NONLOCAL NEUROLOGY:

BEYOND LOCALIZATION TO HOLONOMY

G. G. Globus, M.D.

C. P. O'Carroll, M.D.

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Attribute to: Department of Psychiatry, College of Medicine, University of California Irvine Irvine, CA, USA

Corresponding author: Gordon Globus, M.D.

Email: ggglobus@uci.edu

Address: 400 Newport Center Dr., # 701, Newport Beach, CA, 92660 USA.

Phone: (001) 949 759 9515 (office), 949 275 1633 (cell), 888 474 5034 (fax)

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ABSTRACT

The concept of local pathology has long served neurology admirably. Relevant models include self-organizing nonlinear brain dynamics, global workspace and dynamic core theories. However such models are inconsistent with certain clinical phenomena found in Charles Bonnet syndrome, disjunctive agnosia and schizophrenia, where there is disunity of content within the unity of consciousness. This is contrasted with the split-brain case where there is disunity of content and disunity of consciousnesses. The development of quantum brain theory with its nonlocal mechanisms under the law of the whole ("holonomy") offers new possibilities for explaining disintegration within unity. Dissipative quantum brain dynamics and its approach to the binding problem, memory and consciousness are presented. A nonlocal neurology armed with a holonomic understanding might see more deeply into what clinical neurology has always aspired to: the patient as a whole.

INTRODUCTION

Neurology has made great advances based on traditional ideas of localization and hierarchy. The concept of "nonlocality," which is central to quantum physics, seems utterly foreign and anyway unnecessary to neurological concerns. Nonlocality refers to the "entanglement" of different systems which cannot be considered as independent entities even though spatially distinct. According to Bell's celebrated theorem,[1] nonlocal processes are characteristic of most natural processes.[2] Experimentally confirmed entanglement[3] is not a function of signals passing between the separate systems, not even at the speed of light. (Einstein famously called entanglement "spooky action at a distance.") Nothing could be further from the dynamics of networks of neurons having local connections and organized into richly interconnected neural systems.

Recent work in quantum brain theory, however, has opened the possibility of nonlocal mechanisms[4-6] which may be of relevance to neurology[7] and psychiatry.[7-11] The idea to be made use of here is *not* that there is a finer quantum level beneath the neural networks, a level at which information is processed with quantum degrees of freedom. We do not apply to neurology the idea that the brain is a quantum computer but a more radical proposal, viz., that quantum degrees of freedom allow another "holonomic" type of functioning whose laws are altogether different. (Bohm's term "holonomy" means literally "law of the whole."[12]) Instead of a "centrencephalon,"[13] or some kind of "global workspace,"[14] or "emergent properties"[15] at the highest level, there are global operators near-instantaneously transforming brain systems. The goal here is to thematize a "nonlocal neurology" which does not go against current neurology but instead supplements it and opens a path to new ways of functional thinking that are clinically relevant.

Our approach is "neurophenomenological" in this sense: Phenomenology as a discipline is concerned with the systematic description of the fine-grained character of experience as such and neurophenomenology with the neural correlates of phenomenological description. Clinical neurology has traditionally been unself-consciously phenomenological but in the contemporary framework prizes objectivity. We shall draw below some clinical neurophenomenological distinctions which turn out to have powerful theoretical implications.

Although systematic proposals that brain functioning has quantum degrees of freedom have been around for over forty years,[16,17] the concept admittedly remains at the fringe of current thought in brain science. Recently quantum brain theory has at least been taken seriously enough that thoughtful assessments of it have begun to appear.[18-21] The critiques have been mainly directed at the most widely known version of quantum brain theory, which is due to Hameroff and Penrose.[5,22,23] The central objection raised is that any quantum "wave function" could not persist long enough to be relevant to brain functioning but would instead quickly collapse in the hot, wet and noisy brain environment which is so inimical to quantum preparations. So, it is argued, putative quantum brain mechanisms would not function at a time scale at all relevant to brain science. Further against exploration of quantum explanation in neurology, there is no contemporary "crisis"[24] in its theoretical framework that would motivate an interest in revolutionary foundations. Any discussion of nonlocality would seem to be well below the radar of today's neurology, a situation that we seek to mitigate.

