THALAMO-CORTICAL REVERBERATION IN THE BRAIN PRODUCES ALPHA AND DELTA RHYTHMS AS ITERATIVE CONVERGENCE OF FUZZY COGNITION IN AN UNCERTAIN ENVIRONMENT

J. Faber, M. Novák[*]

Abstract: In this paper, an extended analysis of the human electroencephalographic signals (EEG) in the region of alpha rhythms is presented. The consequences of the existence of spindle-like (fusiform) shape are discussed and verified on the set of experimental measurements. The hypothesis of possible interrelations of the EEG alpha fuses with a tested person's psychical state and restrictions is presented.

Key words: *Electroencephalography (EEG), alpha activity analysis, spindle-like (fusiform) shape, psycho tests, iteration, multilayered iterative algorithms (MIA)*

Received: January 24, 2011
Revised and accepted: February 10, 2011

1. Introduction

The thalamus, a large subcortical nucleus, houses rhythmic thalamic generators (RTG) which act as terminals of nerve pathways from sensory organs (eye, ear, skin, muscles, nose and tongue). The RTG nerve cells (neurons) send out fibers to the brain cortex. Nerve impulses reverberate between the RTG and the cortex unceasingly, i.e. in vigilance (wakefulness) and in sleep, throughout our life, the phenomenon, being known as the thalamocortical reverberation system (TCRS). In the brain's electric activity recorded from the cranial surface (EEG) this cyclic activity takes the form of frequencies of 1 – 30 Hz. The alpha frequency (8 – 13 Hz), typical for vigilance, mostly appears in the form of undamped oscillations which immediately change into damped oscillations. That is what gives the alpha rhythm its spindle-like (fusiform) shape. One alpha wave lasts about one tenth of a

---

[*] J. Faber, M. Novák
Czech Technical University, Institute of System Reliability and Telematics, Prague

second, consistent with one cycle in the TCRS, in which tens of billions of neurons and hundreds of billions of their impulses are involved. That is why we presume – as shown in our previous works [9], [10], [11], [12], [16] – the presence of not only periodic but also stochastic processes.

One alpha spindle (AL) lasts roughly one second, corresponding to reiterated exchange of impulses (information) in the TCRS. This is rather like iteration with convergence to the target solution of a task (problem) in the descending portion of the alpha spindle (ALDE). The ascending portion of the alpha spindle (ALAS) might correspond to the mechanisms of MIA (multilayered iterative algorithm), as described by A. G. Ivakhnenko, see e.g. [46]. In the course of learning with a "teacher", MIA, an inductive artificial neuronal network, takes on new neurons and neuronal layers according external criterion. "Redundant" neurons are excluded in subsequent selection for the neuronal population to approach the task solution, i.e. from the signal point of view convergence to global minimum (or attractor) and from the psychological point of view to problem solution or to abstraction, creation of notio, epistémé, and sémém.

It appears that – using Gabor's frequency filtration (GF), local coherence function (LCF) and Poincaré's analysis (PA) – we have come closer to our hypothesis of a dual type of iteration: MIA in ALAS and "common" iteration in ALDE.

24 persons were examined during EEG recording and simultaneous psycho testing. For our purposes we made use of sections in relaxation and during the addition of two-digit numbers, both with the eyes closed. The results showed quite an amount of interindividual differences. However, there was a preponderance of higher values of alpha energy in GF and lower values of coherence (LCF) in ALAS over those values in ALDE. PA demonstrates the cyclic feature of alpha spindle during ALAS and ALDE during relaxation and contrary noncyclic one during psychic activity. This shows the alpha spindle asymmetry, i.e., greater and more complex recruitment of alpha in ALAS. The method may well prove to be useful as a supplement of tests for attention or for personality.

The thalamus is a large subcortical part of brain, from which neuronal impulses are sent to the cerebral cortex and vice versa. These synchronized electrochemical impulses keep being repeated (reverberating) in groups. Hence, once appropriately amplified, they can be recorded from the intact surface of the head (scalp) as *rhythmic electric potentials in what are called electroencephalograms (EEG), [6], [20], [35]. Alpha waves (8 – 13 Hz) and beta waves (14 – 30 Hz) predominate during relaxed wakefulness (vigilance), accompanied – during mentation – by delta activity (0.5 – 3.5 Hz).* The brain stem regulates arousal as well as the magnitude of the alpha rhythm, as described by Moruzzi and Magoun [28] and corroborated by a number of authors, such as Kandel and Schwartz [24] and others.

The macroscopic organization of the brain is determined genetically in the prenatal period though after birth its microscopic structure continues being perfected under the impact of information (impulses) coming from the sensory organs (eye, ear, muscles, skin, nose and tongue). Neurons in the brain are analogical to "neuroids" in artificial neuronal networks, complete with inputs and outputs of impulses and a variable impulse threshold determining the level to be exceeded for the impulse to be sent out.

Different areas of the cerebral cortex are specialized for different functions, such as analysis and formation of speech, target-oriented movement, reading, writing, arithmetics, abstract mentation etc. Brodmann [7] was the first to identify, with the aid of microscopic histological analysis, 52 different areas in either hemisphere. Today, we associate each area with specific functions according to the outcome of psychological testing carried out together with the isotope method of PET (positron emission tomography), see [27], [31]. The areas can also act as formators, i.e., centers of regulation similarly as the brainstem structures in control of vigilance and sleep, see [17], [10], [11], [12], [14].

Experiments have brought convincing proof of the difference between the resting state of the mind with the eyes closed and complete relaxation with, among other things, alpha amplitude increase [15]. In terms of psychophysiology, we have yet to decide whether the “nonalpha time index” (EEG desynchronization) during habituation after eye opening is directly proportional to intelligence [19] or to arousal [21]. Apparently enough, resting alpha is not exactly sinusoidal as the ascending part of this wave is steeper than the descending part and prone to becoming more symmetrical during psychic activity [12].

