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An Electroencephalographic and Neuroinformatic Study

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CHARLES UNIVERSITY IN PRAGUE

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CONTENT

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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 Servít 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, speach 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 "neurophilosophical" 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 imiginatio rei presentis et imaginatio est idem, quod perceptio rei absentis," in other words "nihil est in intelectu, 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.

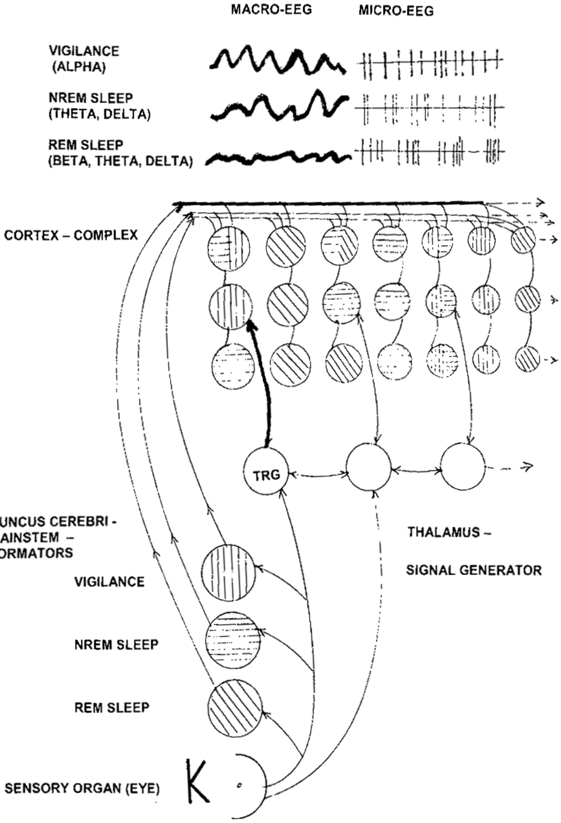


Figure 1

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 approximatelly 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, tactil 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 hemispheral 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 supresors with low neuroticism, not in sensitors. 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 (Brodmnan's optical areas 18, 19, acustic 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), "Bereitschaftpotentialen" – 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 "defuzzyfied 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 impulsation 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.

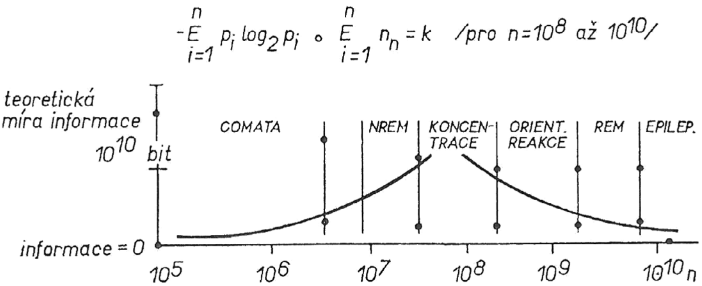
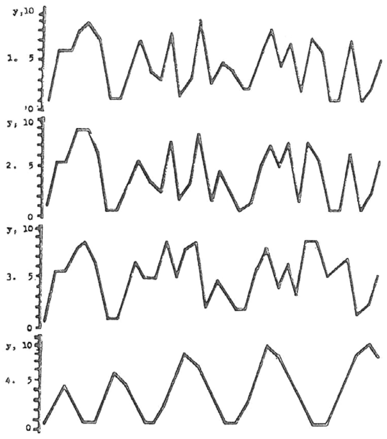


Figure 2

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 dystress with typical EEG grafoelements and incresing stress hormons, e.g., ACTH, cortisol and prolacatin (Gallagher 1987). (Both axes are logarithmic.)