THE UNITY OF CONSCIOUSNESS AND THE BINDING PROBLEM

The critical thrust of our discussion is organized around what is called in philosophical circles "the unity of consciousness," whose provenance is Cartesian and Kantian.[25] The unity of consciousness is related to the "binding problem," which is a class of problems that have to do with how information processing in different brain locations is integrated into perception of objects.[26] The unity of consciousness is that all objects, after different sets of information have been bound to form the objects, and whatever the modality (e.g. perception, thought, affect), all participate in a grand "super-binding" which results in a single, unified, phenomenal field.[27,28]

Wolf Singer has well formulated the super-binding problem and the unity of consciousness.[29]

> A unique property of consciousness is its coherence. The contents of consciousness change continuously, at the pace of the experienced present, but at any one moment all the contents of phenomenal awareness are related to one another, *unless there is a pathological condition causing a disintegration of conscious experience*. This suggests a close relation between consciousness and binding. It seems that only those results of the numerous computational processes that have been bound successfully will enter consciousness simultaneously. (p. 67, italics added)

In exempting pathological conditions from discussion of the unity of consciousness, Singer sweeps them under the rug, whereas such conditions provide the very incision for the present discussion.

The super-binding of participating systems in nonpathological circumstances has been explained in terms of a central information exchange called the "global workspace." [14,30-34] The global workspace gets information from and feeds back information to the participating neural systems. There is nothing passive about the global workspace; it is no "Cartesian theater"[35] but a dynamical, richly interactive, working memory which broadcasts messages to all participating systems. At any moment there are of course many modular brain systems which are active in parallel and operate outside of consciousness. It is the global availability of information through the dynamical workspace that is experienced as consciousness.

An alternative conception is the "dynamic core" hypothesis of Tononi and Edelman,[36] which has been further developed as a "scale-free dynamics" of hierarchical self-similarity.[37] The dynamic core is a functional cluster of participating groups of neurons having high complexity (consisting in many possibilities). These participating neuronal groups which cluster through their interactions are widely distributed. The integration of the dynamic core takes place through strong, rapid, reciprocating and repeated "re-entrant" interactions. On this formulation the binding mechanism which achieves the unity of consciousness is re-entry.

It is noteworthy that both the global workspace and the dynamic core replace the traditional static idea of hierarchy in which consciousness sits at the top. Hierarchy is in effect succeeded by density of interaction, which might be called "functional reciprocation." *Yet these new theories remain at heart localizing* … having a "workspace," a "core" … whereas the present formulation of binding will be *nonlocal*, which entails a paradigm shift indeed.

DISUNITY OF CONTENT WITHIN THE UNITY OF CONSCIOUSNESS

Neurology is so successful in its endeavors that lacunae in explanation are easily passed over. There is for neurology nothing like a menacing "ultraviolet catastrophe," which was an unexplained fact having to do with black body radiation that hung over classical physics at the turn to the twentieth century, until Planck formulated his quantum of action and inaugurated quantum physics. One has to look to the "margins"[38] of neurology for signs of trouble that might solicit neurology. The focus here will be on Charles Bonnet syndrome, disjunctive agnosia and the pathognomonic "splitting" of schizo-phrenia, where disunity of content within the unity of consciousness are not easily explained by classical brain theory but turn out amenable to quantum explanation.

Charles Bonnet syndrome (CBS)

The sometimes cartoon-like worlds of Charles Bonnet syndrome may appear in retinal scomata, which are otherwise dark. Typically the hallucinated world appears within the central scotoma of bilateral macular degeneration (though lesions at any level of visual processing can produce the phenomenon[39]). A "cartoon world" is a simplified world, resembling world, preserving world's abstract structure but in a less richly differentiated manner, such that the cartoon world is populated by simple stick figures. The cartoon world decreases ambiguity, that is, is more defined.[40] When a region of the visual cortex is not driven by retinal input, it may self-organize on its own, in simplistic cartoon form. Inside the scotoma there is one perhaps fantastic world and outside the scotoma in peripheral vision there is another ordinary world. Thus the scotoma in CBS can be a cartoon world within a world.

The patient with this syndrome has no difficulty in distinguishing the visual hallucination from the world. The patient described by Ramachandran and Blakeslee[41] (p. 108) reports figures as line drawings filled in with uniform color that are absolutely stationary, without depth, shading or curvature. There is an ordinary humdrum world and an independent and entertaining scotoma world. The cartoon world and the world, despite their disunity, appear to one consciousness. That is, they are dis-integrated worlds *within the unity of consciousness*.

