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BULBO-THALAMO-CORTICAL STRUCTURES
AND THEIR ACTIVITIES SIMULATED
BY “FORMATOR-COMPLEX” AND
“MULTILAYERED ITERATIVE ALGORITHM” MODELS
An Electroencephalographic and Neuroinformatic Study

JOSEF FABER



CHARLES UNIVERSITY IN PRAGUE

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An Electroencephalographic and Neuroinformatic Study

Josef Faber

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Dedicated to my family.

PREFACE

All neurophysiologists, neurologists, psychologists and psychiatrists wish they could learn more about the system of the human brain. We cannot develop an idea of its activities as a whole. We are unable to model its global function. It is debatable whether an isomorphous model of the brain can ever be devised at all. All we can do is venture partial simulation or imitate merely some of its functions in more or less defined structures. To the best of our good intentions, we can then correlate our conclusions with already established facts, albeit with a guaranty more limited than the results of concrete experiments.

We know of the existence of the **sensory system**, a sort of interface enabling information from the outside world to **enter the brain where information is processed** (and **saved** in memory), whereupon the “brain decides” to perform or not to perform a movement of the body or speech organs, i.e., to activate or not to activate its **motor system** (Descartes 1672, Marcus Marci 1675 – in Servit 1965, Laufberger 1947, Bouchal and Konečný 1966, Atkinsonová et al. 1995, Jiang et al. 2000, Hall 2003, Fields 2005). A marked correlation between movement and mentation, i.e., motor activity and mentation is found in phylogenesis and ontogenesis. Evidence of this can be seen in first-formers imitating letters of the alphabet not only by their hands, but also by their whole bodies, in performing toy soldier movements on a model/ in war school games of tactics and strategy or, in more general terms, in oneroid dreaming with many movements in REM sleep.

Afferentation, analysis and efferentation are more or less complex reflex activities, the perfection of which depends on the sensory system accuracy, experience and memory, on the rate of sophistication of the analytical-synthetic centre and precision of motoricity such as in speech (Kandel and Schwartz, 1985, Posner and Raichle 1994, Mazziota et al. 2000, Raichle 2010). However, that will hardly do to help interpret the complexity of human ethology.

That accounts for the many hypotheses of the brain’s “integration” such as parallel distributed processing (PDP, Rumelhart and McClelland 1986) or connectionistic or controller models of organisation in neural networks (Roy 2008). The trend today is again to accentuate the brain as a system of connectomes; in other words, to lay more emphasis on contacts between nuclei, which do not seem to exist as it were. The problem was widely discussed as long ago as the second half of the 19th century, the times of the French anatomist, speech centre discoverer, Paul Broca.

That was also when neuroscientists started to pursue (follow) two creeds: the holistic theory (in terms of function, the brain cortex is non-specific and designed to work as a whole) and the localist theory (the cortex is made up of specialised centres). The truth is somewhere between the two. As follows from neurophysiological experiments, clinical observations and evidence provided by modern diagnostic technologies, the centres (Broca, Wernicke, primary optic area etc.) and connections (with evidence present in the practice of tractotomy and modern fNMR tractography) do, indeed, exist. At the same time, we are aware of the fact that psychic categories such as phatic and gnostic functions or vigilance and consciousness cannot simply be derived from the

reflectological principle. While these phenomena also depend on the activities of the bulbo-thalamo-cortical system, the algorithms of those structures will be substantially more sophisticated.

Our speculations lead to the particularly intricate “neuropsychological” problem of awareness of oneself and one’s environment. For a number of others, let us quote Crick and Koch (2003): “... whether the neural activity in the front of the brain is largely unconscious. One proposal, e.g., is that humans are not directly conscious of their thoughts, but only sensory representation of them in their imagination. At the moment, there is nothing conscious about this.” The authors go as far as referring to an isolated optic consciousness in agreement with obvious sensory afferentation and with the peak of neuronal synchronisation and relative dominance of alpha activity over occipital visual areas (anatomically, according to Brodmann, areas 17, 18 and 19).

