRI) showed considerable enlargement of the frontal horns of the lateral ventricle – somewhat more pronounced on the right. The orbital part of the frontal lobes appeared shrunken as did the medial surface of the temporal poles.

TK appears to have no ability for quantifying the passage of time [what Bergson (1922/65) called *durée*] and no experiential appreciation of the meaning of time units. For example, a few minutes after tutoring begins, he cannot say – even remotely – how long it has been since the session started. He is as apt to answer this question in years as in minutes. He does always use one of seven terms of time quantification (seconds, minutes, hours, days, weeks, months or years) when asked to estimate the duration of an episode but uses them randomly. He can put these terms in order, but does not have any sense of their meaning or their numerical relationships to one another.

When TK returned from a trip to the Bahamas he did recall that he had been on the trip; however, the details he could recount about the trip numbered fewer than 5. His estimates of how long it had been since his trip, were typical in that they were inaccurate and wildly inconsistent on repeated trials. Also, the first five times back at tutoring he stated that he had not been at tutoring since his trip. It appears that he is unable to place in sequence those few past events that he can recall. Nonetheless, he can answer questions correctly based on his application of general knowledge about development, e.g. he knows he was a baby before he could talk because „everyone starts as a baby.“ But, one day he asked his tutor if he knew him when he was a kid, indicating, I think, his incomprehension of the duration of each of these developmental periods and his unawareness of what events constituted such a period for him.

TK is aware that he has a past, that events have happened to him but he cannot recollect those events. He also spontaneously speaks of events in his future such as driving an automobile and dating and growing a beard. He has play-acted on separate occasions his own old age and death. TK is capable of excitement about the immediate future. On the very day that he was going to the Bahamas he was very excited as he exclaimed repeatedly: „I'm going to the Bahamas.“ But when his tutor asked him when, he said blankly: „I don't know.“ He also displayed keen anticipation when one day he saw a helicopter preparing to take off from the hospital. The helicopter engines revved approximately 13 minutes before it took off and TK became increasingly more vocal and motorically active, laughing as he repeated „When's it going to take off?“ He also anticipates future punishment when he is „bad.“ He is aware, on some level, of the immediate future in his constant question „what's next“ which he asks his mother at the end of each activity.

There are a variety of other occasions on which he demonstrated this capacity regarding tempo (as opposed to evaluating the duration of an experience). There have been several breaks in his usual thrice weekly tutoring schedule. Each of four times this schedule has been interrupted, he has run to meet his tutor when he approached rather than waiting inside as he usually does. Also, on these occasions he has typically asked if his tutor missed him. However he states he does not know how

long it has been since his last session, and there was no evidence that he knew it had been longer than usual.

TK compares who walks faster or who draws faster. He has at least a basic sense of sequencing as when he says „I'll take a turn and then you take a turn.“ He also uses terms like „soon“ and „quick“ correctly in conversation. For example, when he wanted to do a drawing at the beginning of a session, and his tutor said that we needed begin to work and he countered „this will be quick.“ Unsurprisingly, he finished his drawing at his normal pace. He somehow seems to use such terms correctly without any experiential appreciation of them.

Modified from Letter written by Richard Ahern
on 19 March 1995, Addressed to Karl H. Pribram
(For a complete description, see Ahern et al., 1998)

Note that TK has no difficulty whatsoever in processing entities or allocentric and egocentric space. His categorical and propositional skills are so well developed that he can use these „semantic“ processes to veil his deficit in „episodic“ processing to some extent.

Episodic processing organizes experience not according to invariant frames (as defined above) but according to covariations among events. Covariations are „parsed“ into episodes, (de)marked at both ends by a „stop“ constituted of an orienting response. Orienting is ordinarily accompanied by visceromotoric arousal, arousal which fails to occur after amygdectomy (Pribram et al., 1979; Pribram, 1991, Lecture 8). In the absence of this visceromotoric arousal, habituation of the orienting response fails to occur and the organism (monkey or human) continues orienting to a repetition of the event. There is no closure; experience is ever novel and never familiar.