Nerve cells of sensory organs send information along nerve fibers to the brain stem and from there on to the thalamus to pass impulses on to other neurons. Besides sensory nuclei, the thalamus houses also motor neurons, which control muscle activity, in particular movement of the extremities, trunk, mimic muscles, respiration, speech etc. Most of the thalamic nuclei have yet another microstructure and function: groups of neurons called rhythmic thalamic generators (RTG) which generate mainly the already mentioned alpha and beta rhythms. This cyclic activity appears to be analogical to clock pulses in automatic computers.

The cortex is organized horizontally into 6 layers and – vertically – into columns numbering roughly one or ten million. Most of the outputs from the particular RTGs are aimed at the cortical microstructures, i.e., at the columns (echelons) totaling about 25 thousand in the cat, and approximately one or ten million in humans. Each column contains about ten thousand columns to receive specific information (SI) from sensory organs in layer 4 and, in part, in layer 6 [1] of the cortex, and non-specific information (NI) in cortical layers 1 and 2. NI coming from “nonspecific“ brainstem structures determine the brain’s programme: wakefulness, relaxation, concentration or sleep.

The thalamic nuclei then have two principal functions (and thirty more, [14], [15]): transmission of impulses from sensory organs to the specific areas, and sending cyclic and synchronized impulses to large non-specific association areas of the cortex. Specific areas of the cortex: for optical analysis – areas 17, 18, for acoustic analysis – areas 41, 42, for tactile analysis – areas 1, 2, 3, for motor control – areas 4, 8, for speech – areas 44, 45, 46. The large so-called association areas serve the following purposes: for optical analysis – area 19, for acoustic analysis – areas 21, 22, 39, 40, for tactile control – areas 5, 7, for motor control – areas 6, 10 to 14, for speech – area 47. The main psychic (cognitive – gnostic, speech – phatic) processes appear to be facilitated mainly thanks to *the cyclic activity of neuronal impulses between the thalamus and the cortex as well as to their analytical-synthetic processing inside those structures in what is called the thalamo-cortical reverberation system (TCRS).*

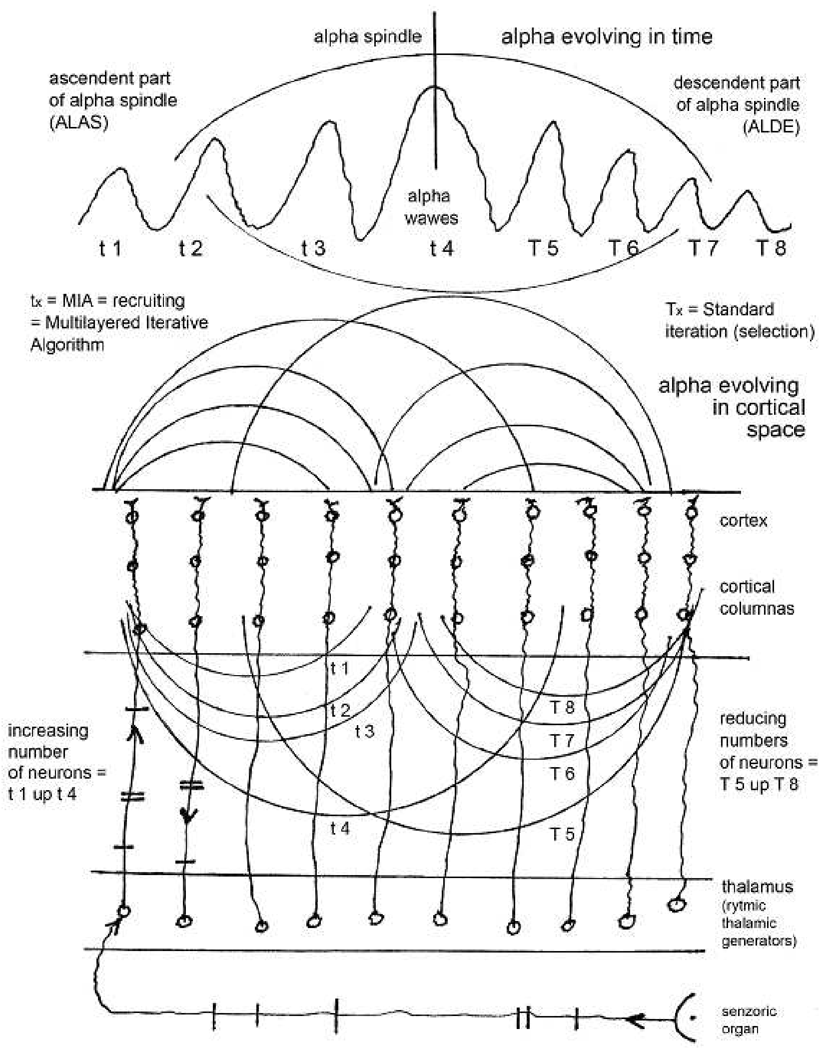

Fig. 1 *The upper part carries a schematic representation of a typical fusiform shape of alpha activity with t 1 to t 4 showing the development of alpha waves of growing amplitude at times t 1 to T 4 (ascending alpha = ALAS, a build-up of the number of neurons involved in MIA iteration; T5 to T8 - alpha waves of decreasing amplitude at times T5 to T8 (descending alpha = ALDE, diminishing number of neurons involved in a selective iteration programme). 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 fibers interconnecting thalamic and cortical neurons. The large semicircular curves represent increasing (tx) or decreasing (Tx) amounts of the neuronal population and, thereby, also the alpha activity synchronized recruitment in the cortex.*

There is no questioning the existence of the TCRS. Its function has been recognized since the days of the discoverers [8], [4], [5], [3] right up to our times [23]. 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 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 at or become absorbed in the sound repeatedly. That is where the *TCRS comes into play in order to, among other purposes, "defuzzify" our "fuzzified" sensory perception with its reverberation activity.* Actual perception is apparently the TCRS primary activity extending from the thalamus to the primary cortical area, and lasting about 300 ms. In terms of neuronal impulses this is a perceptogram. Abstract notions (symbols, epistemes, sememes) are manifestations of repetitive secondary activity between the thalamus and other less specific areas (TCRS) lasting about 500 ms up to a few seconds. In terms of microEEG we refer to ideograms [15].