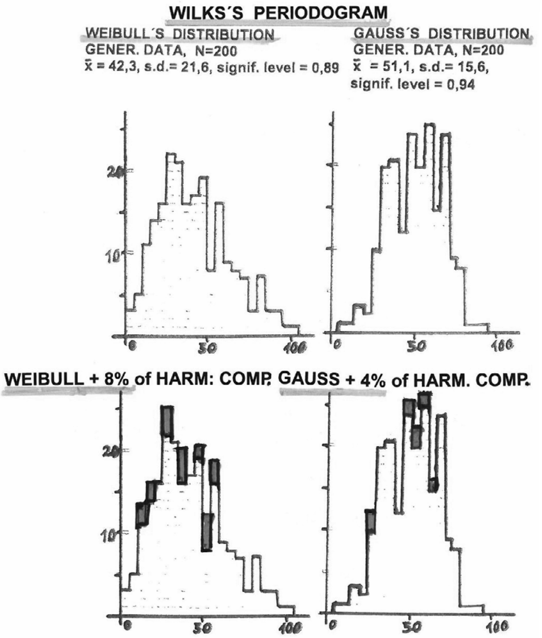
Example No.	Multiple correlation coefficient	Number of harmonic frequencies	Level of significance	Residual variance
1	0.13	0	1 (insign.)	6.52
2	0.20	1	10^{-3}	6.28
3	0.37	3	10^{-7}	5.92
4	0.97	20	10^{-7}	0.38

Figure 3

The upper part shows four curves with different numbers of regular variables. Curve 1 (from above) contains only random numbers in matrix span (axis y) from level 1 to 9 composed according to tables of random numbers only. The statistical distribution is equalised, i.e. all numbers have the same probability of presentation with a sequence of one-digit numbers: 1, 5, 5, 8, 9, 7, 1, 1, 4, 7, 4, 4, etc. totalling 500. Next, curve 2 is enriched with regular – periodic variables: 1 was added to every 4th and 5th number, and 1 was subtracted from every 9th and 10th number. Curve 2 then has 4.4% of the regular variables. Curve 3 has twice as many regular – periodic variables, and 8.8% of regular (harmonic) variables. Curve 4 is a model of alpha wave and alpha spindle without random variables.

The bottom table shows the results of an analysis using Wilks's periodogram. The multiple correlation coefficient (MCC) shows nonsignificant harmonic variables in curve 1, while the next two curves have significant periodic components, MCC showing 0.20 and 0.37 respectively. MCC for alpha activity is 0.97. Only 4.4% of harmonic components (also in the EEG curve?) is enough for the detection of meaningful information detection in a big pool of noise with equalised distribution. We suppose similar situation in brain (biological neuronal net, BNN) and artificial neuroidal nets (ANN).

Our hypothesis is based on the fact that neurons show, already in the prenatal period, a random impulsation activity, and that after birth comes a period of imprinting or impression of new neuronal "3f" algorithms into the original stochastic "arrangement". Finelly similar mechanism – simulated annealing is often used in ANN (Šnorek 2004). In psychological terms, this is consistent with imprinting, a process which is seen in birds only hours after hatching, and which in mammals is likely to take a long time and to be more complex. In the human young, imprinting in the form of attachment proceeds until about 3 years after birth.



Name of example	*Multiple correlation coefficient*	*Period (Hz)*	*Critical level*	*Note*
"Gauss 1" (0 % regul. signal)	0.27	(0.36)	0.28	—
"Gauss 2" (2 % regul. signal)	0.27	(0.36)	0.21	—
"Gaus 3" (4 % regul. signal)	0.29	0.99	0.02	1 significant period
"Gauss 4" (6 % regul. signal)	0.51	0.99	0.0001	2 significant periods
"Gauss 5" (8 % regul. signal)	0.70	0.99	0.000001	4 significant periods
"Gauss 6" (10 % regul. signal)	0.77	0.99	0.000001	4 significant periods
"Weibull 1" (0 % regul. signal)	0.22	(0.41)	0.63	—
"Weibull 2" (2 % regul. signal)	0.22	(0.99)	0.64	—
"Weibull 3" (4 % regul. signal)	0.20	(0.41)	0.83	—
"Weibull 4" (6 % regul. signal)	0.24	(0.99)	0.30	—
"Weibull 5" (8 % regul. signal)	0.59	0.99	0.001	2 significant periods
"Weibull 6" (10 % regul. signal)	0.63	0.99	0.0001	2 significant periods