It is necessary to agree to “semiautomatic” (iterative) and subthreshold mentation. Moreover, in our opinion a marked portion of mentation proceeds in deep NONREM with slow delta waves and in REM. In this connection, let us mention some of the ideas of Johan Marcus Marci (1675, Servít 1965), a 17th century scientist who lived in Prague: “perceptio est idem, quod imaginatio rei presentis et imaginatio est idem, quod perceptio rei absentis,” in other words “nihil est in intellectu, quod non fuerit in sensu,” a thesis which he advanced a number of years before the English thinker John Locke (1714, de novo in Czech 1984).

The universal adaptability of living matter in general and developed animals in particular, such as mammals, requires time for the processing of an enormous quantity of everyday information, in particular motor – efferentation as well as sensory – afferentation rest, i.e., sleep (Asserinski and Kleitman 1953, Dement 1958, Faber and Vladyka 1984, 1987, Kryger et al. 2000). Further on, sleep is complexly organised into synchronous (NONREM) and paradoxical (REM) stages and their phases. Psychic rest, however, is not present in either REM or NONREM. Information accumulated during wakefulness is further “automatically” processed in sleep to undergo association, abstraction, classification and selection according to its relevance, albeit merely subjective. Information is classified relative to the hierarchy of each individual personality and experience of life (Říčan 1972, Říčan and Hampejsová 1972, Cohen 1975, Faber et al. 1980, 1981).

Despite our knowledge of the brain and spinal cord pathways (Borovanský 1951, Petrovický et al. 2002, Hagmann et al. 2008, Ge et al. 2012) and of the microscopic and submicroscopic make-up of the nervous tissue and the histochemical and biochemical composition of neuron organelles (Voet and Voetová 1990) and their function at the information input and output as well as engram storage (Hall 2003, Fields 2005), **we are hard put to describe the structural and functional pattern of behaviour – both physiological (mentation, waking, sleep) and pathological (anxiety-based phobic states, psychosis, epilepsy).**

Hence we propose the application of some of the neurocybernetic models for the purpose of orientation in the cerebral structures and functions – even at the cost of simplification. These are, in the best case, homomorphous models, though no longer models of behaviours. This means that we try and model what are already some elements of

the universum (“hardware”) and characteristics – number and importance of relations (“software”). For the brain-stem – cortex correlation we propose a mathematical model as devised by **Farley and Clark** (1954, 1958) such as could help up to define the **states of consciousness** (waking, sleep, or psychosis, epilepsy as pathological states), **types of consciousness** (rational and emotional mentation, in pathological terms: dysattachment/attachment disorder) and **parts of consciousness** (motor, imaginative, propositional verbal, performance, “talent” mentation; in pathological terms: aphasia, dys-dys syndromes /e.g. dyslexia, dysgraphia/, derealisation etc).

The next to consider is model sec. **Ivakhnenko and Müller** (1984) which might help us study in more detail the genesis of cognition and alpha activity in the thalamo-cortical system and noogenesis. Simple mentation and abstraction appear to be realised during the alpha rhythm. Both models fit in well with one another as formators in the Farley-Clark system and can control the complex by altering the input thresholds of action elements and thereby also extensive cortical structures. In this way, it is possible to modulate mentation represented, among other things, by alpha activity. In the following chapters we shall try and present clinical, psychological and laboratory, mainly electroencephalographic, evidence in support of the above claims.

As follows from the diagram (Figure 1), the **neural network static anatomical structure remains unaltered for a long period of life**, e.g., months or even years (Colantuoni et al. 2011, Kremláček et al. 2013). However, what does **change every day relative to the actual state of consciousness** (vigilance, sleep, concentration, relaxation, etc.) is the **dynamic structure of the network** and, accordingly, also the BNN information performance and psychic processes (behaviour, mentation, emotions). Thus, for instance, if we hear water running in wakefulness, we think correctly that there must be water flowing somewhere near. An identical sound in NONREM sleep may give rise to a reflex dream of being by the riverside. Someone in REM sleep can be led to believe and fear that they are floating in a turbulent torrent. Overton (1973) speaks about “state-dependent retention of learned responses”, he simulated this situation on experimental animals using drugs. It is a model of dissociated state with different dynamic but not anatomical neuronal structures changes. Such changes in cerebral activity can, to a certain extent, be monitored in fNMR, MEG, SPECT, PET, (EEG and NIRS, Faber 2010) etc. Details about EEG are given in subsequent sections.

