

A TESTABLE FIELD THEORY OF MIND–BRAIN INTERACTION

Benjamin Libet,¹ Department of Physiology, University of California, San Francisco, CA 94143-0444, USA

Abstract: The paper begins by contrasting the unitary nature of conscious experience with the demonstrable localization of neural events. Philosophers and neuroscientists have developed models to account for this paradox, but they have yet to be tested empirically. The author proposes a ‘Conscious Mental Field’, which is produced by, but is phenomenologically distinct from, brain activity. The hypothesis is, in principle, open to experimental verification. The paper suggests appropriate surgical procedures and some of the difficulties that would need to be overcome in such an experiment.

One of the most mysterious and seemingly intractable problems in the mind–brain relationship is that of the unitary and integrated nature of conscious experience. We have a brain with an estimated 100 billion neurons, each of which may have thousands of interconnections with other neurons. It is increasingly evident that many functions of cerebral cortex are localized. This is not merely true of the primary sensory areas for each sensory modality, of the motor areas which command movement, and of the speech and language areas — all of which have been known for some time. Many other functions now find other localized representations, including visual interpretations of colour, shape and velocity of images, recognition of human faces, preparation for motor actions, etc. Localized function appears to extend even to the microscopic level within any given area. The cortex appears to be organized into functional and anatomical vertical columns of cells, with discrete interconnections within the column and with other columns near and far, as well as with selective subcortical structures. This columnar view began with findings by Mountcastle (1957) and has been greatly extended by him and others; for example, there are the columnar localizations of visual shapes and motions and of binocular vision as discovered by Hubel and Wiesel (1962).

In spite of the enormously complex array of localized functions and representations, the conscious experiences related to or elicited by these neuronal features have an integrated and unified nature. Whatever does reach awareness is not experienced as an infinitely detailed array of widely individual events. It may be argued that this amazing discrepancy between particularized neuronal representations and unitary integrated conscious experiences should simply be accepted as part of a general lack of isomorphism between mental and neural events. But that would not exclude the possibility that some unifying process or phenomenon may mediate the profound transformation in question.

The general problem had been recognized by many others, going back at least to Sherrington (1940) and probably earlier. Eccles (in, Popper and Eccles, 1977, p. 362) specifically proposed that ‘the experienced unity comes not from a neurophysiological synthesis but from the proposed integrating character of the self-conscious mind’. This was proposed in conjunction with a dualist–interactionist view in which a separate non-material mind could detect and integrate the neuronal activities. Some more monistically inclined neuroscientists have also been arriving at related views (e.g. Sperry, 1952, 1980; Doty, 1984), i.e. that integration seems to be best accountable for in the mental sphere even if one views subjective experience as an inner quality of the brain ‘substrate’

¹ This paper was originally published in a collection of the author’s own work, B. Libet, *Neurophysiology of Consciousness* (Boston: Birkhauser, 1993).

(as in ‘identity theory’) or as an emergent property of it. There has been a growing consensus that no single cell or group of cells is likely to be the site of a conscious experience, but rather that conscious experience is an attribute of a more global or distributed function of the brain. Recent discovery of a widespread synchronization of oscillatory neuronal responses to certain visual configurations (Gray and Singer, 1989; Singer, 1991) has led to some speculation that a ‘correlation’ model might represent the neural coding for recognizing a unified image in an otherwise chaotic background. This speculation is still to be tested.

A second apparently intractable problem in the mind–brain relationship involves the reverse direction. There is no doubt that cerebral events or processes can influence, control and presumably ‘produce’ mental events, including conscious ones. The reverse of this, that mental processes can influence or control neuronal ones, has been generally unacceptable to many scientists on (often unexpressed) philosophical grounds. Yet, our own feelings of conscious control of at least some of our behavioural actions and mental operations would seem to provide *prima facie* evidence for such a reverse interaction, unless one assumes that these feelings are illusory. Eccles (1990; Popper and Eccles, 1977) proposed a dualistic solution, in which separable mental units (called psychons) can affect the probability of presynaptic release of transmitters. Sperry (1952, 1985, 1980) proposed a monistic solution, in which mental activity is an emergent property of cerebral function; although the mental is restrained within a macro-deterministic framework, it can ‘supervene’, though not ‘intervene’, in neuronal activity. However, both views remain philosophical theories, with explanatory power but without experimentally testable formats.