Seizures originating around the amygdala produce experiences such as *déjà vu* (a feeling of familiarity in a strange place) and *jamais vu* (a feeling of estrangement in what should be a familiar place). When the seizures are prolonged, an entire experienced episode fails to become encoded into the person's retrievable life story. As an example, one Friday I was accompanied by a young psychologist to my car after having lectured at Napa State Hospital in California. I wished her a happy weekend, and she said that she looked forward to it because of a party the group was having. The following week, she and others of the group were again accompanying me to my car, and I asked how this young lady had enjoyed the party. She answered that she had become overly tired and had fallen asleep and not gone to the party. The others in the group turned to her in surprise – they had all seen her, seemingly enjoying her attendance, „a bit spaced-out because, perhaps she had had a bit much to drink.“ On examination it turned out that the young lady had psychomotor seizures due to an epileptic focus in the region of her medial temporal lobe. In extreme, when this part of the brain is not just temporarily out of commission, but is permanently injured as in TK, experience simply never engenders the feeling of familiarity. What remains is an encoding of experience in reference frames. Interpersonally the impaired transaction feels „strange“ (estranged).

As to how a „stop“ process that marks an episode might operate, I have for years suggested to my laboratory colleagues that the marking could work

somewhat like pagination in a computer program, or setting a bandwidth in a content-addressable holographic-like memory. This would account for the effect of priming and the intrusive retrieval of material by a subject with „memory loss“ due to excessive alcoholism as in Korsakoff's syndrome or in HM who has had both amygdala and hippocampus bilaterally removed (Weiskrantz et al., 1974). The suggestions need to be modelled in a PDP type program to understand more fully the observations.

The Frontal Executive System

To this understanding must be added what we know about the role of the anterior frontal cortex in organizing executive working memory (reviewed by Pribram, 1991, Lecture 10; and 1997). This part of the frontal lobe is anatomically intimately related to the amygdala via the uncinate fasciculus and to the hippocampal formation by way of the adjacent cingulate cortex (Papez circuit: hippocampus → septal region [n. accumbens septi] → mammillary bodies of the posterior hypothalamus → tract of Vicq D'Azyr → anterior thalamic nuclei → cingulate cortex). Essentially, the executive working memory, in conjunction with these limbic structures provides flexibility in processing experienced events. This is accomplished by connections with the rest of the brain to allow monitoring of what is going on – by inducing the delay in processing necessary for the signals in a circuit to engage extended parts of the synaptodendritic web.

An experiment by Fuster (1997) demonstrates this delay function. Using the delayed matching from sample technique, Fuster recorded from neurons in the inferotemporal cortex (part of the reference frame system critically involved in making visual choices; see Pribram, 1991, Lecture 7 for review). He found neurons to be active at all stages of the task – different neurons for different stages. He then temporarily deactivated the frontal cortex by cooling it. Now he found *no* cells active during the delay – only during the initial (sample) and final (matching) stages. Monitoring is thus achieved by virtue of the operations of the anterior frontal cortex but not within it. Rather the anterior frontal cortex apparently actively *facilitates delay* within the circuits that are critical to the performance of a task, making it possible for alterations in that circuitry to occur. In computer language, the executive routine influences (e.g. sets up delays within) ongoing programs and the relations (such as priorities) between them.

In 1966 I described a process by which such delays and priorities become assigned under the heading „The Temporal Hold“ (which is in the same paper in which I suggested the holographic metaphor). The paper was entitled „Some Dimensions of Remembering: Steps Toward a Neuropsychological Model of Memory,“ pp. 179-188:

This „temporal hold“ is assumed to be accomplished through an operation similar to that which gives rise to a temporary dominant focus in the experiments of Ukhtomski (1926), Rusinov (1956),

and Morrell (1961). Without regulation by such a hold mechanism, the organism fluctuates inordinately among possible temporal codes and thus produces only a jumble of arrival patterns. In such circumstances even temporary combinations, i.e., moiré effects necessary to the registration of interference patterns as holograms cannot be achieved. Support for some sort of temporal hold process emanating from the frontolimbic portions of the brain comes from electrical recordings made in man in the form of a contingent negative variation (CNV).

Episodic processing and its working memory component (especially when considered as short term memory) have often been considered to precede semantic processing (what has been discussed here as processing involving reference frames). The clinical evidence presented indicates, however, that episodic and semantic (referential) processing can effectively proceed independently of one another although the brain systems that organize these processes do, of course, ordinarily interact. Thus ordinarily, episodic awareness uses referential systems and referential systems become modifiable by virtue of input from the episodic systems.

Summary

According to the analyses presented here, automatic, reflexive, processing occurs whenever a neural circuit has become thoroughly established with a minimal synapto-dendritic delay. Such referential, phenomenal, processing is semi-automatic but easily accessible to monitoring when shifts among reference frames are initiated between circuits, either „spontaneously“ or by some more organized sensory or central input.