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 [14]. Again, *since delta activity is generated by the cortex and its auxiliary systems (DACAS*), using short and long association fibers and commissural connections, *it represents a "more complex" sort of mentation. The TCRS and DACAS take regular turns in their activities* [11]. Walter et al. [40], Timsit et al. [38] and Howard et al. [22] 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", P 300 wave of cognitive evoked potentials or "readiness" potentials.

Apart from recognizing the perceived image (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.* Example: seeing a roundish object, I can specifically recognize that this is the red apple I bought the day before, whereupon I realize it is the Nonetit 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., they are not able to recognize 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 billion, most of them in the cerebral cortex. It appears that for reactivity as such, i.e., for both the specific (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 information 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 [33]. For brevity's sake, we use the "3f" algorithm: "firing rate, firing pattern a space firing" [15]. 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.

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* ([9], [32]). 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 these 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 [1]. 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 or vectors and their rotations. Lion and Winter [26] and Saunders [34] devised and experimentally proved ways of obtaining "alpha-like" activity by appropriate filtration of generated noise. Using Wilks periodogram, we found a significant quantity of random variables in the EEG curve during vigilance, a lesser amount during an epileptic discharge, and the least amount during NONREM sleep [10]. However, the situation is too complex to warrant unanimity of official expert opinion. Thus, e.g., Reinis [33] has this to say: "To our knowledge, there are no proven neuronal systems with a documented fractal or chaotic time series." However, Freeman [18], using mathematical models proves a chao-dynamic character of impulsation in neuronal populations. 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". 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.

We have in mind an analogy with iteration as such or MIA (multilayered iterative algorithm) processes, as described by Ivakhnenko (quoted from Šnorek [36] and Novák et al. [29]). In our opinion, it is exactly *reverberation in the TCRS that stands for iteration represented in the EEG curve by fusiform alpha activity with its ascendant (ALAS) and descendant (ALDE) parts.* The neuronal network in ALAS operates in accordance with the MIA algorithm, while ALDE represents typical iteration, i.e., a more or less stereotype process aimed at the desired end.

The MIA (multilayered iterative algorithm) was described by Ukrainian mathematician A. G. Ivakhnenko as early as 1958. He devised a mathematical procedure, by which an artificial network of neuroids is developed using the inductive method and a teacher. This means that neither the number of neurons in hidden layers nor even the number of layers are set beforehand, but that this number keeps growing and forming in the course of learning as needed, i.e., the network keeps being built up until certain required external criteria are met. What follows then is neuronal restriction by selection. If the number of neuroids continues to grow, learning becomes worse, the network is said to be overlearned. This brings the artificial network still closer to the actual development of biological, in particular, cortical structures. Genetic programmes used in artificial neural networks also follow examples from evolution [25].

The fusiformity of EEG graphoelements, alpha activity in particular, results from recruitment. This means that with every alpha wave or every cycle of impulses reverberating between the thalamus and the cortex the number of involved neurons increases [3], [4], [5]. *This part of the alpha amplitude growth is discernible in the first half of the alpha spindle (ALAS).* This is perhaps due to *the search for the optimum size of the neuronal population.* Optimum here means the number of neurons, their layers and areas needed for coping with a given task.

However, the aim of the solution for differently complex problems is differently remote, which is why the alpha spindles are differently long, as a rule, one half up to one to two seconds. The *search for the "right kind of programme*" culminates in the appearance of one or two alpha waves of the highest amplitude with the height of the waves declining from there on. *The ALDE phase is alpha wave amplitude decreasing in the second half of the alpha spindle due to a decline in the neuronal population. This can be likened to the process of neuroid selection in an artificial neuronal network (ANN), as devised by Ivakhnenko. The ALDE phase also coincides with the task solution proper running on the rules of the ordinary iteration process, i.e., with the computation aimed at the desired results, in other words, at maximum cognitive approximation and cognitive success.* This is where iteration takes on particularly complex forms in what is stereoiteration in an environment of stochastically operating neurons. Hence, we sometimes refer to "*interation*" [15].

It seems that in the ALAS phase the TCR system tries to find an algorithm for the solution of the problem, while in the ALDE phase it is already working on the problem according to the algorithm found. The purpose of our computation is to find out whether or not this is actually the case. Obviously enough, most of the alpha spindles fail to find a meaningful solution of the task; on the contrary, very many such "alpha attempts" are necessary for successful cognition.

The differences between alpha activity at rest or during hyperventilation or cogitation in one and the same human are discernible with the naked eye. That was what made us use some mathematical methods for alpha rhythm analysis under diverse conditions in order to define its character. In our view, the EEG curve still hides a great deal of important information. It should be added, though, that emotions and affectivity, too, have an impact on the human mind, mainly rational power. Our consciousness is known to have a dual character; it is both rational and emotional. Here, for the sake of simplicity, we refer primarily to rational consciousness and mentation. So far, there has been no experimental or mathematical way how to synthesize the two aspects of consciousness.

2. Method and Experimental Data

Our cohort of tested persons consisted of 22 healthy people, 17 men (age range 22 to 37), one 70-year-old man, one 80-year-old man) and 7 women (age range 22 to 36), and two 60-year old women. All 22 had normal EEG with basic alpha rhythm. The 70-year-old man had subclinical episodes of typical epileptic graphoelements of the spike-wave type in the EEG record, but no seizures in the past 35 years. The 80-year-old man had the pseudoneurasthenic syndrome but good logical judgment and memory, EEG showing slow alpha (8 Hz, sporadically also low-voltage theta, i.e., 4 – 7 Hz), while all the rest – except one – had alpha 9 Hz and faster frequency.