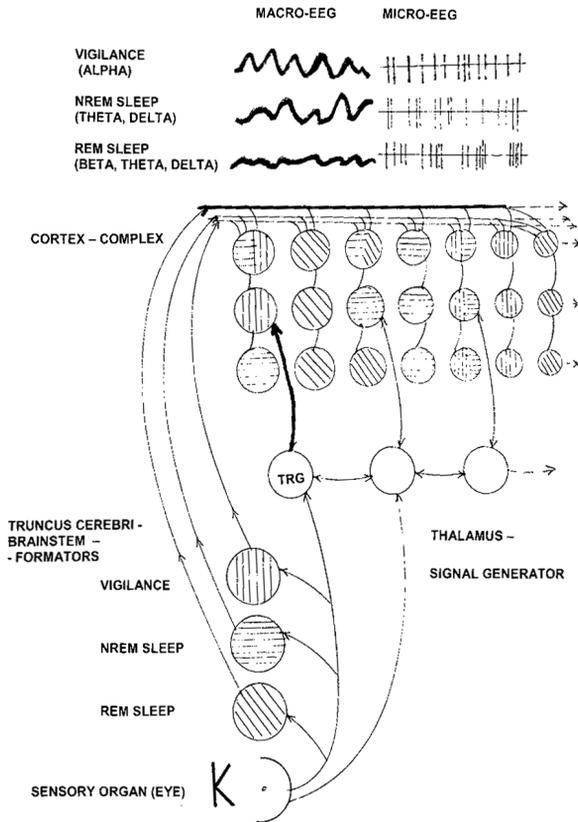


Figure 1

For easier understanding we shall discuss only three important parts of the brain; from the bottom up these are: the brain stem structures, the putative seat of regulatory nuclei serving as formators, the thalamus as a thalamic rhythmic generator (TRG), and the cortex which is analogical to the complex of active elements, i.e., neurons in the brain. (The brain is a set of biological neural networks (BNN), cybernetic models can also be mathematical functions or sets of artificial neural networks (ANN) with neuroids representing active elements).

Formators (non-specific brain stem nuclei) control waking and sleep and act on some of the neurons of the thalamus and cortex. **The signal generator (thalamic nuclei and their rhythm generators TRG)** receive messages from sensory organs and are in themselves able to generate rhythms well discernible on the electroencephalogram (EEG). TRGs send impulses further on into the cortex.

The complex (cortex) is the main processor of information (neural impulses) which it returns back to the thalamus, from where it keeps receiving them repeatedly. Thus, the **Farley and Clark ANN (1954)** is a suitable model for correlations between brain-stem, thalamic and cortical structures. The **Ivakhnenko ANN (1968)**, **Ivakhnenko and Müller (1984)**, an interesting device, is good for repetitive cycles between the thalamus and the cortex.

Each neuron is hatched (shaded) differently relative to its involvement in any of the three different basic states: vigilance, NONREM sleep and REM sleep. Some neurons work in only one state, others in two or even in all three states. This also corresponds to macro-EEG recorded from the human scalp (top on the left) or to micro-EEG recorded from a neuron (top on the right). Used for the purpose were the results of studies by a number of authors (Li and Jasper 1953, Ricci et al. 1957, Evarts 1964, Hobson and McCarley 1971, Creutzfeldt and Houchin 1974, Verzeano 1975, Creutzfeldt et al. 1989, etc.).