As one possible experimentally testable solution to both features of the mind–brain relationship, I would propose that we may view conscious subjective experience as if it were a field, produced by appropriate though multifarious neuronal activities of the brain.

The Conscious Mental Field (CMF)

A chief quality or attribute of the conscious mental field (CMF) would be that of a unified or unitary subjective experience. A second attribute would be a causal ability to affect or alter neuronal function. The additional meaning or explanatory power of describing subjective experience in terms of a CMF will become more evident with the proposed experimental testing of the theory. That is, the CMF is proposed as more than just another term for referring to ‘unified subjective experience’.

The putative CMF would *not* be in any category of known physical fields, such as electromagnetic, gravitational, etc. The conscious mental field would be in a phenomenologically independent category; it is not describable in terms of any externally observable physical events or of any known physical theory as presently constituted. In the same sense as for all subjective events, the CMF would be detectable only in terms of the subjective experience, accessible only to the individual who has the experience. An external observer could only gain valid direct evidence about the conscious mental field from an introspective report by the individual subject. In this respect the conscious mental field would differ from all known physical fields, whose existence and characteristics are derived from physical observations.

On the other hand, the proposed CMF should be viewed as an operational phenomenon, i.e. as a working and testable feature of brain function. It is not proposed as a view of the metaphysical origin and nature of the mind; indeed, it could be shown to be potentially compatible with virtually any philosophical mind–brain theory. The CMF may be viewed

as somewhat analogous to known physical fields. For example, a magnetic field is produced by electric current flowing in a conductor, but it can in turn influence the flow of the current. However, as indicated, the CMF cannot be observed directly by external physical means.

The proposed interaction between brain and CMF differs from the 'unitary hypothesis of mind-brain interaction' proposed by Eccles (1990). Eccles postulates that each putative unit of mental function (a 'psychon') is associated with a specific neural aggregate (a 'dendron'); the present theory does not postulate such a specific and fixed relationship. In Eccles' theory, the question of how neural activation is translated into a mental event is dealt with by hypothesizing a specific synaptic-psychon interaction. He proposes that when the synaptic input to a dendrite makes it possible for a 'psychon (to) successfully select a (presynaptic) vesicle for exocytosis (that is for release), the 'micro-success' is registered in the psychon for transmission through the mental world'. In the present theory the appropriate (presently unspecified) neural activity directly contributes some alteration in the overall CMF; the contribution does *not* depend upon an action by the mental phase (the psychon, in Eccles' theory) on synaptic function.

How is the CMF attribute of unified subjective experience related to its production by contributions from local neuronal areas? Local alterations in the CMF would be reflected in a changed overall field, but there would not be a separately-required mechanism for transmission and integration of such local contributions. To think in terms of a transmission and integrative process would be to continue thinking in terms of the externally observable neural events. To do so would be a misunderstanding of the nature of the proposed CMF, which is in a phenomenological category not reducible to (although intimately related with) neuronal processes. There are no doubt rules for (at least much of) the relationship between the CMF and the physically (externally) observable neural processes. But the rules are not describable *a priori*, i.e. before they are discovered by studying both phenomena simultaneously (e.g. Libet, 1987, 1989).

It seems evident, from the 'split-brain' studies of Sperry *et al.* (1969; Sperry, 1985), that transection of the main communicating commissures between the two cerebral hemispheres can result in simultaneously different contents of experience for the two sides. I shall avoid here the argument about whether the isolated non-speaking right hemisphere does or does not actually 'have' conscious experience. What is clear, however, is that the contents of conscious mental events in the right hemisphere are not available to the left hemisphere in this condition. This would imply that any contributions of right hemisphere activity to a mental field cannot directly alter the CMF of the left hemisphere. That is, unity of the CMF would, in these circumstances, be restricted to a given hemisphere. It would also imply that contributions of local neural areas to the overall CMF of a hemisphere are effective only when contiguous with those of other areas; i.e. the contributions would not be effective across substantial gaps of space or of non-neural barriers.