All the persons had their EEG recorded in the standard way, i.e., with the curves picked up by 19 electrodes placed on the head in the 10 – 20 Jaspers anthropometric array, amplification of 100 microVolt per centimeter of amplitude deflection of the calibration curve, upper filter – 40 Hz, lower filter – 1 sec, time sampling – 128 Hz.

During 30 minutes of diurnal EEG recording, the following situations (states, conditions) were used: eyes closed (EC) and eyes open (EO), nasal hyper-ventilation (HVN) and oral hyper-ventilation (HVO), shortened Raven test (RA) and the adding up of one- or two-digit numbers (CA) with eyes closed. Only two-digit numbers were added up for this particular study. In principle, only two states were used in EEG tests: the resting or native state and the active state. For this kind of psychic activity we also use the term mentation. To serve our purposes, we analyzed alpha activity spindles in two situations (with 8 to 18 alpha waves at a sampling rate of 128 Hz): a) at rest with the eyes closed and b) during the addition of two-digit numbers also with the eyes closed. The outcome was analyzed separately for the first half, i.e., the ascending part of the alpha spindle (ALAS), and separately for the other, descending half of the alpha spindle (ALDE). The addition of ten two-digit numbers took 30 seconds to complete, and the sums were incorrect in three young men, two elderly men and two elderly women.

To analyze each half of the alpha spindle we used spectral computations with Gabor filtration (GF) and local coherence function (LFC). We have also other sophisticated mathematical analyses ready for use such as dimensionality reduction and the like [29], [39], [37]. In some probands we also used interhemispheral coherence function (ICF), amplitude analysis (AA – isovoltage maps) and Poincaré data sequence analysis (PA). These computations were resorted to where GF and LCF had failed to produce conclusive results. Only then did AA, PA and ICF deliver the expected differences between the ascendant and descendent portions of the alpha spindle as much as between the states of rest and calculation (mentation). For lack of space, we plan to present those results in another study.

3. Results

The first group of results is presented in Tab. I.

Proband No.	Pseudo-monogram	Alpha at rest (NA)	Alpha at mentation	Age Age	Comment comment
I	TER	11 Hz	11 Hz		
II.	SIN	10 Hz	11 Hz		
III.	PSN	9.5 Hz	10 Hz		
IV.	KRT	10 Hz	10.5 Hz		
V.	HLO	10.5 Hz	11 Hz		
VI.	STA	10 Hz	11 Hz	senior, 62	
VII.	HAL	11 Hz	11 Hz	senior, 62	
VIII.	SDA	10.5 Hz	11.5 Hz		
IX.	TIC	10.5 Hz	11 Hz		
X.	RDN	9.5 Hz	10.5 Hz		somnus
XI.	LPK	10 Hz	11 Hz		in driving
XII.	HEK	8 Hz	9 Hz		in driving
XIII.	SAF	8.5 Hz	9.5 Hz		
XIV.	VEL	12 Hz	13 Hz		
XV.	SLN	11 Hz	11.5 Hz		somnus
XVI.	MOD	9 Hz	10.5 Hz		somnus
XVII.	SJK	10.5Hz	10.5 Hz		
XVIII.	BRD	10 Hz	10 Hz		
XIX.	VBR	9 Hz	10 Hz		meditatio 8 Hz
XX.	BAK	10.5 Hz	11 Hz		
XXI.	SAF	9 Hz	10 Hz		neurotic syndrome
XXII.	FRN	10 Hz	10.5 Hz		senior, 70
XXIII.	KTO	8 Hz	8.5 Hz		senior, 80

Tab. I *Roman numerals are used to denote the probands, second column contains their pseudomonograms, the third column contains the values of alpha frequency at rest (NA), the fourth column contains the values of alpha in mentation, while adding up two-digit numbers (CA). Included are also data of age and comments.*

The next Tab. II presents an overview of all the results of all probands' calculations. To save space, abbreviations are used for states in the columns, actual results in lines.

1. Column 1 shows the amount of alpha in the power spectrum (GF) in the ascending part of the alpha spindle in native – resting – state (NA),
2. the same in the delta band, NA,
3. the amount of alpha in the descending part of the alpha spindle, NA,
4. the same in the delta band, NA,
5. GF results in the ascending part of the alpha spindle during calculation, CA,
6. the same for the delta band, CA,
7. GF results for the alpha spindle descending part, CA,
8. the same for the delta band, CA,
9. LCF results in the alpha spindle ascending part for alpha, NA,
10. the same for delta, NA,
11. LCF results in the alpha spindle descending part for alpha, NA,
12. the same for delta, NA,
13. LCF results for the alpha spindle ascending part for alpha, CA,
14. the same for delta, CA,
15. LCF results for the alpha spindle descending part for alpha, CA,
16. the same for delta, CA.

The data with exclamation marks show that while no major change was noted in the particular frequency band, the distribution on the cranial surface was entirely different.

Since the data were not normalized, the intraindividual results are given in relative values. Consequently, the data indicate declining or rising values for each individual separately. The results obtained from the native EEG alpha activity represent the mean quantitative levels of the alpha or delta frequency bands. Low level is marked +, medium ++, high +++. A low level decline to a still lower one is marked -, a medium level decline is marked +, a high level decline is marked ++. A rise in the level of alpha or delta is marked with another cross, i.e., from low to higher ++, from medium to higher +++, and from high to a still higher one ++++.