Figure 4
The upper part shows two sets of variables with different types of statistical distribution: Weibullian and Gaussian. Again we undertook an experiment designed to enrich these curves with regular variables from 0% to 10% (gray lines) of periodic addition of number one (medium part of figure). The bottom part shows, that both noise sets are good for information transmission, though the Gaussian distribution is better. All three types of noise (equalized, Gaussian, Weibullian) can really exists in ANN and BNN too because they do not interfere with the information process, they are good information carriers. Only one condition must be met, both ANN and BNN must have suitable noise filtration programs.

THALAMOCORTICAL REVERBERATION SYSTEM

The thalamocortical reverberation system (TCS) is anatomically defined in its very name (neocortex and thalamus), in terms of function by its **periodically permanently maintained impulsation interneuronal contact**. It is exactly the permanent circulation of impulses between the thalamus and cortex that makes it a very robust system function-wise.

Thalamic nuclei are arrayed in a number of specific nuclei designed to transduce impulses from peripheral senses (mainly from the eye, ear, skin and muscles) into the cortex and non-specific brain-stem nuclei, and from those nuclei of the reticular and raphe formations again into the cortex and back into the thalamic nuclei. Or to put it in a simpler way, the specific nuclei transduce concrete data from the surrounding world along specific pathways into the cortex with non-specific nuclei acting as eutopic formators (see later), whose impulses determine the programmes for the way these data are to be treated, i.e., processed (Faber et al. 1981).

Specific fibres terminate mainly in layer 4 of the cortex, non-specific one in cortical layers 1 and 2 (Eccles 1953, Andersson and Holmgren 1975, Faber 2001, Jones 2002).

Most of the above listed thalamic nuclei are made up of small groups of neurons capable of not only transducing impulses from the senses into the cortex, but also of changing the codes and setting their own rhythm; hence their name: thalamic rhythmic generators (TRG). The cortex then receives from the thalamus not only information (data, facts) about the surrounding world but also the thalamic rhythm. **The cortex-received and modified TRG rhythm is recorded in the form of EEG where it is present primarily in the alpha and beta bands**. One cycle of impulses reverberating between the thalamus and cortex during vigilance (psychic concentration and relaxation lasts approximately 100 ms, i.e., about 10 Hz, giving rise to one alpha wave in the shape of a sine wave if registered graphically.

The autonomous rhythm of the cortex appears mainly in the delta band (Stein 1965, Steriade et al. 1993). These EEG curves are not mechanically precise but rather quasi-periodical and quasi-stationary rhythms, yet “for convenient empirically corrected practice” they are made subject to mathematical analysis (e.g., harmonic Fourier transform or Fast Fourier Transformation – FFT, or Gabor filtration (GF) or polynoms of higher order etc.).

For precision’s sake, distinction has to be made between macro-EEG or scalp EEG such as is routinely used for diagnostic purposes, and micro-EEG designed to visualise electric impulsation activity recorded with intra- or extra-cellular (neuronal) microelectrodes.

As already mentioned, macro-EEG operates at another, indeed, the fastest frequency band – gamma. However, it is almost impossible to record from the scalp as it is “filtered away” by the meninges, diploic bone and scalp skin. It is well discernible only from electrodes attached directly to the cortical surface in what is known as electrocorticography. It would be really worth learning more about this gamma activity because it reflects far more precisely than other EEG bands the activity of the interneuronal impulsation information game in visual structures (Wróbel 2000, Hoogenboom et al. 2006).