Executive monitoring comes about when frontolimbic processes become addressed, thus producing delays that allow shifts among reference frames in the systems of the posterior convexity. Ordinarily such shifts are included within episodes marked with a beginning and an end (a function of the amygdala) and by re-organizing the frames' serial position (a function of the anterior frontal cortex; see review by Pribram, 1991, Lecture 10). The experiment by Tucker (Tucker et. al, 1995) provides support for this view. Using a dense electrode array to record event-related changes in brain electrical activity, Tucker showed that a response to visual stimulation evoked in the occipital cortex is followed in about 100 msec. by a response (also visual event related) in the anterior frontal cortex only to „reprise“ back to the occipital cortex within another 100 msec. Interaction between the referential and executive systems and between the executive and referential systems (the Fuster experiments) has thus been shown to occur. I wonder how the occipital-frontal-occipital reprise might change in blind-sight patients. Might there still be a back to front to back event-related response? Or would the frontal system have nothing to work with - thus, accounting for the blind part of blindsight? The experiment would be well worth doing.

Epilogue: Philosophical Considerations

The mind-brain relationship developed in this paper is monistic in indicating that another class of orders lies behind the level of organization we ordinarily experience. The ordinary order of appearances can be described in space-time coordinates. The other class of orders is constituted of fine-grain distributed organizations which can be described as potential in the Aristotelian sense because only after „radical“ transformation is their palpability in spatiotemporal terms realized. When the potential is actualized, information (the form within) becomes unfolded into its ordinary space-time manifestation; in the other direction, the transformation enfolds and distributes the information much as this is done by a holographic process. Because work is involved in transforming, descriptions in terms of energy are suitable, and as the form of information is what is trans-formed, descriptions in terms of entropy (and negentropy) are also suitable. Thus, on the one hand, there are enfolded potential orders; on the other, there are unfolded orders manifested in space-time.

Even at the surface level, one has to separate space-time manifestations transformable into one another, from a deeper invariant. For instance, among the instantiations of Beethoven's Sonata (Opus 111) are an initial composition, a score, a performance, a recording on compact disc, and the sensory and brain processes that make for appreciative listening. But in the transitions from one instantiation to the next, a certain relation-structure, in the Russellian (Russell, 1948) sense, remains invariant. This invariant relation-structure is unaffected by the centuries of „performances, recordings and listenings;“ it is the essence of Beethoven's Opus 111.

What remains invariant across all instantiations is abstract structure, „information“, the form within. Thus, according to this analysis, it is Platonic „ideals,“ interpreted as informational structure, that motivate the philosophical dialogue spawned by the information revolution (e.g. „information processing“ approaches in cognitive science) and distinguishes this dialogue from the continuing dialogue between dualists such as Popper & Eccles (1977), materialists such as Dennett (1991) and mentalists such as Searle (1992) and Sperry (1980). These recent dialogues are a vestige of the now waning industrial revolution. The machine was then treated as dead-matter without a trace of life or mind in it. But there is a more penetrating Leibinizian view of the machine based on the functions of computers. This was well articulated by Wiener in the words:

For us, a machine is a device for converting incoming messages into outgoing messages. A message, from this point of view, is a sequence of quantities that represent signals in the message. Such quantities may be electrical currents or potentials, but are not confined to these, and may be distributed continuously or discretely in time. A machine transforms a number of such input messages into a number of output messages, each output message at any moment depending on the input messages up to this moment. As the engineer would say in his jargon, a machine is a multiple-input, multiple-output transducer. (Wiener, 1964, p. 32)

To return to Platonic ideals and their relation to the information constituting a message, Haldane (1934) noted that Platonic ideas are limits of real ideas. Russell's (1948) relation-structures provide the manner by which these limits are attained. According to my perspective, information is conceived as negentropy and thus is formed by the active structuring of massless bosonic radiant energy (see Pribram, 1986 for detailed argument). Radiant energy is not material but can be formed either into material or informational structures. And Jibue, Yasue and I (Jibu et al., 1996) have indicated how ordered water at dendritic membrane surfaces might operate by structuring Einstein-Bose condensations (see also Pribram, 1999).