Certainly there are manifestations of CBS in which the hallucinated world is fully integrated with the ordinary world. The patient sees “golden chariots” moving across the bed-curtain or water spilled right there on the floor which disappears when an attempt is made to mop it up.[42] Ramachandran’s patient hallucinates a monkey sitting in the neurologist’s lap![41] Such integrated CBS hallucinations are not the present focus, which is the neurophenomenologically distinct dis-integrated hallucination within consciousness along with the phenomenal world. There is a cartoon world and an ordinary world within the same consciousness, and these worlds do not fit. There is disunity of content within the unity of consciousness. The Charles Bonnet hallucination manifests dis-integration. We will shortly point out the difficulty CBT has in explaining such a clinical phenomenon.

A case of disjunctive agnosia

In disjunctive agnosia there can be failure in integrating what is seen with what is heard within the unity of consciousness. The Charles Bonnet phenomenon lies within one sensory mode—the visual—whereas disjunctive agnosia is cross-modal. Here is a patient reported by Prof. O. L. Zangwill.[43]

> Patient: It sounds quite absurd but there were two distinct things. One was that so and so was speaking to me and I could hear and understand what he said; two, that he was standing in front of me and I could see his mouth moving, but I noticed that the mouth moving did not belong to what I heard any more than a – than one of the old talkie pictures would make sense if the voice tape had been the wrong tape for the conversation.
>
> . . .
>
> Interviewer: Was this a failure to localise the source of the voice?
>
> P: No. No. It was as though they were two different things.
>
> I: They didn't belong together.
>
> P: Didn't belong together at all.

Here again there is disunity, dis-integration between what is seen and what is heard within the unity of one consciousness.

The splitting of schizophrenia in thought insertion

A similar problematic appears in a clinical neuropsychiatric phenomenon characteristic of schizophrenia: the "splitting" (*die Spaltung*) of schizophrenia, as described by Bleuler.[44] Splitting is well illustrated by the Schneiderian first rank symptom of "thought insertion." The same phenomenon was also described by Clérambault[45] who called it "mental automatism" (*automatism mentale*). Here is a phenomenological description of thought insertion.

> *He* is experiencing thoughts that seem to be generated by others. His phenomenology is this: he has a sense of ownership for the stream of consciousness which is impossible to misidentify (and is, in fact, in no need of identification, since it is his own), but into which are inserted thoughts for which he has no sense of agency.[46] (p. 231)

There is someone else—some alter subjectivity—that is thinking one stream of the patient's thoughts. Thought insertion is distinguished from "thought control."

> [T]hought insertion involves more than merely supposing that another agent has influenced, or caused, one's thinking: it involves the impression that a thought occurring in one's own stream of consciousness actually is someone else's thinking… . It is remarkably odder than believing that another person is somehow influencing or directing our thinking.[47] (p. 142)

Thought insertion strikingly demonstrates a disunity of content within the unity of a single consciousness.

A FAILURE OF CLASSICAL BRAIN THEORY

How might classical brain theory (CBT) explain disunity of content within the unity of consciousness? If there were some "centrencephalon"[13] which could house a "Cartesian theater,"[35] then disunity of content might be easily accounted for. The disunity would just be put in to the passive central system. But of course the centrencephalon notion does not fit with what neuroscience has discovered so a passive Cartesian theater displaying dis-integrated contents is not explanatory of disintegration within unity.

The brain is well known to be a system of richly interacting subsystems. Rich interconnectivity characterizes different levels of system analysis all the way down to the neuronal level. *The brain cannot but be integrated because functional connectivity is the* *principle of its operation.*[48,49] If there were a true schism, then each of the systems would have its own integration.

The conventional brain has been formally characterized as a nonlinear dynamical system of neural networks.[48] ("Nonlinear" simply implies here that output is not slavishly proportional to input.) Although its workings might be *simulated* by a powerful logical computer, the dynamics are not governed by rules but by an energy minimization principle (Hamiltonian "least action"). The system spontaneously evolves so as to reach minimum energy states called "attractors." Attractors are visually represented as valleys in the topography of the system's N-dimensional state space. (For ease of visualization N = 3.) The system self-organizes away from "repellors" (peaks) and settles into state space attractors (valleys). State space topography is not static but modulated ("tuned') moment to moment.[50] The self-organizing brain is founded in least action and moves rapidly from attractor to attractor in the dynamical landscape. As the noise level rises the system state can be jostled off the attractor and find a new settlement. The system lives at the edge of chaos and so its states have fluidity.[51]

The least action is obtained when the system participants are harmoniously engaged, having maximized agreement.[48] Neural networks naturally find a good consensus that achieves self-consistency. It is the nature of nonlinear dynamical neural networks that they do not tolerate disunity but make the best compromise possible. It follows that nonlinear dynamical neural network theory does not explain disunity of contents within the unity of consciousness found in Charles Bonnet syndrome, disjunctive agnosia and thought insertion. Nonlinear brain dynamics might explain the unity of consciousness but not the dis-integrated contents within conscious unity found in such clinical conditions.