Many authors have described – in experimental animals and peroperatively in humans, too macro- and micro-EEG and their correlations under different circumstances such as during epileptic activity (Li and Jasper 1953, Ward 1969, Langmeier et al. 1982), during sleep (Evarts 1964, Hobson and McCarley 1971, Battaglia et al. 2005), during conditioning (Ricci et al. 1957), during rest and photostimulation (Lopes da Silva et al. 1973, Steriade 1974, Verzeano 1975), during speech (Creuzfeldt et al. 1989) and others.

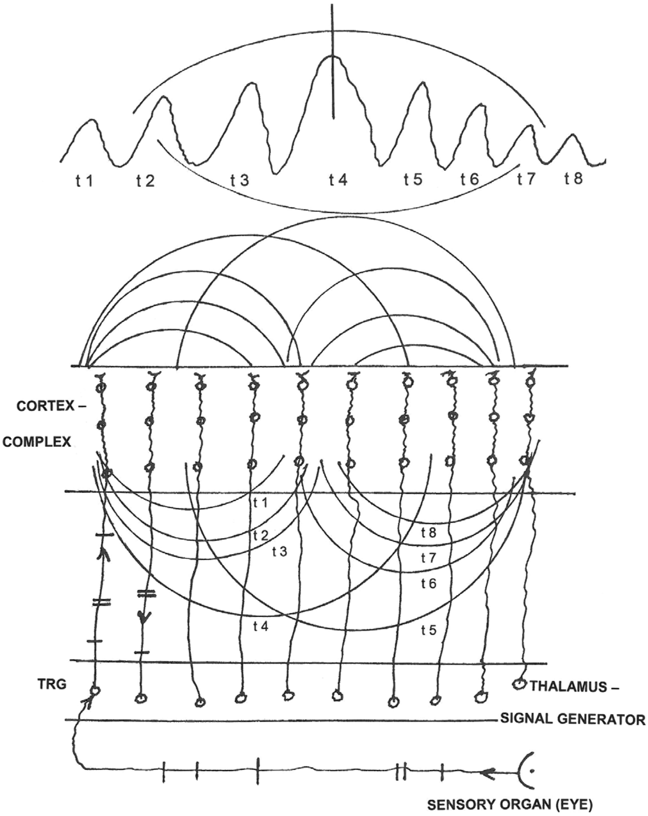


Figure 5

The upper part carries a schematic representation of a typical fusiform shape of alpha activity with t 1 to t 4 showing the development of alpha waves of growing amplitude at times t 1 to t 4 (ascending alpha = ALAS, a build-up of the number of neurons involved in MIA iteration; t 5 to t 8 – alpha waves of decreasing amplitude at times t 5 to t 8 (descending alpha = ALDE, diminishing number of neurons involved in a selective iteration programme). In the cortex are schematized ten cortical columns (CC). Timed alpha activity is shown. The lower part shows a schematic representation of TCRS. The small circles represent neurons, with the arrows indicating the direction of impulses shown as short lines crossing the axons. The neurites or axons are fibres interconnecting thalamic and cortical neurons. The large semicircular curves represent increasing (t x, x = 1–4) or decreasing (t x, x = 5–8) amounts of the neuronal population and, thereby, also the alpha activity synchronized recruitment in the cortex.

As follows from those studies, neurons operate at nearly noise level, and the simplest way is to express them by description, e.g., that they congregate into groups, that such groups are followed by pauses, which kind of interimpulse interval histogram they have and the like.

To describe such activity, means of non-linear dynamics definitely fit such purpose (Wünsch et al. 1977, Freeman 1987, Le Van Quyen et al. 2001). It is also obvious that interneuronal impulsation invariably has an unknown code and that for the time being it is best expressed using an interval histogram which then helps to express statistical distribution. For example, motoneurons exhibit Gaussian distribution during vigilance, but Poisson distribution during sleep. Small interneurons may have bimodal or multimodal distribution, etc. (Wilgenburg and Smith 1970).