Experimental Design to Test Theory

The theory of a CMF makes crucial predictions that can, at least in principle, be tested experimentally. If local areas of cerebral cortex could independently contribute to or alter the larger, unitary CMF, it should be possible to demonstrate such contributions when (a) that cortical area is completely isolated or cut off from neuronal communication with the rest of the brain, but (b) the area remains *in situ*, alive and kept functioning in some suitable manner that sufficiently resembles its normal behaviour. The experimental prediction to be tested would be as follows: Suitable electrical and/or chemical activation

of the isolated tissue should produce or affect a conscious experience, even though the tissue has no neural connections to the rest of the brain. Possibilities of spread of influences from the isolated block via physical non-neural paths (e.g. electric current flow) would have to be controlled for. If a subjective experience is induced and reportable within a second or so, that would tend to exclude spread by chemical diffusion or by changes in vascular circulation or in contents of circulating blood as a cause (see Ingvar, 1955b).

Suitable neuronal isolation could be achieved either (a) by surgically cutting all connections to the rest of the brain, but leaving sufficient vascular connections and circulation intact, or (b) by temporarily blocking all nerve conduction into and out of an area. Surgical isolation (a) will be discussed further below. Functional isolation (b) might be achievable by injecting blocking agents in small amounts so as to form a ring of blockade around and under a selected block of cerebral cortex. A local anaesthetic agent might be used, such as procaine suitably buffered to pH 7.4 in Ringer's solution. Or, the selective blocker of sodium-conducted action potentials, tetrodotoxin, could be combined with a calcium-channel blocker like verapamil (to ensure that calcium-mediated action potentials would not escape blockade; see Garcia Ramos and Ibarra, 1973). The advantage of pharmacological method (b) for isolation is its reversibility; this would permit its use on areas of cortex not scheduled for surgical excision, thus greatly enlarging the potential pool of subjects (if risk factors are suitably met). The disadvantages of method (b) are (i) the difficulty of limiting the blockade to a narrow band around the slab, because of diffusibility, (ii) the need to prove that complete blockade has been achieved; (iii) a reduced ability to introduce neural inputs into the isolated slab by the excitation of ascending nerve fibres within the slab but near its lower borders.

Surgically Isolated Slab of Cortex, *In Situ*

A slab of cerebral cortex can be neurally isolated surgically, remaining in place but viable by retaining its blood supply as the only connection with the rest of the brain. This is accomplished by making all of the cuts subpially. Studies of the electrophysiological activity of such isolated cortex *in situ* have been reported (Kristiansen and Courtois, 1949; Burns, 1951, 1954; Echlin *et al.*, 1952; Ingvar, 1955a, 1955b; Goldring *et al.*, 1961). The basic method involved introducing a narrow curved blade through an opening in an avascular area of the pia-arachnoid membrane. This could undercut a block or slab of cortex and, by bringing its tip up to meet the pia at some distance away, also cut the connections to adjacent cortex. In an earlier study (of how vertical cuts in cortico-cortical connections might affect the integrated, organized function of the sensorimotor cortex in monkeys) Sperry (1947) had used a somewhat different technique. The cutting instrument was an extremely thin double-edged blade made from a fine wire or sewing needle. The sharpened end of this wire was bent to a right angle; this terminal portion of the blade could be sunk vertically into the cortex so that its horizontal arm lay just below the pia. When the vertical knife is pushed forward it cuts through the cortex while its horizontal carrying arm slides just below the pia. This technique could easily be arranged to produce undercutting of the cortex as well. The potential advantage to Sperry's method lies in the very thin line of tissue damage created by this knife, capable of producing chronic scars less than 100 μm . thick. That would be particularly desirable if the isolated slab were to remain *in situ* for therapeutic reasons.

Isolation of a cortical slab has also been performed in human subjects, by Echlin *et al.* (1952), with both general and local anaesthesia (patient awake). They reported an

immediate reduction but not complete abolition of rhythmic electrical activity (EEG) in the area. After 20 min., paroxysmal bursts of high voltage activity appeared. This kind of seizure pattern in normal brain is usually associated with disruption or distortion of normal functions and, in the motor area, convulsive motor actions. There was no spread of activity from the isolated slab to surrounding areas. With only undercutting of a cortical area in human subjects under local anaesthesia, Henry and Scoville (1952) also reported autogenous spontaneous activity but of a markedly decreased amount. In addition, bursts of fast and slow waves alternated with quiet periods; these were confined to the undercut areas even though there was superficial neural continuity with adjacent areas. In one case a prolonged period of high-voltage electrical activity followed probing for the sphenoid ridge below frontal cortex; this indicates that stimulation (in this case mechanical) of already cut input fibres can induce further activity in acutely isolated cortex.