The unity of consciousness is not at all impaired in CBS. The world and the cartoon world are of a single phenomenal field. By way of contrast, it is the very unity of consciousness that is destroyed in the split brain case. After the corpus callosum is surgically cut or in cases of callosal agenesis, there are two consciousnesses, each with its own unity,[52-54] but in CBS there is one consciousness with contentual disunity: a well-defined cartoon world within the scotoma and an ordinary world outside of it.

The issue highlighted here is: Do classical brain theories provide an explanation for the disunity of content within the unity of consciousness in the cases under consideration? The nonlinear dynamical brain is believed to process information, not so much like a logical computer does but according to an *optimization principle* (which a computer might logically simulate). A certain quantity is minimized—the “computational energy” is spontaneously reduced—under the Hamiltonian “least action” principle. Least action is when participants in the system are most harmonious. Conscious content settles out of consensus in the process of what is called “self-organization” by neural networks.[48] One self-organized consensus, one conscious content, one phenomenal world. Nonlinear brain dynamics demands a unity of content within the unity of consciousness and so is inconsistent with such clinical phenomena as Charles Bonnet syndrome, disjunctive agnosia and thought insertion.

Now Edelman and Tononi’s “dynamic core” theory of brain functioning is not dependent (at least not explicitly dependent) on least action but on “coherence” between neuronal groups.[36,55,56] Ongoing re-entrant interactions between widely distributed brain regions generate a coherent neural process that underlies conscious integration. Different neuronal groups corresponding to different modalities are rapidly and effectively bound together into a “functional cluster.” It is this integrative process based on reentrant signaling and coherence of neuronal groups that would account for the unity of consciousness. Edelman and Tononi have suggested that “defective interactions among distributed brain areas may underlie certain dysfunctions of conscious integration such as those seen in schizophrenia” (p. 391).[55] They propose that the dynamic core can split so that multiple cores might coexist in the same subject.[36]

Then the dynamic core theory of splitting runs into the same explanatory problem as nonlinear brain dynamics. The dynamic core is identified with consciousness, and so with multiple cores there would be multiple contents of multiple consciousnesses. But as we have illustrated above, there are multiple dis-integrated contents within the unity of one consciousness, so dynamic core theory is inconsistent with clinical neurology. In the split-brain case there would be two dynamic cores indeed but not in Charles Bonnet syndrome, disjunctive agnosia and schizophrenia.

Global workspace theory runs into the same type of explanatory difficulty. This theory also does not explicitly depend on a least action self-organizing principle but on a “dynamical mobilization” determined by top-down activation of workspace neurons.[57] A subset of workspace neurons are intensely activated at any moment while the rest are inhibited, so that at any given moment only a single global representation is sustained.[57] The particular set of activated neurons allows many different regional brain systems to exchange information in a global and flexible manner. It is the global availability of information made possible by the workspace that correlates with the conscious state.[14]

Though the descriptor “global workspace” provokes a contrasting image to “dynamic core,” such theories have the same kind of problem in explaining disunity of content within the unity of consciousness. The single global representation at any moment is the content of consciousness. For those contents to be split, as in the clinical illustrations provided above, consciousness would have to be split too, but as shown, the unity of consciousness is maintained despite contentual disintegration. This explanatory failure on the part of nonlinear brain dynamics, dynamic core theory and global workspace theory cracks opens the door to at least considering a revolutionary paradigm of brain functioning.

BACKGROUND FOR QUANTUM BRAIN THEORY

The father of the computer, John von Neumann, did not believe that the brain works like one.

> Brains lack the arithmetic and logical depth that characterize our computations ….
>
> We require exquisite numerical precision over many logical steps to achieve what brains accomplish in a very few short steps.[58] (p.63)

Of course with brute computational power (up to three billion cycles/second) brain functioning might be logically *simulated* but the brain does not actually work that way. Penrose argued from a consideration of Gödel's theorem that thought itself cannot be computational in any computer sense.[59,60] However technology dominates the imagination in different historical epochs[61] and so even when the brain is believed to have quantum degrees of freedom in its functioning, the conception is still of quantum *computation*. That the idea of quantum computers has been around for over 15 years[62] without substantial progress in realizing practical machinery has not dimmed the conviction that the brain just wetly computes, whether by classical or quantum mechanisms. An additional and crucial function will be suggested below.