Tab. II presents results of measured 24 probands arranged in 16 columns, of which 8 are for GA results, 8 for LCF results. Hence, eight relationships were calculated in two ways. In other words, we have here 8 relationships ($x : y$) listed in eight columns for 24 probands, amounting to 192 relationships. However, only the most interesting will be analyzed here, i.e., only those with a marked predominance in one variable. Thus, there are 120 instances of alpha activity asymmetry ($x < y$ or $x > y$) with the ascendant (ALAS) relative to the descendent (ALDE) portion of

	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**
I.	++	+	+	+	++	++	+	+	++	+++	+++	+++	++	+++	+	++
II.	++	+	++	-	++	+	+	-	++	+	++	+++	++	+	++	+
III.	+++	+	+++	+	++	+	++	+	+++	+	+++	+	++	+	+++	+
IV.	++	+	++	++	+	+	++	++	+	++	+++	++	-	++	+	-
V.	++	++	+++	++	+	++	++	+	++	++	+	+++	++	++	+	++!
VI.	+++	+	+	+	+++	++	+++	+++	++++	+	++	+++	+++	++	+++	++
VII.	+++	+	+++!	+	+++	+	+++!	-	+++	+	+++	++	++	-	++!	+
VIII.	+++	+	++++	++	+++	+	+++!	++	+	+++	++	+	+++	++	+++	++
IX.	++	+	+	++	+	+	+	++	+++	+	+	+	++	+	++	-
X.	++	+	+++	+	+	+	+++	-	+	+++	+++	++	+++	++	++	+++!
XI.	+++	+	+++!	+	+++	+	+	+++	++	+	+++	++	+++	+	++	++
XII.	+++	+	++	++	+++	+	++	+	+++	+	+++	+	+++	++	+++	+
XIII.	++	++	+	+	+++	+	++	++	+++	++	+++!	++!	++	+	+	++
XIV.	+++	+++	++	+++	++	+++	+++	++++	++	++	++!	+++	++	+++	+++	+++
XV.	++	++	+	+	+	+	++	++	+++	++	+++	+	++	++	+	+++
XVI.	++	+++	+++	++++	+++	+++	++!	++	+++	+++	+++!	+++!	++	+++	++	++
XVII.	+++	++	+++	+++	++	++	++	++	++	+	++	++	+	++	+	+++
XVIII.	+++	++	++	+	++	++	++	+++	+++	++	+	++!	+++	++	+++!	+++
XIX.	+++	++	+++!	+	+++	+	+++!	+	+++	++	+++	+	+++	++	++	+
XX.	+	++	++	++	++	++	+	++!	++	++	+++	+	++	++	++!	++!
XXI.	+	+	++	++	++	+++	+++	+++	++	++	+++	+++	++	+++	++	++
XXII.	++	++	++!	+++	+	+++	+++	+	+	+++!	++	+++!	+	+	+++	++
XXIII.	++	+	+	+	+++	+	++	+	++	+	+!	++	++	+	+	+!
XXIV.	+++	++	+++!	+	+	+	+!	+!	++	+	++	-	+	++	-	+

Tab. II *The results of GF (columns 1–8) and LCF (columns 9–16) calculations in XXIV probands. Probands I to VII are women, the last two – elderly women. Probands VII to XXIV are men, the last two elderly men. Exclamation marks in some of the results show that while the values in the alpha or delta bands remained unaltered, there were major changes of relocalization, i.e., for example, maximum alpha in ALAS was in the occipital, in ALDE in the temporal region, etc.*

GF Columns	α NA			α CA			δ NA			δ CA			α NA--CA			α NA--CA			δ NA--CA			δ NA--CA		
	1 : 3			5 : 7			2 : 4			6 : 8			1 : 5			3 : 7			2 : 6			4 : 8		
	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ
$x > y$	2	7	**9**	2	6	**8**	1	6	**7**	4	4	**8**	3	8	**11**	3	6	**9**	0	4	**4**	2	5	**7**
$x < y$	1	5	**6**	2	4	**6**	1	7	**8**	2	7	**9**	0	5	**5**	1	6	**7**	2	2	**4**	1	6	**7**
$x = y$	3	1	**4**	2	3	**5**	5	4	**9**	1	4	**5**	4	4	**8**	3	5	**8**	5	11	**16**	4	6	**10**
disl.	1	4	**5**	1	4	**5**	0	0	**0**	0	2	**2**	0	0	**0**	1	4	**5**	0	0	**0**	0	2	**2**
LCF columns	9 : 11			13 : 15			10 : 12			14 : 46			9 : 13			11 : 15			10 : 14			12 : 16		
	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ	♀	♂	Σ
$x > y$	2	2	**4**	2	7	**9**	0	6	**6**	2	6	**8**	4	6	**10**	3	11	**14**	1	4	**5**	6	4	**0**
$x < y$	2	6	**8**	3	2	**5**	4	4	**8**	1	7	**8**	0	3	**3**	1	4	**5**	1	4	**5**	0	7	**7**
$x = y$	3	9	**12**	2	8	**10**	3	7	**10**	4	4	**8**	3	8	**11**	3	2	**5**	5	9	**14**	1	6	**7**
disl.	0	4	**4**	1	2	**3**	0	4	**4**	1	3	**4**	0	0	**0**	1	5	**6**	0	1	**1**	1	5	**6**

Tab. III *Numerically expressed relations from Tab. II (a,b) between activity in ALAS and ALDE in the resting state (NA), during calculation (CA) and between the NA and CA parts of the EEG curve in the alpha and delta bands – based on the results in columns 1 – 8 from **GF** in the upper part of the table, and from columns 9 – 16 from **LCF** in the lower part of the table. Bold numbers mean sum of men and women.*

the alpha spindle, 68 instances of symmetry ($x = y$), 4 instances of relocalizations or topic predominance on the skull surface.

As Tab. II and III indicate, the frequency spectrum (GF) shows a great interindividual variability with discernible differences between ALAS and ALDE in both the native and the mentation EEG curves. Power of alpha is **9** times greater in the native ALAS (column 1:3), and **8** times greater in the mentation ALAS phase (column 5:7). This is evidence of spindle asymmetry with more alpha in ALAS, though, seen with the naked eye, this formation appears to be a paradigm for symmetry.

Delta activity tends to be symmetrical, at rest (in column 2:4) the ALAS and ALDE values are nearly equal (7 cases to **8**). A similar situation exists during mentation (column 6:8), **8** cases to **9**. Likewise, the alpha band reveals considerable difference between the resting and mentation (mental activity) curves.