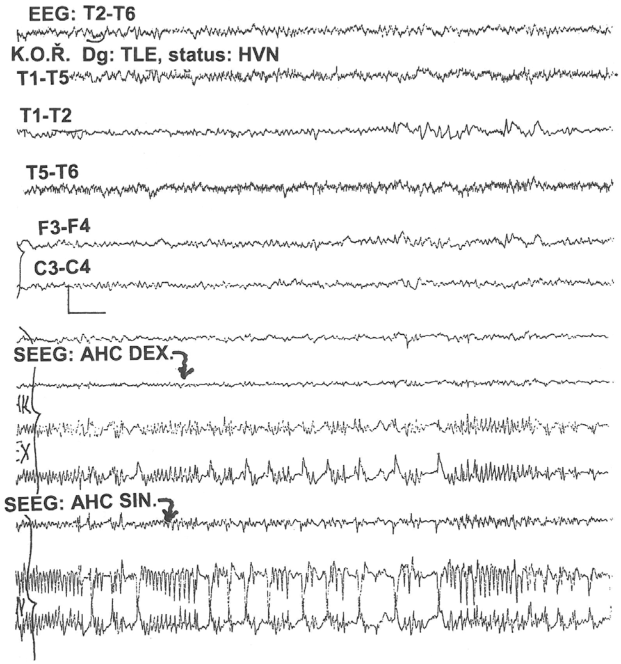


Figure 6
A 32-years-old patient suffered from complex partial epilepsy (temporal lobe or psychomotor attack with optic pseudohalucinations and sometimes with states of anxiety). Owing to its intractable nature (pharmacoresistance), he was indicated for epileptosurgical intervention, in particular for amygdalohippocampectomy (AHCE). What remained after this step were sporadical short pseudohallucinations without obnubilation and typical psychomotor attacks. The upper part shows 6 scalp EEG channels with minial abnormality (atypical spike and wave complexes of low amplitude) in T1-T2 derivation (before operation). The next three channels are stereo-EEG (SEEG) from electrodes implanted in the right AHC, and the last three channels show SEEG from the left AHC. Both AHCs shows pathological recruitment of sharp “beta” activity of very high amplitude with intermittent delta waves. These bursts are accompanied by intensive short anxiety without areactivity and with speech disturbances. This is quite good evidence of relatively autonomous and variegated activities in the thalamocortical (rational function) and septohippocampal (limbic, emotional functions) systems (Faber and Vladyka 1984, 1987).

Having used FFT and periodographic analysis of macro-EEG from scalp and implanted (stereo-EEG = SEEG) electrodes in epileptics and psychotics at rest and during psychotests, we found major changes in the EEG spectra of the neocortex as well as in the SEEG spectra of amygdalohippocampal complexes (AHC), i.e., in the septohippocampal (limbic) system (SHS) (Faber and Vladyka 1984, 1987, 1994).

The neocortex shows a considerable build-up of delta during psychotests, (Dolce and Waldeier 1974) e.g., during Raven's test, reading, or in adding up two-digit numbers (Faber 2005): the more difficult the test, the higher the delta level, though at times it