Quantum computation does introduce the idea of computing with waves (in the form of superpositions or interferences) and waves provide a point of contact with a historical leitmotif in brain theory. Karl Lashley[63] spoke somewhat vaguely of wave interference and his student, Karl Pribram,[64,65] fleshed out the idea substantially in his development of holographic brain theory (inspired by Gabor's Nobel prize winning work on holography). Pribram proposed that memory is like a hologram in which many memory traces are superposed in each small region of a neural wave interference pattern. (As the region becomes very small, the resolution of the image decreases.) Recovery of a memory is like producing an image by transillumination of a hologram. The terminology of the physicist David Bohm[7] is convenient here: the memory trace is "enfolded" or "implicated" to the hologram and "unfolded" or "explicated" from the hologram in a spontaneous dynamics that Bohm called the "holomovement."

Pribram's holographic brain theory with its wave logic never caught on, and its natural evolution to quantum brain dynamics, following the lead of Jibu and Yasue,[66-70] has not been widely discussed. Quantum brain dynamics has been further developed by Vitiello [4,71,72] to a *dissipative* quantum brain dynamics in which thermodynamical principles come into play. We will show below that this theory naturally accounts for disunity of content within the unity of consciousness, which the present discussion features, but first we present dissipative quantum brain dynamics.

A BRIEF SKETCH OF DISSIPATIVE QUANTUM BRAIN DYNAMICS

Dissipative quantum brain dynamics (DQBD) is a highly elaborated theory which admits quantum degrees of freedom to brain functioning and thereby opens novel ways of explaining phenomena of concern to neurology. Only a rough sketch of DQBD can be provided here with emphasis on three novel mechanisms: (1) A second form of communication within the brain: a nanolevel filamentous protein web pervading neurons and neuroglia. (2) A parsimonious explanation of memory and forgetting consistent with well-established physical principles is offered by DQBD.[4,71,72] (3) Contentual schisis within the unity of consciousness fits with DQBD.[8]

The nanolevel web and gap junctions

Jibu and Yasue emphasize quantum properties of a nanolevel web within neurons and neuroglia made up of protein filaments, which is a kind of Golgian reticulum of uninterrupted filaments.[69] This intracellular space is continuous with the web-filled extracellular space via proteins embedded within cell membranes. This pervasive filamentous web which does not respect neuronal and glial boundaries is the brain's second communication system. Its innermost reach is the water-filled microtubules. Signals propagate rapidly through the filamentous web, with no synapses to plow through, which makes it much faster than the classical communication system with all its synaptic delays. The nanolevel filamentous web is the communication system of the cryptic holonomic brain that Jibue and Yasue characterize in terms of "quantum brain dynamics."

The proposal is that there is soliton signaling through the filamentous web, propagating at speeds up to the limit at which sound travels, without synaptic delay (since the web disregards the membrane barrier as it passes through membrane proteins). Solitons are self-sustaining pulse-like waves travelling in nonlinear systems that do not disperse in space but act as quasi-particles.[73-79] They are generated only at the ends of protein chains and are induced by ATP hydrolysis energy release. The same α-helic protein structure that supports soliton formation and propagation also characterizes transmembrane glycoproteins which solitons readily pass through to protein structures in the extracellular space.

Soliton particles are accordingly local expressions of a whole; the whole acts as if it were a particle, hence the term "quasi-particle." Solitons can travel long distances in biological systems with little loss of energy or structure and are robust against thermal perturbation at body temperature.[80,81] The cryptic brain at the nanolevel uses soliton messaging at velocities up to that of sound which serves to integrate brain functioning.

Hameroff's proposal utilizes gap junctions between neurons and glia in which there is direct cytoplasmic continuity between cells so that "fleetingly shifting dendritic webs" (p. 81) are formed by lateral connections[82] These dendritic webs according to Hameroff form topological syncytia which serve to control neurocomputational elements. Quantum information processes in microtubules

> extend through gap junctions and in principle throughout brain-wide dendritic webs. Thus, dendritic integration webs may unify (on a brain-wide basis) fine-scale processes comprising consciousness.[82] (p. 85)

However Fukuda is emphatic that the continuous network of gap junction-linked dendrites does *not* work as a huge syncytium since it does not extend beyond 1 mm, which casts doubt on Hameroff's proposal.[83]

The nanolevel web and perhaps gap junctions explain why electrophysiological signals coherent over wide cortical regions are found with near-zero correlation lag after a stimulus is delivered.[84-86] The spread takes place too fast to be accounted for by local mechanisms.