This philosophical approach is scientifically pragmatic, akin to that practiced by Pythagoreans and early Ionians.¹ I believe that the issue of realism versus idealism will displace mentalism and dualism as well as materialism as a central concern of philosophy. Both the ideal mathematical structures which are essentially informational (and when actively organized, mental) and the material structures in which they are instantiated are „real“ to me. (I have dubbed this position a transformational realism - see the Preface to Pribram, 1991.) Thus, by temperament, I need to be grounded in the nitty gritty of experimental and observational results as much as I am moved by the beauty of theoretical formulations expressed mathematically. In my opinion, therefore, the tension between idealism (the potential), and realism (the appearance) which characterized the dialogue between Plato and Aristotle, will replace that between mentalism and materialism. This change in tension will lead to a new surge of experimentation, observation and theory construction in the spirit of a Pythagorean pragmatism.

Thus, an answer to the questions as to how mind becomes organized by brain rests on our understanding of the lessons of quantum mechanics and especially of that aspect which structures phase is the spectral domain. Although engineers daily use the spectral domain in radar, crystallography and tomography - wherever image processing is important - cognitive neuroscientists are, as yet, only barely acquainted with the pervasive nature of this domain. It is the virtue of Giselher Guttman's leadership of the Vienna group of investigators that they are helping to make accessible, both by experiment and by theory, the rules for „tuning in“ on the spectral domain so that this domain can become more generally understood and scientifically validated. It is critical to our well-being that this domain be accepted as operating by virtue of those specific brain processes that allow us to resonate to universal orders as cognized by Leibniz, Haldane and Wiener and that we are apt to call spiritual.

¹ „The claim of the early Ionians that nature was intelligible was based on their view that the practical arts were intelligent efforts of men to cooperate with nature for their own good.“ (Farrington, 1961, p. 46). This view was shared by C. S. Pierce and N. Wiener.

References

- Alkon, D. L., Blackwell, K. T., Barbour, G. S., Werness, S. A., & Vogl, T. P. (1996). Biological plausibility of synaptic associative memory models. In K. H. Pribram & J. King (Eds.), *Learning as Self-Organization* (pp. 247-262). Mahwah, NJ: Lawrence Erlbaum Associates.
- Ahern, C. A., Wood, F. B., & McBrien, C. M. (1998). Preserved semantic memory in an amnesic child. In K. H. Pribram (Ed.), *Brain and Values: Is a Biological Science of Values Possible* (pp. 277-298). Mahwah, NJ: Lawrence Erlbaum Associates.
- Basar-Eroglu, C., Strueber, D., Kruse, P., Basar, E., & Stadler, M. (1996). Frontal gamma-band enhancement during multistable visual perception. *International Journal of Psychophysiology*, *24*, 113-125.
- Bergson, H. (1922/1965). *Duration and Simultaneity*. Indianapolis: Bobbs-Merrill.
- Bishop, G. (1956). Natural history of the nerve impulse. *Physiological Review*, *36*, 376-399.
- Brentano, F. W. (1973). *Psychology from an Empirical Standpoint*. London: Routledge & Kegan Paul.
- Coss, R. G., & Perkel, D. H. (1985). The function of dendritic spines: A review of theoretical issues. *Behav. Neural Biol.*, *44*, 151-185.
- Dennett, D. C. (1991). *Consciousness Explained*. Boston: Little, Brown & Comp.
- DeValois, R. L., & DeValois, K. K. (1993). A Multi-Stage Color Model. *Vision Research*, *33*, 1053-1065.
- Diamond, M. C. (1990). Morphological cortical changes as a consequence of learning and experience. In A. B. Scheibel & A. F. Wechsler (Eds.), *Neurobiology of Higher Cognitive Function* (pp. 1-12). New York: The Guildord Press.
- Eccles, J. C. (1958). The physiology of imagination. *Scientific American*, *199*, 135-146.
- Edelman, G. (1989). *The Remembered Present*. New York: Basic Books.
- Farrington, B. (1961). *Greek Science, Its Meaning for Us*. London: Penguin Books.
- Ferrier, D. (1876). *The Functions of the Brain*. London: Smith Elder and Co.
- Freud, S. (1895). *Project for a Scientific Psychology* (Stand Ed., Vol. 1, pp. 281-397). London: Hogarth.
- Fuster, J. (1997). Frontal & Temporal Lobe Interaction. In H. Sakata, A. Mikami & J. M. Fuster (Eds.), *The Association Cortex: Structure & Function*. New York: Gordon & Breach Publishing.
- Guttman, G., Goodman, F. D., Korunka, Ch., Bauer, H., & Leodolter, M. (1988). *DC-Potential Recordings during Altered States of Consciousness (Research Bulletin, Vol. 27)*. Vienna: Dept. of Psychology, University of Vienna.
- Haldane, J. B. S. (1934). Quantum mechanics as a basis for philosophy. *Philosophy of Science*, *1*, 78-98.
- Hebb, D. O. (1949/1961). *The Organization of Behavior. A Neuropsychological Theory*. New York: Wiley.
- Hoffman, W. C. (1978). The Lie transformation group approach to visual neuropsychology. In E. L. J. Leeuwenberg & H. F. J. Buffart (Eds.), *Formal Theories of Visual Perception* (pp. 27-66). New York: Wiley.
- Jibu, M., Pribram, K. H., & Yasue, K. (1996). From conscious experience to memory storage and retrieval: The role of quantum brain dynamics and boson condensation of evanescent photons. *International Journal of Modern Physics B*, *10*, 1735-1754.
- Kaada, B. R., Pribram, K. H., & Epstein, J. A. (1949). Respiratory and vascular responses in monkeys from temporal pole, insular, orbital surface and cingulate gyrus. *Journal of Neurophysiology*, *12*, 347-356.
- Kaku, M. (1994). *Hyperspace*. New York: Oxford University Press.
- Köhler, I. (1964). Psychological issues. In G. Kleine (Ed.), *The Formation and Transformation of the Perceptual World*. New York: International Universities Press.
- McCullough, W. S., & Pitts, W. (1943). Logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics*, *5*, 115-133.
- Morrell, F. (1961). Lasting changes in synaptic organization produced by continuous neuronal bombardments. In J. F. Delafresnaye, A. Fessard & J. Konorski (Eds.), *Symposium on Brain Mechanisms and Learning*. Oxford: Blackwell.

