

Reviews

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Cajal and Today's Consciousness Research

One hundred years ago, the question of whether the nervous system consists of individual separate neurons (the neuron doctrine), or instead of neurons that fuse together, was hotly debated. Like Einstein and Boltzmann, who together raised the atomic theory of matter to a level beyond reasonable doubt, the work of Santiago Ramón y Cajal firmly established the neuron doctrine over what Cajal once referred to as the "contagion of reticularism" [1]. It is certainly worth commemorating the publica-

tion of Cajal's masterwork, *Textura del sistema nervioso del hombre y de los vertebrados*, which was published in Spanish and French over a five-year span beginning in 1899. The book represents Cajal's monumental effort—astonishing in quality, quantity, and beauty (1800 pages and 887 original illustrations)—that laid the foundation for modern neuroscience.

Cajal himself described *Textura* as "the principal work of my life" [2]. He wrote, "In writing such a voluminous book, in which was summarized and rounded out the work of fifteen years... I sought honor more than profit." (Indeed, he seems to have netted a loss of 3000 pesetas in publishing it!) He continues [3]:

There are works for which there is no greater reward than the consciousness of the personal esteem and the approval of the learned. On that occasion my exertions and efforts obtained the sole recompense to which I aspired; the respectful eulogies of the critics and the complimentary opinions of the most eminent scientists.... The book cited, moreover, was an expression of an egoism too human not to be forgivable. Fearful of oblivion and uncertain of followers capable of affirming and defending before strangers my modest scientific accomplishments, I was determined to

combine into one organized whole the neurological monographs published during [15 years] in periodicals at home and abroad, besides filling in with new inquiries the points not formerly considered. But before and beyond everything else, I desired my book to be—pardon the presumption—the trophy and the offering of fervent love rendered by a Spaniard to his... country.

François Jacob, writing in the volume presently under review, points out that it is rare to find a book that is still read by students 100 years after its publication.

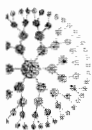
Clearly the publication of *Textura* is a seminal event in the development of our understanding of consciousness. The search for the substrate of consciousness must begin with a clear understanding of the basic anatomy of the nervous system. But in 100 years, how far have we come in understanding consciousness?

A meeting entitled "Cajal and Consciousness: International Centennial Conference Commemorating the Publication of *Textura del Sistema Nervioso del Hombre y de los Vertebrados*" was organized by the Government of Aragón and the University of Zaragoza and was held November 20–December 1, 1999, in Zaragoza, Spain. The *Annals of the New York Academy of Sciences* has devoted its volume 929 to the pro-

Cajal and Consciousness

Scientific Approaches to Consciousness on the Centennial of Ramón y Cajal's *Textura*

Editor
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CAJAL AND CONSCIOUSNESS: SCIENTIFIC APPROACHES TO CONSCIOUSNESS ON THE CENTENNIAL OF RAMÓN Y CAJAL'S *TEXTURA*

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ceedings of this conference in a book titled *Cajal and Consciousness: Scientific Approaches to Consciousness on the Centennial of Ramón y Cajal's Textura*. The volume serves as a useful overview of the current state of consciousness research.

One is led to wonder what Cajal himself would have thought of this event. There is very little among Cajal's own writing to suggest what he might have thought about the study of consciousness. Certainly, Cajal was above all a pragmatist and would have demanded that all ideas worth scientific consideration be firmly grounded in experiment and observation.

Unfortunately, consciousness is so elusive to scientific measurement that its study has often been, and to some extent remains, exclusively within the domain of philosophy and pure theory. About theorists, Cajal's opinion is clear: in his book *Advice for a Young Investigator*, Cajal writes the following in a chapter entitled "Diseases of the Will" [4]:

[Theorists] claim to view things on a grand scale; they live in the clouds. They prefer... brilliant and audacious hypotheses to classic but sound concepts. When faced with a difficult problem, they feel an irresistible urge to formulate a theory rather than to question nature.... The method is legitimate in principle, but they abuse it by falling into the pit of viewing things from a single perspective.... Basically, a theorist is a lazy person masquerading as a diligent one. He unconsciously obeys the law of minimum effort because it is easier to fashion a theory than to discover a phenomenon.... If, in spite of everything, [the student] feels compelled to create vast scientific generalizations, let him do so later on when the abundant observations he has reaped have earned for him a solid reputation. Then and only then will he be listened to with

respect and discussed without ridicule.

For Cajal, hard data was of the utmost importance:

Hypotheses come and go, but data remain. Theories desert us, while data defend us. They are our true resources, our real estate, and our best pedigree. In the eternal shifting of things, only they will save us from the ravages of time and from the forgetfulness or injustice of men....

What would Cajal think of the current state of consciousness research?

The present book offers a concise overview of exactly that. It is divided into three parts, the first of which is entirely devoted to an excellent overview of progress in the neural sciences since Cajal's time written by Thomas D. Albright, Thomas M. Jessell, Eric R. Kandel, and Michael I. Posner. Beginning by placing Cajal and his work in the context of his contemporaries, the authors emphasize what has been learned about the structure and organization of the visual system. It is quite striking that as the authors consider higher and higher levels in brain organization, well-established experimental data thins considerably.