> [t]he electric field of the extracellular dendritic current and the magnetic fields inside the dendritic shafts appear to be much too weak and the chemical diffusion appears to be much too slow to be able to fully account for the cortical collective activity observed in the laboratory. … Classical statistical mechanics and short range forces of molecular biology, *although necessary*, do not seem to be completely adequate tools. Therefore, it appears to be necessary to supplement them with a further step so to include underlying quantum *dynamical* features.[84] (p. 12)

Freeman and Vitiello offer a way to think about brain mechanisms which surpasses Pribram's holographic brain theory by introducing quantum degrees of freedom to the wave logic.

Total memory and forgetting

A second new conception offered by quantum brain dynamics (QBD) is a counter-intuitive theory of memory. In QBD *memory is total*.[69] At every moment a new memory formed convolves with all previous memories into a total memory. The total memory is a wave superposition. Over time with random quantum tunneling the trace is diminished. Forgetting dilutes the superposition that is total memory.

Although the idea of a total memory sounds bizarre at first blush, it is based on fundamental physics. There is an infinite resource for memory, an indifferent plenum of undifferentiatedness that physicists call "symmetry." Whereas Pandora's box is a classical plenum of actual differences, symmetry is a plenum of possibility. The possibilities are enfolded to the whole; they are implicate orders within each region of the whole.

The quantum theory of total memory developed by Jibu and Yasue[69] exploits the properties of the minimal energy state, called the "ground" or "vacuum" state, where there is a minimally energetic froth of quanta. The ground states of certain materials are of the symmetry-breaking kind. Consider quanta that are "electric dipoles," with a dipole moment vector arrow extending from the negative to the positive pole. (Water molecules and many biochemical molecules are dipoles. To simplify this discussion it is restricted to the water electric dipole field.) When the system is in higher energy states the dipole moment vector arrows point every which-way. But in the ground state the arrows all point in the same direction. They are "correlated," "coherent." The symmetry of pointing every which-way is broken in the vacuum state of the water dipole field. Now all the vector arrows are aligned and momentary deviation of one will spread like a wave across the others. (Jibu and Yasue use the image of synchronized swimmers.) The vacuum state of the water electric dipole field is of the symmetry breaking kind.

Sensory input imposes order on the brain. The input representation dissipates its energy and falls into the vacuum state, breaking its symmetry and forcing a vehicle for memory trace. Symmetry is a conserved quantity in physics.[87] As a consequence of Noether's theorem the symmetry broken in the ground state by input must be preserved. The conservation of broken symmetry is through the formation of massless bosons that condense over macroscopic regions. These are called Nambu-Goldstone bosons (N-G bosons). (Nambu shared the 2008 Nobel Prize in physics for his work on symmetry-breaking.) An N-G boson condensate forms in the ground state, in which the quanta are coherent over 50 micron or larger regions (in the case of water molecules). The N-G condensate provides a trace of sensory input, conserving the symmetry the particular sensory input has characteristically broken.

Now what has been called above "the" vacuum state is in fact an infinity of vacuum states: the "θ-vacua." The transformations between θ-vacua are governed by the Bogoliubov transformation which carries points to superpositions. The θ-vacua are "unitarily inequivalent," which means that their transformations are irreversible. Time can only flow in one direction. The continually updated total memory (which becomes riddled with erasure by quantum tunneling) is by Bogoliubov transformation of a θ-vacuum with conservation of broken symmetry. In this fashion quantum brain dynamics offers a theory of memory to back up its theory of communication.

In brief: Feynman's quantum electrodynamics (QED) is very well established physics and Jibu and Yasue observe that DQBD is at heart just the QED of the water dipole field coupled with the nonlinear dynamics of molecular chains supporting soliton signaling.[70] Rather than being some wild speculation, quantum brain theory is a natural extension of conventional quantum field theory to dissipative biological circumstances. What is brought out presently is the implications for neurology which might move beyond localization to nonlocality and holonomy.

Consciousness and the between-two

The development of quantum brain dynamics has provided a new theory of communication within the brain, its memory, and forgetting. A third innovation to be brought out here is its account of consciousness. In quantum brain dynamics consciousness was explained as the recovery of memory traces, when repetition of sensory input signals activates the N-G traces recorded in the vacuum state. This is a very limited conception of consciousness, which is truncated to memory recall. Vitiello[4,71,72] proposed an enriched version of QBD called "dissipative quantum brain dynamics" (DQBD). The brain as a living autopoietic system is dissipative, exchanging energy with its environment. When the brain's order increases, then its environment must achieve balance by decreasing in order. Eventually in death the brain will dissipate its stored order back to the environment.