- Mountcastle, V. B., Lynch, J. C., Georgopoulos, A., Sakata, H., & Acuna, C. (1975). Posterior parietal association cortex of the monkey: Command functions for operations within extrapersonal space. *Journal of Neurophysiology*, *38*, 871-908.
- Perkel, D. H. (1982-1983). Functional role of dendritic spikes. *Journal of Physiology Paris*, *78*, 695-699.
- Perkel, D. H., & Perkel, D. J. (1985). Dendritic spines - role of active membrane in modulating synaptic efficacy. *Brain Research*, *525*, 331-335.
- Pert, C. (1997). *Molecules of Emotions: Why You Feel the Way You Feel*. New York: Scribner Press.
- Petsche, H., & Ertlanger, S. C. (1998). *EEG and Thinking*. Wien: Verlag der Österreichischen Akademie der Wissenschaften.
- Popper, K. R., & Eccles, J. C. (1977). *The Self and Its Brain*. New York: Springer.
- Pribram, K. H. (1960). The intrinsic systems of the forebrain. In J. Field, H. W. Magoun & V. E. Hall (Eds.), *Handbook on Physiology, Neurophysiology II* (pp. 1323-1344). Washington, D.C.: American Physiological Society.
- Pribram, K. H. (1961). Limbic system. In D. E. Sheer (Ed.), *Electrical Stimulation of the Brain* (pp. 563-574). Austin, TX: University of Texas Press.
- Pribram, K. H. (1966). Some dimensions of remembering: Steps toward a neuropsychological model of memory. In J. Gaito (Ed.), *Macromolecules and behavior* (pp. 165-187). New York: Academic Press.
- Pribram, K. H. (1971). *Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology*. Englewood Cliffs, NJ: Prentice-Hall; Monterey, CA: Brooks/Cole, 1977; New York: Brandon House, 1982. (Translations in Russian, Japanese, Italian, Spanish)
- Pribram, K. H. (1986). The cognitive revolution and mind/brain issues. *American Psychologist*, *41*, 507-520.
- Pribram, K. H. (1991). *Brain and Perception: Holonomy and Structure in Figural Processing*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Pribram, K. H. (1997). What is mind that the brain may order it? In V. Mandrekar & P. R. Masani (Eds.), *Proceedings of Symposia in Applied Mathematics, Vol. 2: Proceedings of the Norbert Wiener Centenary Congress, 1994* (pp. 301-329). Providence, RI: American Mathematical Society.
- Pribram, K. H. (1999). Status Report: Quantum Holography and the Brain. *Acta Polytechnica Scandinavica: Emergence Complexity, Hierarchy, Organization*, *2*, 33-60.
- Pribram, K. H., & Gill, M. M. (1976). *Freud's 'Project' Re-Assessed: Preface to Contemporary Cognitive Theory and Neuropsychology*. New York: Basic Books.
- Pribram, K. H., King, J. S., Pierce, T. W., & Warren, A. (1996). Some Methods for Dynamic Analysis of the Scalp Recorded EEG. *Brain Topography*, *8*, 367-377.
- Pribram, K. H., Reitz, S., McNeil, M., & Spevack, A. A. (1979). The effect of amygdectomy on orienting and classical conditioning. *Pavlovian J. Biol. Sci.*, *14*, 203-217.
- Ramachandran, V. S. (1995). Illusions of body image in neurology: What they reveal of human nature. Decade of the Brain lecture given at the 25th annual (Silver Jubilee) meeting of the Society for Neuroscience. Published in *The Mind Brain Continuum* (Ed. R. Llinas and P. Churchland), MIT Press (1996).
- Rodriguez, E., George, N., Lachaux, J., Martinerie, J., Renault, B., & Varela, F. J. (1999). Perception's shadow: long-distance synchronization of human brain activity. *Nature*, *397*, 430-433.
- Rosch, E. (1975). Cognitive representation of semantic categories. *Journal of Experimental Psychology*, *104*, 192-233.
- Rusinov, U. S. (1956). 20th International Physiology Congress (Brussels), 785 (Abstr.)
- Russell, B. (1948). *Human Knowledge, Its Scope and Limits*. New York: Simon & Schuster.
- Schmitt, F. O., Dev, P., & Smith, B. H. (1976). Electronic processing of information by brain cells. *Science*, *193*, 114-120.
- Searle, J. R. (1992). *The Rediscovery of Mind*. Cambridge, MA: MIT Press.
- Shepard, R. N. (1981). Psychophysical complementarity. In M. Kubovy & J. Pomerantz (Eds.), *Perceptual organization* (pp. 279-341). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Shepherd, G. M., Brayton, R. K., Miller, J. P., Segey, I., Rindsel, J., & Rall, W. (1985). Signal enhancement in distal cortical dendrites by means of interactions between active dendritic spines. *Proceedings of the National Academy of Science*, *82*, 2192-2195.