INTRODUCTION

At a given time, the sensory organs supply the thalamus with not entirely precise information of images, sounds and tactile impressions. **These messages** from the outside have somewhat blurred outlines, meaning that they **are fuzzy**. We can be easily mistaken in case the perception is too short or if the perceived image, sound or touch is too complex. If the impression is to be eliminated, we have to take a closer look or become absorbed in the sound repeatedly.

That is where the **thalamo-cortical reverberation system (TCRS) comes into play in order to, among other purposes, “defuzzify” our “fuzzified” sensory perception with its reverberation activity**. By “defuzzification” arises from perceptogram ideogram. The actual perception (perceptogram) is apparently, e.g. in macro-EEG record so called brainstem acoustic evoked potentials (BAEP) lasting approximately 8 ms, which represent the way from sensory organ to thalamus. Next activity from thalamus to cortex lasts about 70–130 ms. Higher perception (ideogram) occurs in TCRS activity extending from thalamus to the primary cortical areas (Brodmann’s optical area 17, acoustic areas 41, 42, tactile areas 3a, 3b, 1, 2 as cognitive potentials (P300–P600 ms).

Physiological changes in vigilance (lucid vigilance, relaxation, attention focussing, NONREM and REM sleep) arise from neurodynamic changes in the thalamocortical reverberation system (TCRS) and in the brainstem. They are accompanied by EEG changes, e.g., evoked potentials amplitude is increased in NONREM and decreased in REM sleep, the alpha/delta ratio shows substantial changes in relaxation or in attention, with as much as hemispherical asymmetry developing.

Posner and Raichle (1994) found right parietal lobe dominance for attention with PET measurement invariably showing high activity regardless of whether the stimulus came from the right or the left half of the field of vision.

Brázdil et al. (1998) noted a similar phenomenon with supra- and sub-limit stimulation in P300 evoked potentials in pharmacoresistant epileptics with electrodes implanted into the anterior cingulum, gyrus rectus, orbitofrontal region, laterofrontal cortex, gyrus temporalis medius and gyrus temporalis superior, and also into the amygdala, gyrus parahippocampalis and hippocampus bilaterally. In all of the above listed areas, cognitive P300 potentials were found bilaterally in response to supra-limit stimulation (as for amygdala, on the left side only). During sub-limit stimulation, P300 potentials were discernible solely in the left-side neocortical areas, never on the right side, except in the hippocampus and the gyrus parahippocampalis where they remained elicitable on both sides. **These findings indicate the right hemisphere’s greater significance for vigilance and possibly greater sensitivity in the limbic system.**

Epileptic foci seem to “prefer” localisation in the dominant hemisphere, mostly in the left one (Servít 1989). However, if they appear on the temporal lobe (mainly right), they usually give rise not only to epileptic paroxysms but also to personality deformation and psychosis (Flor-Henry 1969, Faber and Vladyka 1984). Epileptic activity rises in NONREM and declines in REM sleep. **Epileptic focus is a stressor**. Cold stress in sleep lowers the phasic phase of REM sleep, though with the secretion of corticoids rising

(Zloty et al. 1973). Long-distance runners have the greater amount of NONREM sleep the longer distances they cover (Buguet et al. 1979).

But McGrath and Cohen (1978) found augmented REM sleep after psychic stress, mainly in some persons, i.e. in supesors with low neuroticism, not in sensors. The sleep reactions depend on the personality, probands age and stress intensity, low or middle intensity represents rather eustress, epileptic seizures rather dysstress. During stress increases sympathicomimetics tendency and glukokortikoids levels which reduce immune response by suppressing of interleukin-1 and macrophage activities (Dinarello and Wolff 1993). Post-insulin hypoglycaemic stress will not increase prolactin in melancholics while it will in healthy persons, but during healing are hormonal reactions normalized (Grof et al. 1983). Thalamocortical and brainstem structures and their functions (psychic condition, vigilance, epilepsy, psychoses), immunity and endocrine activities are all closely interrelated.