Comparisons between the native state and mentation in ALAS in the delta band are as follows: (column 2:6) **4** cases each and **7** cases each (column 4:8) between the native state and mentation in the ALDE phase. In other words, the situations are very well balanced, and delta does not seem to be different in the ascendant and descendent phases of the alpha spindle. Indeed, delta is **16** times identical in ALAS (column 2:6) and **10** times the same in ALDE when the resting state and mentation are compared.

Clearly enough, alpha is marked by differences, i.e., higher in ALAS than in ALDE; its differently numerous neuronal populations on recruitment seem to suggest MIA iteration, whereas only a slightly different delta shows equal quantities in both ALAS and ALDE. This is evidence of constantly equal delta energy in ALAS and in ALDE, i.e., regardless of relaxation or mentation, the TCRS keeps iterating in the delta rhythm all the time. Delta would then be consistent with routine and incessant iteration or selection of neurons. In physiological terms, this points to a constantly high activity of the associative and commissural systems.

Considerable ALAS-ALDE differences stand out when comparing EEG at rest and during mentation in the alpha band. In the ALAS phase (column 1:5) there is **11** times more alpha at rest against **5** during addition; in the ALDE phase the ratio is only **9** cases to **7**. The recruitment of alpha then is greater at rest than in mentation as regards the ALAS-ALDE ratio.

There seem to be no major sex differences, but then there are only 7 women in the cohort.

In other words: the subtotals show a preponderance of alpha activity at rest in ALAS (**9**) over ALDE (**6**) (column 1 relative to column 3). In the ALAS phase, there is obviously a greater tendency toward synchronization, which is hidden to the naked eye. A similar situation exists when ALAS and ALDE are compared during mentation (column 5 in relation to column 7). In either case, however, there are 5 relocalizations of alpha activity, i.e., more than in other relations. Alpha activity predominance in ALAS suggests an increased recruitment of neurons and their impulses and, thereby, also a larger neuronal population in the ALAS phase.

The delta band (columns 2:4 and 6:8) shows a fairly balanced amount of delta between ALAS and ALDE displaying, however, a negligible number of dislocations. In general, delta activity is predominant in the frontal and frontotemporal regions, albeit sometimes contaminated with oculomotor artifacts.

Marked changes are in those parts of the EEG curve where higher values of alpha at rest predominate over mentation in ALAS (**11**) (columns 1:5). This can be put down to greater attention during mentation when, as a rule, alpha is on the decline. The number of equal values is growing in ALAS and in ALDE (8), the spindles are assuming more symmetry during mentation. There is no alpha relocalization.

In the ALDE phase, the numbers of asymmetric and symmetric spindles at rest are leveling up with those during mentation (**9 a 8**), (columns 3:7). There are five alpha dislocations here, suggesting a major difference in the distribution of alpha in ALAS and in ALDE when the relaxed state is compared with mentation.

Delta activity in ALAS exhibits its greatly balanced amount between relaxation and mentation (**16**) (columns 2:6). There is no delta dislocation.

Delta activity in ALDE is again very well balanced when relaxation and mentation are compared (**10**) (columns 4:8). There are two cases of dislocation.

The bottom part of Tab. III shows the LCF results. The GF and LCF computations are not identical but complementary. While GAs show the magnitude of energy in each particular part of the spectrum, LCF indicates mutual similarity (coherence) with the local "neighboring" spectra.

As Tabs. II (a, b) and III also suggest, the **local coherence function (LCF)** at rest (NA) operates conversely in the alpha band compared with alpha energy computed on the basis of GF: in ALAS – **4 to 8** cases, in ALDE – **5 to 8** cases; i.e., coherence is lower in cases of increased alpha activity. This could mean that greater coherence accompanied by lesser alpha energy would represent greater mental power with increased attention. Yet, the equivalence of the number of cases ($x=y$, i.e., the same amount of alpha in ALAS as in ALDE) is almost invariably greater than the reverse ($x\neq y$), (applicable also to delta activity), as it shows little change in ALAS relative to ALDE.

In contrast, during adding up (CA) both alpha and delta show a substantially greater coherence in ALAS than in ALDE, i.e., during mental activity the similarity of the spectra is on the increase in the first half of the alpha spindle whereas in the second half it is on a very marked decline in what points to a great deal of dissimilarity between the ascendant and descendent phases of the alpha spindle.

Of considerable interest is the high delta coherence during mentation in ALAS (**14** cases) compared with ALDE (**none**). It appears that delta has a major role to play in mental activity, indeed, even in the first half of recruitment, i.e., in the ascending part of the alpha spindle. This shows that "invisible" changes in the EEG curve are well calculable and that it makes sense to monitor those changes.

Relocalization is a characteristic feature of mainly alpha and delta during mentation with **6** cases each.

Three persons were prone to falling asleep, and on those occasions we were able to see that the alpha spindle after sleep showed more alpha energy in GF and more coherence in LCF than at rest and during relaxation at the start of the experiment. At the same time, there was a bifrontal decline of delta activity. This appeared to coincide with a decrease in oculomotor artifacts during the sleep onset, artifact being almost invariably present in wakefulness. Admittedly, the number of the probands was low, but should this finding be corroborated, it could be used for the prediction of imminent transition from relaxation to sleep.

The average alpha frequency at rest was 9.5 Hz, during mentation – 10 Hz. In 19 cases alpha accelerated during mentation by 0.5 to 1 Hz.

Apart from the resting state and psycho tests, proband XX also engaged in meditation according to Mahareshi Mahesh Yogi. As shown in optical description, his alpha was of a relatively higher amplitude than in the resting state and found spreading also into the frontal region. His alpha frequency dropped from 9 to 8 Hz, whereas during mentation it stood at 10 Hz. While his GF and LCF alpha increased, the analogical results in delta decreased. A similar situation without frequency analysis was described already by Anand et al. (1961) in Indian yogis. Poincaré's analysis (PA) carried out in three probands revealed major cyclic activity at rest in both ALAS and ALDE, though this was considerably altered during mentation (CA). As these exceptional situations pertain to too few probands, it is too early to draw any conclusions.