To model this dissipative situation the vacuum state has two modes. The dual modes representing system and environment do not exist independently of their relationship. The vacuum state is *necessarily* between two modes. The relationship between the modes is governed by "thermofield logic." The unique state of this "between-two" is when the dual modes "match" in the way that the complex number a+bi matches its complex conjugate a-bi. Their product is real (since the cross terms cancel and $i^2 = -1$). The between-two hosts observables.

Vitiello places consciousness, not in the activation of memory traces from the vacuum state but in the match between dual modes. One mode represents memory and the other mode represents sensory input: their match is the conscious state. (The match of the between-two has also been as interpreted as existence rather than consciousness;[88,89] these are disagreements in philosophical interpretation, not the physics.) Consciousness is the state in which the dual modes of the between-two belong together. One mode represents sensory input and the other mode represents memory, with consciousness between them in their match. Since this model is somewhat impoverished as it stands, it can be added that signals internally generated by brain systems, broadly conceived emotional, motivational and cognitive signals which are not limited to expressions of sensory input, also participate in the matching process that results in conscious states. Sensory input, memory and (in the broadest sense) “intention” play upon the between-two and the state of consciousness is their belonging-together.

DQBD EXPLAINS DISUNITY OF CONTENT WITHIN THE UNITY OF CONSCIOUSNESS

Three innovations of DQBD have been discussed above. Communication between brain regions is near instantaneous via soliton signaling in the nanolevel web of protein filaments percolating through brain tissue. This accounts for what Lashley called the brain’s “mass action.”[63] Memory is a consequence of Noether’s theorem regarding symmetry conservation. Memory traces are Nambu-Goldstone boson condensates. Consciousness is between-two in the match of dual quantum thermofield modes.

Binding now becomes a matter of temporal coordination: whatever matches in the between-two at any moment will be a content of consciousness bound together by soliton signalling. Disparate matches are not mutually exclusive but co-occurrences. Whatever belongs together is dis-closed within the unity of consciousness. This accounts for Charles Bonnet hallucination within a scotoma, disjoint agnosia and thought insertion, all clinical phenomena which conventional brain theory has difficulty in explaining. The unity of consciousness is between-two. The contents of a unified consciousness are normally integrated but in pathological conditions may be dis-integrated. The unity of consciousness is inviolate—which only disruption of the corpus callosum might break, and there consciousness becomes two consciousnesses, each with its own unity.

DISCUSSION

A Sherringtonian focus on localization and hierarchy, continually furthered in the advance of basic and clinical sciences, has served neurology well. In neo-Sherringtonian neurology the role of localization is by no means minimized. If some subsystem does not function properly or if there is some kind of disconnection between perfectly good subsystems, pathology will result. The neurological emphasis on localization is not lost with neo-Sherringtonian emphasis on the whole. However a shift in thinking to a nonlocal holonomy would be a fundamental change.

A phenomenologically subtle form of neo-Sherringtonianism has been provided by Zeki who presents a "theory of multiple consciousnesses" (214).[90,91] The lowest level of Zeki's hierarchy is that of many functionally specialized "microconsciousnesses." Each is an autonomous subsystem with its own organizing principle and conscious correlate. For example, V4 correlates with conscious visual abilities and V5 with conscious motion detection. Lesions in V4 lead to acquired achromotopsia and in V5 to acquired akinetopsia. Perceptual color and motion are distinct microconsciousnesses which are normally fully unified. Not only are the color and motion quales correlated with different regions of the brain space but they are distinct in time. The perception of color actually precedes the perception of motion but normally they are seamlessly unified into a "macroconsciousness."[90,91]

Zeki distinguishes (in an explicitly Kantian vein) a third level above microconsciousness and macroconsciousness, which is that of "myself as a perceiving person." This level of the subject is reminiscent of Sperry's emergent theory where the subject at the highest level of emergence is different from and more than the sum of the neural parts.[15] Zeki considers "what neural 'glue' may be used to bring the results of activity in them [the microconsciousnesses] together, to give us our coherent and conscious view of the visual world" (p. 58).[90] The "neural glue" is what has been called "binding" above and the proposal developed here is that the neural glue is nonlocality. Such a holonomy is out of step with current neurology.