The physiological properties of the isolated slab are obviously immediately altered because of the sudden loss of all inputs. For example, it is well known that destruction of the reticular activating system in the brain stem results in a coma; this afferent input would have to be properly excited so as to 'wake up' the isolated slab of cortex. Some procedures to restore some levels of sufficiently normal activity would be necessary. These could involve local electrical stimulation (e.g. Libet *et al.*, 1964) or the application of exciting chemical agents. Chemical stimulation of isolated cortex has already been studied (Kristiansen and Courtois, 1949; Echlin *et al.*, 1952; Rech and Domino, 1960). With longer term chronic isolation, the nerve fibre inputs and their synaptic contacts with cells in the slab would degenerate and no longer provide these normal structural contacts. The studies proposed in this paper would be better carried out in the acute phase, during the initial period after isolation. Indeed, with the afferent cut axons still viable and potentially functional, they could be utilized to restore some degree of neural inputs by electrically stimulating them within the slab in a highly localized and controlled fashion.

With surgical isolation the irretrievable loss of normal neural function for a cortical slab would limit studies to cases in which a slab of tissue has been designated for therapeutic surgical removal from the brain. The study would then be carried out in the operating room before the actual excision of the tissue, if other conditions are also met. These include — the patient being awake and responsive; using local rather than general anaesthesia; informed consent and ready cooperativeness by the patient; approval of any risk assessments by all concerned, particularly the hospital/university committee for protection of human subjects. Actually, many patients have been found to tolerate brain surgery under local anaesthesia and to participate fruitfully in many past studies (e.g. Penfield, 1958; Libet *et al.*, 1964; Libet, 1973).

A further special requirement of the experiment is that the cortical slab to be isolated should be one for which, when that cortical tissue is still intact before isolation, local electrical stimulation can elicit a conscious subjective experience that is introspectively reportable. The obvious candidates are any of the primary sensory areas — somatic, auditory or visual, for which suitable surface electrical stimulation is known to elicit a primitive sensory experience (e.g. Libet, 1973, 1982). However, stimulation of some other cortical areas, particularly in temporal lobe, have been reported to elicit more complex conscious experiences (e.g. Penfield, 1958). In every case, it would be desirable that a bit of fairly normal responding tissue be included within the slab scheduled for excision; but neurosurgeons almost always include such normal bits in order to achieve an adequately therapeutic removal of pathological tissue.

The test of the existence of a CMF that can unify subjective experience would be to see whether electrical or chemical stimulation of a suitably 'normalized' isolated cortical slab can elicit an introspective report of an experience. The cortical site of the slab would have to be one at which suitable electrical stimulation does elicit a reportable experience when the brain is intact. There is the possibility that such a cortical site must secondarily activate certain other additional areas in order to produce the conscious experience. In that case these other areas may have to be identified, and multiple isolated slabs that include such areas be included in the experimental stimulation test. In the event of a positive result, possible sources of physical spread of the stimulus to the rest of the brain would have to be excluded, as noted above.

A test of the causal ability of the putative CMF to affect neuronal functions is already implicit in the test just described for the existence of the CMF. If stimulation of the isolated cortical slab can elicit an introspective report by the subject, that could only come about if the CMF could activate the appropriate cerebral areas required to produce the verbal report. However, other specific tests are also possible with cortical areas that have been found specifically to increase their activity when a subject with an intact brain imagines making some movements or imagines some sensory experience. For example, neural activity (as indicated by measurements of regional blood flow or metabolic rate) has been shown to increase selectively in the supplementary motor area (SMA) when the subject is asked to imagine moving his fingers without actually moving them (Ingvar and Phillipson, 1977; Roland and Friberg, 1985). Eccles has taken this to be a demonstration of a mental action affecting neural activities. But there are difficulties with such a conclusion from that experiment: a) There is the technical limitation of temporal resolution by the blood flow. Metabolism measurement is not fine enough to permit a definite conclusion about which came first — the mental imaging or the increase in SMA activity. b) If it were shown that the mental event did come first here, that would certainly be suggestive of Eccles' kind of interpretation; but there is always the possibility that the whole process was initiated by some neural events elsewhere in the brain, too small or so oriented as to be not recorded by a given recording method. Unless the mental event (of imaging or command) could be shown to precede *any* possible neural event specifically related to the process studied, there could always be doubt about the nature of the causal interaction. With the neurally isolated cortical slab, there are no such difficulties of interpretation. On the other hand, any indirect 'extraneuronal' influences from elsewhere in the brain would have to be evaluated and excluded. For example, Ingvar (1955b) had reported that stimulation of the reticular activating system in the brain stem could influence electrophysiological activity in completely isolated cortex. This effect appeared to be mediated by a change in blood circulation, but had a long latency of 10 to 70 sec.