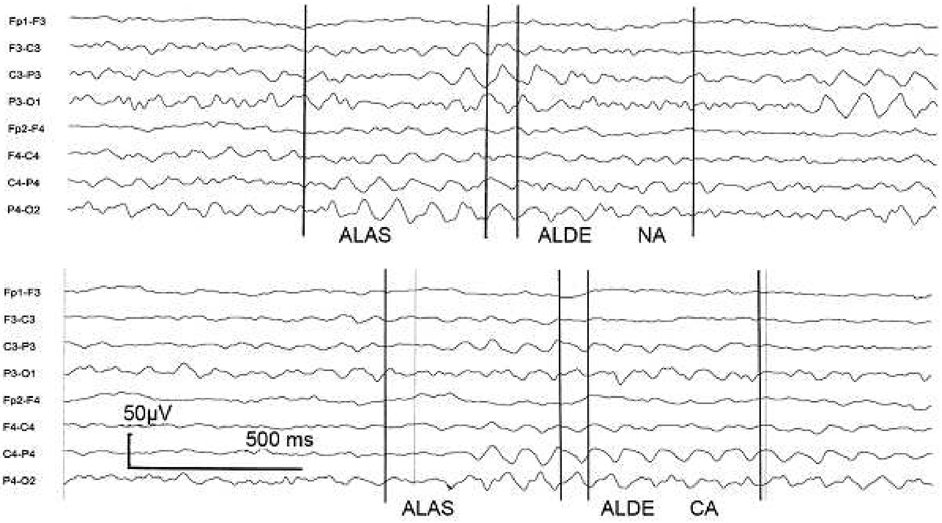

Fig. 2 *Example of twice eight EEG curves from the medial leads of proband XVIII. The graph, expanded in amplitude and in time, represents each time one alpha spindle divided into a first half with the amplitude increasing (ALAS) and a second half with the amplitude decreasing (ALDE). The top and bottom parts of the graphs show merely minor optical differences despite the fact that the upper 8 curves relate to the resting (native, NA) state, and that the lower 8 curves were recorded during the test, in the addition of two-digit numbers (CA). Each part (ALAS and ALDE) was analyzed separately using GF and LCF and then compared against each other or in different states.*

In our previous studies we found differences in the EEG spectrum in relaxation and during psychic activity, in particular, alpha acceleration during the addition of one- and two-digit numbers. Generally speaking, the energy of alpha activity was reduced during increased attention independent of eyes open or eyes closed. In the process of mentation (Raven's test, adding up numbers, reading in young children) the delta band energy was rising, again regardless of whether the probands' eyes were open or closed. Sometimes, but not always, similar changes can be seen in our present study, too. However, the duration of the previously analyzed sections used to be relatively long, 10 to 30 seconds, whereas the current time for alpha spindle analysis is only 0.5 to 1 second. Differently long intervals of the EEG curve have a significant role to play in the detection of each of the frequency bands.

The results of the present study show differences between the ascending (ALAS) and descending (ALDE) portions of the alpha spindle, mainly in the alpha band. In the resting state records, there are 15 cases of difference in the alpha band, i.e., 9 in ALAS and 6 in ALDE. During the addition test, alpha is asymmetrical 14 times, i.e., 8 times in ALAS and 6 times in ALDE. Comparing the alpha spindle at rest and in mental effort, we find 32 cases of asymmetry and 16 cases of symmetry. The delta band shows fewer differences. Our current results are, on the whole, congruent with the previous ones; for example: lower alpha during mentation than in the native resting part, or rising delta in mentation (columns 2:6 and 4:8). During relaxation and incipient sleep, the amount of alpha is on the increase and so is its coherence.

More over, we have proved the Poincaré analysis of interrelations in ALAS and ALDE of measured results in quiet state – NA, see Fig. 5 and also in states when the tested persons were loaded by numerical computation – CA, see Fig. 6.

Comparing of both these figures shows the significant changes of thalamocortical reverberation caused by psychical load, nevertheless the curves look very similar.

4. Discussion

Already in the Introduction we have mentioned physiological and mathematical literature suggesting how to explain the differences in alpha recruitment. The dynamism of alpha activity offers scope for a variety of explanations. Iteration is one of them, and not only simple iteration but also Ivakhnenko's MIA. Both the division of the alpha spindle and the differences between the first and second halves of alpha recruitment seem to substantiate these hypotheses. All interindividual and intraindividual differences in the computations are due to the ubiquitous "random" component in the EEG curve. Hence, our findings are not unambiguous. Also involved are stochastic processes in their "galactic" quantities of cortical neurons and their synapses numbering hundreds of billions.

If we estimate our "alpha life" at some 60 years of duration (roughly from 10 to 70 years of age), and at about 10 hours of alpha activity daily, the time interval of one alpha spindle at approximately one second, then the 3600 alpha spindles per hour multiplied by ten hours amount to 36 000 spindles a day. This number multiplied by roughly 300 days equals 10 800 000 alpha spindles per year, and that multiplied by 60 years means 648 million alpha spindles for all our adult life. That means our disposition singled out for our education, school and professional knowledge and life experience. However, our mentation and memory capacity will be greater than that if the psychic mechanisms in operation during sleep are also brought into play. While we cannot estimate the number of "bytes" contained in an

