

PHONEME COGNITION: THEORETICAL ASPECTS OF NEURO-CORTICAL ACTIVITY

DON GEORGE

There are always limitations on theory building and model making. Were it not for the Heisenberg principle we might, conceivably, determine factually exactly how the human brain performs its various complex activities. Meanwhile, we must be content with inferences and theoretical models. Such models necessitate invention of convenience symbols, such as memory, association areas, 'centers' for various functions, engrams, etc., to furnish referents for the unobservable. Time precludes the inclusion of even a major portion of the research concerning the physio-electric behavior of neural complexes and the inferences drawn about their normal function in humans.

This paper assumes cognition to be a function of specific neuro-cortical activity, and excludes para-psychological and psychic explanations. Cognition is defined as the sum total of neural activities by which an organism gains knowledge of anything; in this case, phonemes.

Jungert (1958) suggests some 25,000 + fibers of first order neurons originate on the internal-external hair cells of the cochlea, systematized so that different frequencies appear to be transmitted by different groups among them. Fulton's (1955) place-mechanism theory of hearing, in which the frequency perceived depends upon the area of the cochlea stimulated and the cells in the cortex correspondingly activated, strongly suggests a matrix system of hearing perception. Since phonemes of different languages are not always the same, and even have a tolerable variance within the system, cognition of the perceived phoneme matrices must be thought of as a learned activity.

The question now becomes: what conditions in the neuroanatomy might explain such learning? Lenneberg (1967) and others have pointed out that for a period of some twelve to fifteen years neural development continues, and that language development is, therefore, related to neural maturation. In addition to general neural growth, synaptic thresholds may be lowered along frequently used pathways. Eccles (1957) points out that a shrinkage occurs at the synaptic knobs from disuse, and suggests that disuse may also quantitatively diminish the chemical substances thought to be responsible for transmission of neural energy. From this we may conclude that

the opposite conditions would hold for repetitious use of any particular synapse. Such assumption would, therefore, suggest the reduction of the firing threshold, thus facilitating the transfer of neural energy along that particular path.

Coupling threshold reduction with the possibility of increased arborization, particularly in the reticular formation of the brain stem, we have a condition of increased modal association and interaction which would develop matrices of greater and lesser probability of synaptic transmission. It is also possible that neuron size, which Kilmer, McCulloch and Blum (1968) indicate run the full range of cell body size in the reticular formation, may be related to stimulus growth and, thus, be involved in threshold reduction.

Reduction of the firing threshold at particular synaptic connections could, therefore, be assumed to account for the greater readiness to respond to stimuli which correspond to other stimuli previously passing along a given path. With increased reduction of threshold by continued use of particular synapses, readiness to respond to recurrence of the same stimuli would be further increased. Thus, memory, which Schlesinger (1962) and others consider roughly to be generally located in the brain stem, may be more specifically thought of as a function of the reticular formation in the brain stem.

Since a neuron fires when the threshold is exceeded by the total weight of synapses receiving impulses during the period of latent summation, the particular frequency combinations associated with the phonemically distinctive features of a sound complex will activate particular neural pathways which, by repeated experiences, become low threshold matrices. Subsequent occurrences of the same features will, therefore, have greater probability of tracing the same route through the reticular formation.

Since the brain stem is believed to be capable of modifying reception, conduction, and integration of all incoming sensory stimuli, it may be assumed that irrelevant or randomly occurring aspects of any stimulus complex would not leave reduced threshold patterns, whereas significant aspects of the complex would. Following Jakobson's suggestion that phonemes possess distinctive features, with other aspects of the sound complex peripheral or non-significant, we would conclude that the phonemically significant features of any language are imprinted as low threshold pathways in the reticular formation by their reoccurrence in the heard language stimuli, while non-significant aspects, being more random in appearance, are **not**.

A number of non-specific axons project into the cortex from the reticular formation and direct the cortex in terms of 'compute' and 'do not compute' (to borrow computer phraseology). Cognition, then, may be viewed as a condition of match and non-match relationships between the perceived signal and the low threshold matrices. In case of matching frequency patterns, information of pattern congruity is relayed to the cortex for instantaneous acceptance. Thus, the constantly shifting matrices in an utterance are accepted as meaningful. The complexity of the reticular matrices reflects the complexities of the variant, or allophonic, patterns regularly occurring in the language.