- Sperry, R. W. (1980). Mind/brain interaction - Mentalism, yes - Dualism, no. *Neuroscience*, 2, 195-206.
- Stent, G. S. (1973). A physiological mechanism for Hebb's postulate of learning. *Proceedings of the National Academy of Sciences*, 70, 997-1001.
- Stratton, G. (1896). Some preliminary experiments on vision without inversion of the retinal image. *Psychological Review*, 3, 611-617.
- Szentagothai, J. (1985). Functional anatomy of the visual centers as cues for pattern recognition concepts. In D. Chagas, R. Gattass & C. Gross (Eds.), *Pattern Recognition Mechanisms* (pp. 39-52). Berlin: Springer.
- Thatcher, R. W., & John, E. R. (1977). *Functional Neuroscience, Vol. 1*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Tucker, D., Potts, G. F., Liotti, M., & Posner, M. I. (1995). *Recursive Event-Related Potentials Over Human Visual Cortex*. Publication of the Brain Electrophysiology Laboratory, Department of Psychology, University of Oregon, Eugene, OR 97403.
- Turnbull, O. H. (1997). A double dissociation between knowledge of object identity and object orientation. *Neuropsychologia*, 35, 567-570.
- Turnbull, O. H., Carey, D. P., & McCarthy, R. A. (1997). The neuropsychology of object constancy. *Journal of the International Neuropsychological Society*, 3, 288-298.
- Turnbull, O. H., & McCarthy, R. A. (1996). When is a view unusual? A single case study of orientation-dependent visual agnosia. *Brain Research Bulletin*, 40, 497-503.
- Ukhtomski, A. A. (1926). Concerning the condition of excitation in dominance. *Novoe y refleksologie i fiziologii nerviosyemry*, 2, 3-15.
- Ungerleider, L., Ganz, L., & Pribram, K. H. (1977). Size constancy in rhesus monkeys: Effects of pulvinal, prestriate, and inferotemporal lesions. *Experimental Brain Research*, 27, 251-269.
- Wiener, N. (1964). *God and Golem, Inc.: A Comment on Certain Points Where Cybernetics Impinges on Religion*. Cambridge, MA: MIT Press.
- Weiskrantz, L., Warrington, E. K., Sanders, M. D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, 97, 709-728.
- Wilson, M. (1987). Brain mechanisms in categorical perception. In S. Harnad (Ed.), *Categorical Perception* (pp. 387-417). New York: Cambridge University Press.
- Zeki, S. (1993). *A Vision of the Brain*. Oxford: Blackwell Scientific Publishing.