The global workspace … the dynamic core … the supersystem … the highest or deepest or most interactive integrative level, however described, does not easily fit certain clinical facts found in Charles Bonnet syndrome, disjunctive agnosia and schizophrenia. As to the possible nature of the "neural glue," Zeki trenchantly observes,

> If biology is anything to go by, the solution, when found, will probably turn out to be dazzlingly simple and elegant. But so far it has been elusive and beyond the reach of all.[90] (p. 80)

Within the framework of dissipative quantum brain dynamics the "neural glue" would be the filamentous nanolevel web with its soliton signals traveling at near the speed of sound (and possibly gap junctions per Hameroff[82]). What becomes "glued" is whatever belongs-together in the between-two of local brain systems. The disclosures of the between-twos are unified within consciousness. That one or more local modules are knocked out or disconnected does not effect the unity of consciousness that remains. Thus strikingly in hemineglect, half the world including half of the body goes unnoticed but consciousness seems to the patient as full and united as ever in the remaining dual mode matchings. We might consciously experience only what belongs-together in the between-two.

This way of thinking makes the phenomenology of Anton's syndrome more comprehendable. Anton's patients maintain that they see the world (albeit dimly) when they are obviously blind. Raney and Nielson report an Anton's patient who to her dismay *discovered* after a year that she was blind.[92] The visual experience of Anton's patients is usually interpreted as a confabulation (and indeed the Anton's patients confabulate away their visual mistakes) but now we can understand their truth as a filling-in of the between-two in visual cortex consistent with connections to other cortical areas. The Anton's patients do have a visual world as they insist, but no longer driven by retinal input. The phenomenal world of experience in its various guises is between-two.

There is in DQBD a lower threshold to the unity of consciousness. For nonlocal mechanisms to operate there must be a certain density of quanta.[69] That is, enormous numbers of quanta (on the order of Avogadro's number) are required before condensation can occur. Below the density threshold there can be no belonging-together, hence no consciousness. That there is such a threshold is consistent with the gradual "fading of the light" in Alzheimer's disease, the patient sinking into a dull stupor near the threshold for condensation. (Cf. Pessa, Penna and Bandinelli.[7])

It might be objected to the present application of quantum brain theory to neurology that there is no experimental proof that the brain utilizes quantum degrees of freedom in its functioning. It must be remembered, however, that theory leads experiment in quantum physics. (It took some 70 years before the theoretical prediction of Bose-Einstein condensation was demonstrated in the laboratory.[93]) Indeed, contemporary neo-Sherringtonian neurology might be accused of what Popper called "promissory materialism."[94] Much is elegantly explained in neurology by localization theory and it seems promising that puzzling clinical phenomena will eventually fall to the same approach and so can be safely ignored.

A case in point is the puzzling chronic pain patient with no local source of pain in the periphery and no apparent local dysfunction within the brain. The pain is typically chalked up to "psychological factors" which promissory materialism will someday explain in terms of some type of local dysfunction. In DQBD these factors are global operators. The state of consciousness is a convolution of global operators acting on the between two, derived from sensory input, from memory and from the brain's "self-tuning" ("autotonoetic"[88]) intentional activities.

To illustrate the application to the chronic pain patient, we offer a vignette of a 17 year old male who complained of continual severe pain in his right arm. He had been unexpectedly bitten by something—he thought a spider—when he reached under a bush and the pain never went away. He was anxiously worried, obsessional and schizophrenic in make-up (though not meeting formal criteria for GAD, OCD or schizophrenia). The referring primary care physician thought he was "imagining" his pain but the patient bitterly insisted that "my pain is real." Investigation by a psychoanalyst did not come up with a primary symbolic meaning for the unrelenting pain (although it surely had its secondary gain); this was no Conversion Disorder.

What is significant in this typical case of chronic pain disorder is the unlikelihood of any local pathology as basis for the pain symptom. Whatever the initial local cause, the pain has "taken on a stubborn life of its own" and continuously permeates his consciousness. It is a global operator on existence, along with anxiety and worry, accentuated by schizoid withdrawal. The patient lives a life of pain under holonomy.

We again emphasize that nonlocal operations should not be confused with computations. The conscious state is not a logical result or a consensus achievement in computational energy minimization or a functional cluster or a dynamical mobilization but a disclosure: an unfolding from the whole. The operations are not serially local (as in a computer) but near-instantly global. Nonlocal neurology armed with a holonomic understanding might see more deeply into what clinical neurology has always aspired to: the patient as a whole.

Conflicts of interest

We have no relevant conflicts of interest.

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