Cognitive function represented by abstract notions (symbols, epistemes, sememes) are manifestations of repetitive secondary activity between the thalamus and other less specific cortical areas (Brodman's optical areas 18, 19, acoustic areas 21, 22, tactil areas 5, 7) lasting about 300–600 ms up to a few seconds (e.g. CNV, Walter et al. 1964, Kutas and Van Patten 1994). In terms of micro-EEG we refer to ideograms (Faber 2005).

We have experimental evidence to show that the addition of one-digit numbers in youngsters up to 15 years of age usually results in alpha acceleration by 0.5 to 1 HZ. **Since alpha activity is a product of the TCRS, we believe that this system serves a "simpler" sort of mentation.** The addition of two-digit numbers causes a similar change in the alpha band, moreover with a build-up of delta activity (Dolce and Waldeier 1974, Faber 2005). Again, **since delta activity is generated by the cortex and its auxiliary delta activity commissural and association systems (DACAS),** using short ("U") and long association fibres and commissural connections, **it represents a "more complex" sort of mentation.**

The TCRS and DACAS take regular turns in their activities. Walter et al. (1964), Timsit et al. (1970), Howard et al. (1982), Faber (1991, 2005) have brought quite a body of evidence to show that delta and subdelta activities invariably underlie complex mentation, e.g., in the form of "contingent negative variation" (CNV), "contingent positive variatios" (CPV), "postimperative negative variation" (PINV, Picton and Low 1971), "Bereitschaftspotentialen" – readiness potentials (Kornhuber and Deecke 1965), P300 wave (Sutton et al. 1965), N400, P600 wave (Kutas and Van Patten 1994), wave of cognitive evoked potentials.

Apart from recognizing the perceived image (light, sound, touch), i.e. from realizing concrete cognition, awareness of the perceived comes in quick succession. In other words, we experience transition from concrete perception to a generalized notion or **attachment of a concrete, albeit "fuzzified perceptogram" to an abstract pattern (notion) in the TCRS, i.e., to a "defuzzified ideogram" – resulting in abstract gnosia. Ideogram is recorded from the scalp as electroencephalogram (EEG).** Example: seeing a roundish object, I can concretely recognize that this is the red apple which I bought the day before, whereupon I realize it is the certain variety, a pome, a tree fruit and so on.

With the help of parents and teachers, a young child learns the process of abstraction. In adulthood, we no longer have to consciously verbalize abstraction as repeated experience has made it automatically known. Young children's and feeble-minded individuals' cognition remains at the level of concreteness so that they need not recognize apples of different shapes, or, indeed, other fruits, i.e., tell the difference between an apple and a pear, and the like.

Formerly, anatomists used to find some 15 billion (= thousand million) nerve cells (neurons) in the human brain; today, about 100 billions (10^{11}), most of them in the cerebral cortex. It appears that for reactivity as such, i.e., for both the concrete (conditioned reflexes, dynamic stereotypes) and abstract mental process (mentation, noesis), cognition and for the generation of motor responses including speech (phatic functions), we do not need such a large number of neurons.

Most of the neurons are likely to serve the purpose of remembering or filing in an archive. This, however, is a dynamic archive where the brain constantly or frequently processes the data stored there either entirely automatically or subconsciously. Primarily, however, it seems to process informations by means of associative operations, by looking for analogies and abstract patterns, thus widening the field of our knowledge and experience.

It seems that in a single process of information or mentation, our brain or rather TCRS would be unable to simultaneously and rationally employ all of the 100 billion neurons. Considering that each neuron will apparently be connected with hundreds up to thousands of other neurons and that it generates 5 up to 50 impulses per second, the whole brain operates with hundreds of billions of impulses per second.

Moreover, the impulses travel in immensely complex networks and circuits. Interneuronal impulses, while subject to binary coding, are usually organized in specific groups the code of which is unknown.

That is why we establish at least inter-impulse interval histograms or, better still, leading cell and mass activity "correlograms" according to Reinis (1997). For brevity's sake, we use the "3F" algorithm: firing rate, firing pattern and space firing (Faber 2007, 2008). Indeed, all our **psychic life is made up of nothing but those impulses**. Though this fact suggests vulgar materialism, we accept it because so far we know of no other mechanisms of information processing in the brain (Hoerness and Heillweil 1969).