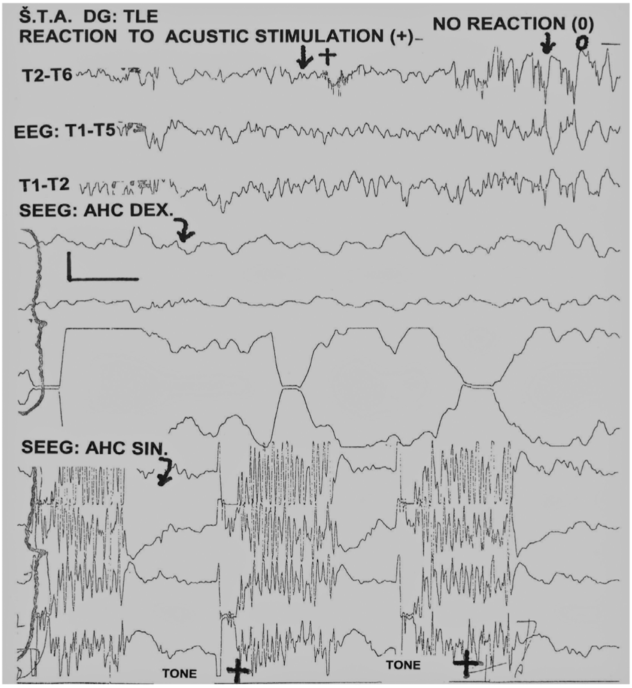


Figure 7
A 20-years-old girl suffering from temporal lobe epilepsy with automatic movements, obnubilation and retrograde amnesia. Owing to her drug resistance, she was indicated for epileptosurgery. Her clinical state after amygdalo-hippocampectomy was substantially improved, only short state of kakophory or anxiety remain, but without psychomotor attacks. The upper 3 channels are scalp EEG curves from the right, left and transtemporal electrodes. The next four are stereo-EEG curves from electrodes implanted in the right amygdalohippocampal complex (AHC), and the last four are SEEG curves from the left AHC. Clinical state before operation. We applied 35 acoustic stimuli during 40 minutes of afternoon EEG and SEEG recording with the patients asked to press the button immediately after hearing the sound. SEEG: very intensive epileptic discharges of high amplitude in the alpha and beta bands and electric silence brought anxiety, but not strong enough to disturb the reaction to the sound. EEG: however, relatively smaller and shorter atypical spike and wave complexes interrupted the sound reactivity in 90% of the stimuli. Again, this serves as evidence of the dual type of consciousnes: thalamocortical rational system (TCRS) and limbic (AHC) emotional system (Faber and Vladyka 1984, 1987).

holds true, to a degree, for theta, too (Faber and Vladyka 1984, 1987). **Hence, to a certain extent, we can apply the mechanism of Prigogin's Brusselator to the TCS and to the TCS-SHS relationship** (Prigogine and Stengersová 2001, Faber 2003).

The **properties and tendencies of thalamocortical reverberation system (TCRS)** can be summed up as follows:

- **to generate** oscillation of synchronised depolarisations and hyperpolarisations of the axonodendritic membranes of the superficial cortical layers and somatic membranes of the neurons of layers of the cortex (standing potentials), sometimes also axonal spiking potentials of the cortex, and also oscillation of rhythmogenic structures in the thalamus (Jasper 1969, Creutzfeldt and Houchin 1974, Steriade et al. 1993),
- **to become manifest** through "eusynchronisation" or generation of rhythmic sine waves and their recruitment, i.e., spindle-shaped configuration in EEG under normal conditions (alpha activity), and also through hypersynchronisation (epileptic graphoelements of the "spike-and-wave" type (SW) under pathological conditions (Jasper and Droogleever-Fortuyn 1946, Steriade 1974, Avoli et al. 1981). This EEG activity may show dynamic changes, e.g.,
- **to disappear**, i.e., **desynchronise** during decreased vigilance in NONREM 1, in REM but also during increased vigilance, eyes open and arousal, or during mentation, which is most likely to happen owing to negative RTG nuclei interference (Berger 1938, Dolce and Waldeier 1974, Faber 2001), or
- **to grow**, i.e., **hypersynchronise** during relaxation, NONREM 2 up to 4, within a certain period of time of the stimulus (Gastaut et al. 1957, Skinner 1971), during meditation (Banquet 1973); probably a case of positive RTG nuclei interference. Consequently, TCTR is able
- **to produce** EEG alpha and beta activity in wakefullness (Berger 1938, Dusser de Barenne and McCulloch 1938) depending on the actual motor and mental situation, and sigma, theta and delta activity in sleep,
- **to generate** dual electromagnetic signals: macro-EEG known as clinically much used scalp EEG for the registration of mainly "standing" potentials, and micro-EEG, i.e., recording neuronal membrane unit potentials or impulses or "spiking" potentials (Li and Jasper 1953, Verzeano 1975, reviewed until 1972 in Faber 1975, Kandel 1985),
- **to code** the external and internal world by means of "interface" sense organs for sequences of neuronal impulses (SNI organized in "3f" algorhitm) characterised by the number of impulses per unit of time (firing rate), by the firing pattern and by the spatial arrangement of impulses in the neuronal networks (space firing); in other words, to code the outer world on the way between the senses and the thalamus into perceptograms, and subsequently, on the way between the thalamus and cortex into ideograms,
- **to receive** two kinds of information, a) directions for solution, i.e., algorithms, e.g., procedures showing how to add up, divide, find the square root, think logically, etc., and b) data designed for processing with the aid of such algorithms, and in this way
- **to generate** gamma activity at frequencies of up to 30 Hz according to Jones (2000), up to 80 Hz according to Wróbel (2000) and up to 110 Hz according to Hoogenboom