Part two consists mostly of brief contributions from pre-eminent elder scientists. Each offers his or her view of consciousness in terms of the contributions for which they have become famous. Thus, Murray Gell-Mann champions emergence and criticizes attempts to include in the description of consciousness any kind of "vital forces" or, more pointedly, "the alleged weirdness of quantum mechanics." Harold Morowitz emphasizes the importance of placing the study of consciousness in an evolutionary context and suggests that the study of the hierarchical levels of emergence may reveal principles of the same epistemological status as the Pauli exclusion principle. Lynn Margulis argues that consciousness originated from "microbial consciousness"—i.e., the ability to

sense the environment and respond accordingly—and more specifically, that neurotubules arose via symbiogenesis with spirochetes. François Jacob emphasizes the role of regulatory circuits in evolution.

This section includes a large article by Stuart Hameroff and an accompanying addendum by Roger Penrose on their theory of "orchestrated objective reduction." According to this theory, the explanation of consciousness requires analysis at the most fundamental level of space-time physics and suggests that microtubule subunit proteins within certain neurons develop quantum-superposed states that grow until a mass-energy-time threshold related to quantum gravity is attained. At this point, a collapse, or "self reduction" occurs and gives rise to a discrete conscious event. The reader wanting to know why such an analysis is required will not find an adequate discussion here and instead should consult Penrose's *Shadows of the Mind*. It is interesting that Penrose claims that this work is "very much a continuation of the line of work so wonderfully initiated by Cajal," especially in light of the absence of experimental support save a suggestion that the theory might be experimentally tested by a "technically feasible, but difficult" spaceborne experiment. This seems a rather odd way to study consciousness.

Cajal would undoubtedly be much more interested in part three of the book, entitled "From primary to higher-level consciousness," in which is reported work that is directly inspired by, and much more closely aligned with, the growing body of empirical data on conscious phenomena. Reading this section, it becomes clear that the contributors generally agree that consciousness must be associated with a dynamic, distributed phenomenon of coherence involving several different areas of the brain. Cajal himself expressed this view in his *Textura*: "...attempts to localize intellectual activity, volition, and self-consciousness amount to pursuing a chimera. In our view, cognitive or intellectual opera-



tions are not elaborated by a privileged area, but result from the combined activity in a great many first- and second-order mnemonic areas" [5].

Gerard Edelman begins by distinguishing between primary and higher-order consciousness. The former consists of a simple awareness of the world, whereas the latter implies a notion of the personal, of past and future, and of being conscious of being conscious. He proposes a model of primary consciousness inspired by what is known about the organization of the brain. In particular, "neuronal groups selection" and reentrant circuits in the thalamocortical system play key roles in his ideas. Wolf Singer proceeds similarly, arguing that primary consciousness arises from the formation of dynamic, functionally coherent cell assemblies defined by synchronization of activity. Experimental evidence for such synchronization phenomena is reviewed in visual perception studies, especially studies of binocular rivalry in strabismic cats.

New since Cajal's time is an effort to understand computational processes on their own terms. Stanislas Dehaene, Michel Kerszberg, and Jean-Pierre Changeux take the preceding ideas into this realm, proposing a hypothesis about the brain processes that underlie effortful tasks. They posit the existence of a "global workspace" plus a set of specialized modular perceptual, motor, memory, evaluative, and attentional processors, and instantiate this hypothesis in a computational model designed to undergo the Stroop task. It is observed that the global workspace is invoked during effortful tasks. Comparison to brain imaging studies is discussed.

Rodolfo Llinas and Urs Ribary describe their idea that cognition arises from distributed gamma-band thalamocortical oscillations whose absence is correlated with pathologies such as Parkinson's disease or depression. Particularly fascinating is Petra Stoerig's review of experimental results comparing conscious and nonconscious visual perception phenomena. An exten-

sive discussion of the role of V1 in blindsight and in nonveridical visual phenomena (e.g., phosphenes, afterimages, dreaming) is included.

There follows a discussion of language that attempts to synthesize in a larger perspective an evolutionary and developmental view of higher-order consciousness. Michael A. Arbib proposes that perceptual-motor behavior and intelligent action can be expressed as a network of interacting "schemas," each of which involves the integrated activity of multiple brain regions. Then, through evolution, new schemas and new brain regions arise as modulators of previously existing schemas or brain regions. Particularly important in the latter process is the migration from an execution/observation matching system that enables an individual to recognize the action of another (systems for which there is experimental evidence in the F5 mirror neurons of monkeys), to an individual becoming able to pantomime "this is the action that I am going to take." This process amounts to a co-evolution of consciousness and language, which Arbib breaks into seven distinct steps.

Part three concludes with a return to computation. Lotfi Zadeh discusses a method for "computing with words" that is based on fuzzy logic and has the purported advantage of manipulating inexact perceptions and making perception-based rational decisions in an environment of imprecision, uncertainty, and partial truth. I found this article confusing, and as far as I can tell, all the relevant rules have not been fully worked out yet, as the methodology is still very much in development. To his credit, however, Zadeh only suggests, and does not explore, the linkage of computing with words to consciousness.

Writing in the introduction, Pedro C. Marijuán admits that much has not been included. He mentions two areas: emotion, and the search for a neurodynamic optimization principle within an evolutionary context. To this I would add a mention of the work of Christof Koch and Francis Crick and

seek more empirical results within the realms of anesthesiology and sleep research (e.g., the work of J. Allen Hobson), in which states of consciousness are actually manipulated. These last two areas are briefly mentioned by several of the contributors, but a more complete review is not included.

This book makes it clear that although much has been learned about the nervous system since Cajal's time, barely a dent has been made in understanding consciousness itself. Instead, the phenomenon has become more and more mysterious. Cajal's own words from the final pages of *Textura* still apply: "The determination of the sequence of molecular processes that the neurons undergo... during the production of the concomitant phenomena of perception and thought, namely feelings, consciousness, and volition... this ideal is still very distant" [6].

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