Naturally, considering this huge quantity of neurons, synapses and impulses, the combinatorial processes are beyond imagination. Hence, we can see the divine spark in so meaningful an organization of the brain in our consciousness and mentation. Indeed, there seems to be a **paradox: the fewer neurons participate in an actual psychic process, the greater the information power seems to be** (Faber et al. 1973, Raichle 2010) (see next Figure 2 and Figure 11).

The power there is understood to mean not only the process in a simple logical, combinatorial or sequential structure but also complicated mentation such as abstraction, deduction or synthesis of information.

Much of complex psychic operations may well unfold in periods of concentration or relaxation or sleep. There may be a certain optimum quantity of neurons, their connections, synapses and impulses in the analytical-synthetic process. Clearly, as mistakes

are bound to occur in such a quantity of neuronal connections, the brain must have **self-repair mechanisms** to cope with errors (Farah 1977, Adams and Cox 2002). Some of the neuronal processes may be reminiscent of mathematical operations.

The mind-boggling quantity of neurons and the complexity of neuronal networks make it inevitable to think of **stochastic processes, of probability, of multivariate analyses** such as the determination of factors (vectors) and their rotations. Lion and Winter (1953) and Saunders (1963) devised and experimentally proved ways of obtaining “alpha-like” activity by appropriate filtration of generated noise. Using Wilks (1962) periodogram, we found in 19 epileptics a significant quantity of random variables in the EEG curve during vigilance (cca 40–50%), a lesser amount during an epileptic discharge (cca 20–30%), and the least amount during NONREM sleep (10–20%) (Faber 1978, Faber et al. 1975, 1981, Faber and Vladyka 1984).

However, the situation is too complex to warrant unanimity of official expert opinion. Thus, e.g., Reinis (1997) has this to say: “To our knowledge, there are no proven neuronal systems with a documented fractal or chaotic time series.” However, Freeman (1987, 2002), using mathematical models proves a chaodynamic character of impulsion in neuronal populations.

To err is human. Galén (2nd century AD) in his treatise *Eisagogé Dialektiké* uses an accomplished logical system in the form of diverse variants of assertoric syllogism – and yet his interpretation of the cardiovascular and nervous systems is entirely mistaken. Descartes (1662) presented a brilliant description of nervous reflexes as the groundwork of behaviour – and yet he failed to understand Harvey’s correct theory of blood circulation. Locke (1714) devised a grand associative and logical system for abstract mentation which must follow a subconscious course with regard to the enormous volume of data and processes in our brain – and yet he never accepted the existence of subconscious mentation. Most of these discrepancies in the minds of great men are resolved by further experimentation later on.

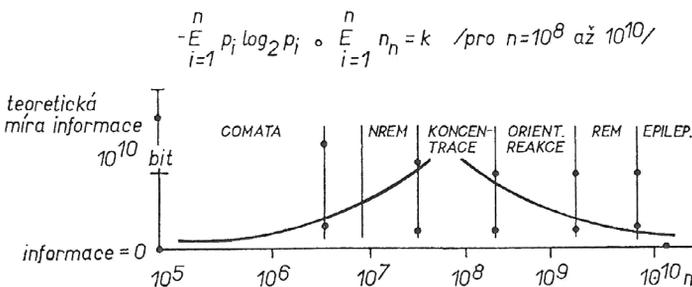


Figure 2

A graphic representation of presupposed correlation between the theoretical brain information rate (capacity: “míra”), on perpendicular axis y, which expressed in units of information (bit) and the number of neurons active at the given time on horizontal axis x. The correlation proper between these two quantities is expressed by the hyperbola. Epileptic activity engages maximum neurons, represent the simplest neuronal nets state, provokes distress with typical EEG grafoelements and increasing stress hormones, e.g., ACTH, cortisol and prolactin (Gallagher 1987). (Both axes are logarithmic.)