If, for example, one had available a neurally isolated cortical slab in the SMA, one could repeat the above described experiment, of asking the subject to imagine moving his fingers. Recordings of electrophysiological responses could be added to those of blood flow and metabolism. Isolation of an SMA slab is one of the more impractical possibilities, but an experiment similar in principle could be designed for certain other cortical areas more accessible to therapeutic isolation.

General Conclusions

Suppose that the experimental results prove to be positive, i.e. suitable stimulation of the neurally isolated cortex elicits some reportable subjective response that is not attributable to stimulation of adjacent non-isolated cortex or of other cerebral structures. That would

mean that activation of a cortical area can contribute to overall unified conscious experience by some mode other than by neural messages delivered via nerve conduction etc. This would provide crucial support of the proposed field theory, in which a cortical area can contribute to or affect the larger conscious field. It would provide an experimental basis for a unified field of subjective experience and for mental intervention in neuronal functions.

With such a finding one may ask, what would be the role for all the massive and complex neural interconnections, cortico-cortical, cortical-subcortical and hemisphere to hemisphere? An answer might be — to subserve all the cerebral functions other than that directly related to the appearance of the conscious subjective experience and its role in conscious will. It should be noted that all cognitive functions (receipt, analysis, recognition of signals etc), information storage, learning and memory, processes of arousal and attention and of states of affect and mood, etc. are *not* proposed as functions to be organized or mediated by the postulated CMF (conscious mental field). In short, it is only the phenomenon of conscious subjective experience, associated with all the complex cerebral functions, that is modelled in the CMF, in an admittedly speculative manner.

It may be easy to dismiss the prospect of obtaining ‘positive’ results in the proposed experimental tests, since such results would be completely unexpected from prevalent views of brain functions based on physical connectivities and interactions. But the improbability of positive results is strictly a function of existing views which do not deal successfully with the problems of unity of subjective experience and of apparent mental controls of brain processes. The potential implications of the CMF theory and of the positive results it predicts are clearly profound in nature. On those grounds, and because the proposed experiments are in principle workable although difficult, the proposed experimental design should merit a serious place in investigations of the mind-brain problem.

References

- Burns, B.D. (1951), ‘Some properties of isolated cerebral cortex in the unanesthetized cat’, *J Physiol (Lond.)*, **112**, pp. 156–75.
- Burns, B.D. (1954), ‘The production of after-bursts in isolated unanesthetized cerebral cortex’, *J Physiol (Lond.)*, **125**, pp. 427–46.
- Doty, R.W. (1984), ‘Some thoughts and some experiments on memory’, in *Neuropsychology of memory*, ed. L.R. Squire and N. Butters (New York: Guilford), pp. 330–9.
- Eccles, J.C. (1990), ‘A unitary hypothesis of mind-brain interaction in cerebral cortex’, *Proc Roy Soc Lond B*, **240**, pp. 433–51.
- Echlin, F.A., Arnett, V. and Zoll, J. (1952), ‘Paroxysmal high voltage discharges from isolated and partially isolated human and animal cerebral cortex’, *Electroenceph & Clin Neurophysiol*, **4**, pp. 147–64.
- Garcia Ramos, J. and Ibarra, B.H. (1973), ‘Studies on the mechanisms of learning, II, on the ionic nature of the dendritic action potentials and mescaline spikes’, *Acta Physiol Latino Amer*, **23**, pp. 202–12.
- Goldring, S., O’Leary, J.L., Holmes, T.G. and Jerva, M.J. (1961), ‘Direct response of isolated cerebral cortex of cat’, *J Neurophysiol*, **24**, pp. 633–50.
- Gray, C.M., and Singer, W. (1989), ‘Stimulus-specific neuronal oscillations in orientation columns of cat visual cortex’, *Proc Natl Acad Sci USA*, **86**, pp. 1698–702.
- Henry, C.E. and Scoville, W.B. (1952), ‘Suppression-burst activity from isolated cerebral cortex in man’, *Electroenceph & Clin Neurophysiol*, **4**, pp. 1–22.
- Hubel, D.H. and Wiesel, T.N. (1962), ‘Receptive fields, binocular interaction and functional architecture in the cat’s visual cortex’, *J Physiol (Lond.)*, **160**, pp. 106–54.
- Ingvar, D. (1955a), ‘Electrical activity of isolated cortex in the unanesthetized cat with intact brain stem’, *Acta Physiol Scand*, **33**, pp. 151–68.