et al. (2006) during mental or sensory activity, i.e. while the major afferent sensory pathways are stimulated.
However, gamma can only be recorded from electrocorticograms (ECoG), not from EEG. The advantage of knowing this is in that the power of gamma activity is directly proportional to the activities of neuronal networks, and perhaps consistent with impulsation activity. By decoding gamma activity we could learn more details about how neuronal networks operate during sleep and vigilance, and possibly also during psychic activity (Lisiené and Mickis 1973, Faber et al. 1999),

- **to maintain** its own rhythm which is apparently necessary for other brain structures within certain limits (such as hourly pulses in computers); it must neither disappear (confusion?, dementia?) nor lapse into undampened oscillations such as in epileptic activity (Jasper and Droogleever-Fortuyn 1946),
- **to keep TCTR in communication with the septohippocampal system,** the SHS representing the memory register and centre of affectivity and personality structure (Mac Lean and Delgado 1953),
- **to convey concrete information to the cortex**; the sensory afferents and primary sensory cortical areas are activated, thus helping to produce an EEG record of the NPN complex in the cortex, often discernible only after EEG signal averaging in what, from the psychological point of view, is sensory perception of mental images (many authors from Bishop and Clare (1959–1960), Holliday up to Jones (2002),
- **to converge impulses** from all sensory (sense) organs (eye, ear, skin, taste and smell) toward the thalamus,
- **to proliferate the information analytical-synthetic process** into the thalamic generators and cortical columns nearby – i.e., to diverge from the thalamus sensory impulses into the large areas of the cortex (Andersson and Holmgren 1975),
- **to integrate sensorimotor impulses already in the thalamus** itself, e.g., the "thalamic" rat deprived of the neocortex, archicortex and basal ganglia is capable of creating operant conditioning, though devoid of plasticity (Huston 1975). The coherence function express integrity of cortex. Therefore depressed alpha coherence and increased delta coherence are significantly correlated to the degree of dementia, mainly Alzheimer disease (Brunovský et al. 2003).
- **to repeat** "data processing"; this appears to be addressing or search for solutions expressed in terms of cognitive evoked potentials, i.e., P300, N400, P600, which again appears to represent TCTR and SHS co-operation; in psychological terms we refer to sensory perception (Sutton et al. 1965, Kutas and Van Patten 1994, Myslivešek 2003), (in computer programme: if – then – else),
- **to express the state of motor preparedness** ("Bereitschaftpotentialen") (Kornhuber and Deecke 1965) or attention preparedness or expectation (expectancy wave) as manifested in EEG subdelta activity – contingent negative variation – CNV, or contingent positive variation – CPV (Walter et al. 1964 in Howard et al. 1982) or as a sign of self-control taking the form of postimperative negative variation – PINV (Timsit et al. 1970 in Howard et al. 1982, Picton and Low 1971),
- **to "interate"**, interation is like iteration, a specific SNI circulation in TCTR, which, however, fails to reach complete mathematical precision since neurons keep sending