Should any incoming signal deviate too far from the tolerance limits of congruity, the message is distorted. However, since the reticular formation is the clearing house for all incoming sensory stimuli, if the distortion is not too great a search for analogous matrices suggested by other input signals will attempt to reconcile the deviation. Increased familiarity with deviant forms broadens the configurational base, so that, as in original language learning, the low threshold matrices are broadened, and matching, or cognition, of perceived signals is facilitated.

*University of Southern Mississippi
Hattiesburg, Mississippi*

REFERENCES

- Arib, M.A.
1965 *Brains, Machines, and Mathematics* (New York, McGraw-Hill Book Company).
- Brazier, M.A.B.
1968 *The Electrical Activity of the Nervous System* (Baltimore, The Williams and Wilkins Company).
- Eccles, J.C.
1957 *The Physiology of Nerve Cells* (Baltimore, The Johns Hopkins Press).
- Fulton, J.F.
1955 *A Textbook of Physiology*, 17th ed. (Philadelphia, W.B. Saunders Company).
- Jungert, S.
1958 "Central Auditory Pathways in the Brain Stem and Inferior Colliculi", *Acta Oto-Laryngology Supplement* 140.
- Kaplan, H.M.
1960 *Anatomy and Physiology of Speech* (New York, McGraw-Hill Book Company).
- Kilmer, W.L., W.S. McCulloch, and J. Blum
1968 "Towards a Theory of the Reticular Formation", in *The Mind: Biological Approaches to its Function*, Wm. C. Corning and Martin Balaban, eds. (New York, Interscience Publishers).
- Lenneberg, E.H.
1967 *Biological Foundations of Language* (New York, John Wiley & Sons, Inc.).
- Riklan, M. and E. Levita
1969 *Subcortical Correlates of Human Behavior* (Baltimore, The Williams and Wilkins Co.).
- Schlesinger, B.
1962 *Higher Cerebral Functions and Their Clinical Disorders* (New York, Grune and Stratton).

DISCUSSION

MACNEILAGE (Austin, Tex.)

Most people have attributed pattern perception to the cerebral cortex. Do you have any evidence that would lead you to prefer the reticular formation to the cerebral cortex for any perceptual function?

GEORGE

While sensory neurons synapse in the reticular formation, I am not denying other connections to the cortex, we have a multitude of acoustic stimuli impinging on the

ear at all times, so the reticular formation may be thought of as related to selective perception. In other words, it separates the meaningful from the incidental. In phoneme cognition, therefore, it would direct the computing of sound complexes having a familiar distinctive feature, and the non-computing of sound complexes occurring as speech which do not contain such features. We may hear, but we do not cognize unless there is a 'match' condition.

WHITAKER (Rochester, N.Y.)

By increased arborization, George refers to the elaboration of dendrites during neuronal maturation; recent studies suggest that sensory stimulation has quite specific effects on dendrite growth and subsequent neural function, and therefore the theoretical base of George's paper is plausible. However, the ascending reticular formation (R.F.) is mature at birth in man, clearly prior to any significant acoustic input to the child's central nervous system that could form a neural basis for speech perception. Although this alone would raise serious doubts that the R.F. plays a role in speech perception like that suggested by George, there are other reasons for rejecting his hypothesis. Current evidence on the function of the R.F. implicates its role in alerting and orienting the organism to sensory stimuli (particularly NOVEL stimuli rather than familiar stimuli) as a precursor to perception and ultimately cognition. There is no evidence that the R.F. has perceptual/cognitive functions, which is why it is usually identified as a non-specific neural system. Man's primary sensory pathways (visual and auditory) do not pass directly through the R.F. as George implies — rather, each sensory (and motor) path sends collaterals into the R.F. Damage to these primary paths does affect perception (and production) whereas damage to the R.F. itself affects the entire functioning of the central nervous system with respect to orienting, alerting, sleep-wake cycles, etc. Although there is clearly a paucity of data relevant to the language functions of the central nervous system in man, a more plausible model would assign perceptual and cognitive functions such as outlined by George, to a higher (cortical) level and would exclude the ascending reticular formation.

GEORGE

The completeness of the reticular formation at birth, as you suggest, does not preclude the strengthening or weakening of synaptic junctions by repeated stimuli, of course.

As I said earlier, these remarks are speculative and inferential, so I would not want to debate with you, or anyone, if you make different inferences based on different information.

I certainly would not insist on the reticular formation being the locus of the match and non-match condition, but I am convinced that something of this sort occurs in cognition.