- Ingvar, D. (1955b), 'Extraneuronal influences upon the electrical activity of isolated cortex following stimulation of the reticular activating system', *Acta Physiol Scand*, **33**, pp. 169–93.
- Ingvar, D. and Phillipson, L. (1977), 'Distribution of cerebral blood flow in the dominant hemisphere during motor ideation and motor performance', *Ann Neurol*, **2**, pp. 230–7.
- Kristiansen, K. and Courtois, G. (1949), 'Rhythmic electrical activity from isolated cerebral cortex', *Electroenceph & Clin Neurophysiol*, **1**, pp. 265–72.
- Libet, B. (1973), 'Electrical stimulation of cortex in human subjects and conscious sensory aspects', in *Handbook of Sensory Physiol., Vol. II: Somatosensory System*, ed. A. Iggo (Berlin: Springer-Verlag).
- Libet, B. (1982), 'Brain stimulation in the study of neuronal functions for conscious sensory experiences', *Human Neurobiol*, **1**, pp. 235–42.
- Libet, B. (1987), 'Consciousness: Conscious, subjective experience', in *Encyclopedia of Neuroscience*, ed. G. Adelman (Boston: Birkhauser).
- Libet, B. (1989), 'Conscious subjective experience vs. unconscious mental functions: A theory of the cerebral processes involved', in *Models of Brain Function*, ed. R.M.J. Cotterill (New York: Cambridge University Press).
- Libet, B., Alberts, W.W., Wright, E.W., Delattre, L.D., Levin, G. and Feinstein, B. (1964), 'Production of threshold levels of conscious sensation by electrical stimulation of human somatosensory cortex', *J Neurophysiol*, **27**, pp. 546–78.
- Mountcastle, V.B. (1957), 'Modality and topographic properties of single neurons of cat's somatic sensory cortex', *J. Neurophysiol*, **20**, pp. 408–34
- Penfield, W. (1958), *The excitable cortex in conscious man* (Liverpool: Liverpool University Press).
- Popper, K.R. and Eccles, J.C. (1977), *The Self and its Brain* (Heidelberg: Springer).
- Rech, R.H. and Domino, E.F. (1960), 'Effects of various drugs on activity of the neuronally isolated cerebral cortex', *Exper Neurol*, **2**, pp. 364–78.
- Roland, P.E. and Friberg, L. (1985), 'Localization of cortical areas activated by thinking', *J. Neurophysiol*, **53**, pp. 1219–43.
- Sherrington, C.S. (1940), *Man on his nature* (Cambridge: Cambridge University Press).
- Singer, W. (1991), 'Response synchronization of cortical neurons: an epiphenomenon or a solution to the binding problem', *IBRO News*, **19**, pp. 6–7 (New York: Pergamon).
- Sperry, R.W. (1947), 'Cerebral regulation of motor coordination in monkeys following multiple transections of sensorimotor cortex', *J Neurophysiol*, **10**, pp. 275–94.
- Sperry, R.W. (1952), 'Neurology and the mind–brain problem', *American Scientist*, **40**, pp. 291–312.
- Sperry, R.W. (1980), 'Mind–brain interaction: mentalism yes; dualism no', *Neuroscience*, **5**, pp. 195–206.
- Sperry, R.W. (1985), *Science and moral priority* (Westport, Conn: Praeger).
- Sperry, R.W., Gazzaniga, M.S. and Bogen, J.E. (1969), 'Interhemispheric relationships: The neocortical commissures: Syndromes of hemisphere disconnection', in *Handbook of Clinical Neurology*, Vol. 4, ed. P.J. Vinken and G.W. Bruyn (Amsterdam: North Holland), pp. 273–90.