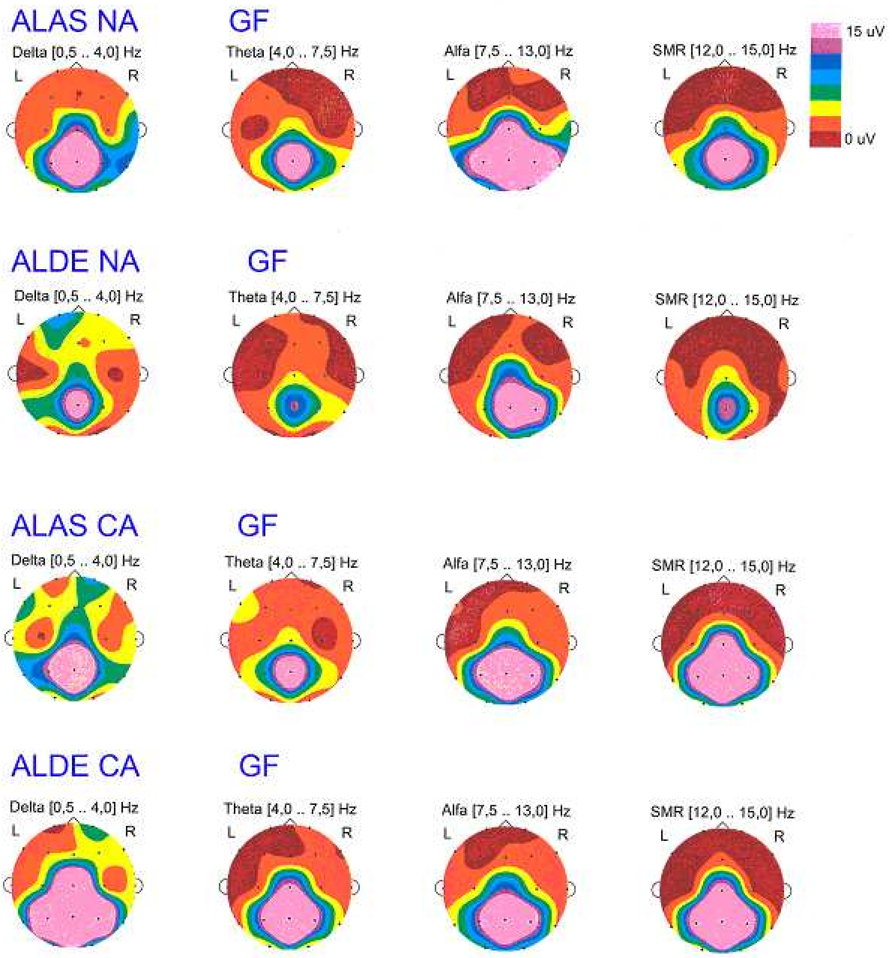

Fig. 3 *Four series of brain mapping (BM) diagrams of proband XVIII. from spectral GF computations in four frequency bands (delta, theta, alpha and "SMR" or slow beta activity); on the extreme right is a scale for easier orientation from 0 to 15 uV of energy in pseudocolors or in different shades of gray. Series 1 are EEG curve computations of the native state (NA) in the ascendant part of the spindle (ALAS), series 2 – computations in the descending part (ALDE), showing decreased alpha and delta values in the ALDE phase (as well as in theta and "SMR", though these bands proved to be of lesser significance in other probands, which was why we refrained from studying them systematically). Series 3 are GA computations of EEG in the process of calculation (CA) in ALAS, and – series 4 – in the ALDE phase. Neither alpha nor "SMR" show any differences there, although there was a significant build-up of delta (and theta) activity during an arithmetics task. Comparisons show a loss of alpha in ALAS during CA as a result of increased attention; then, there is a discernible increase in delta (and theta) in ALDE during CA as a result of increased power of iteration in the TCRS and in DACAS.*

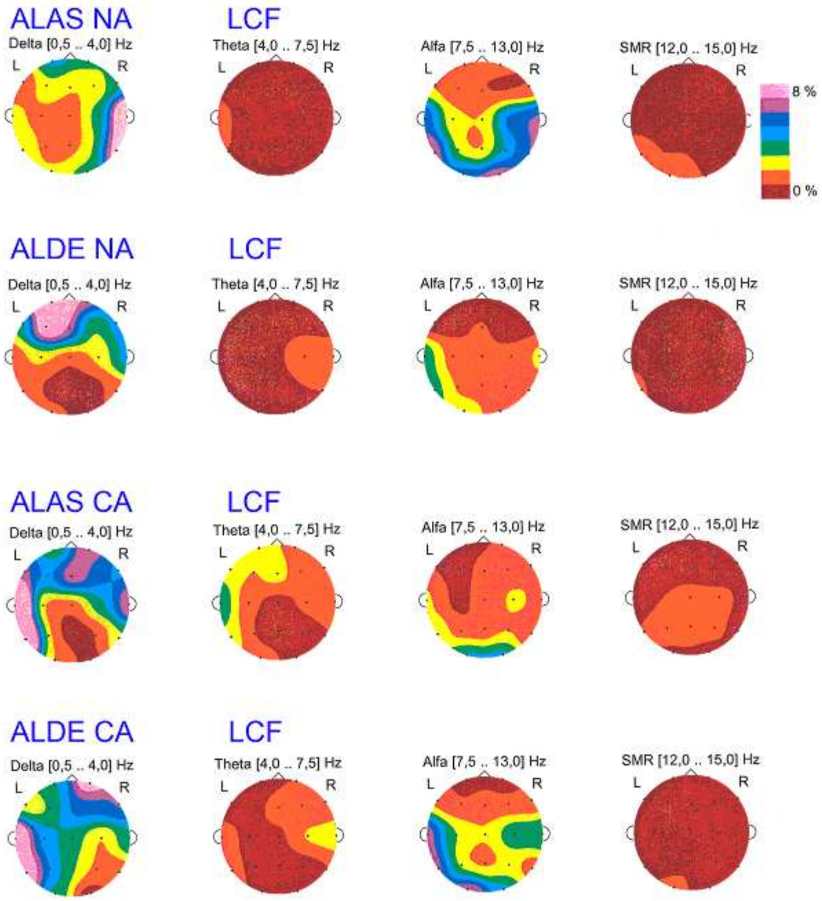

Fig. 4 *Another representation of four BM series (lines) of proband XVIII made up of local coherences (LCF) in four frequency bands. On the extreme right is a scale for rating the intensity of coherence – from 0% to 8%. The first BM series shows the ascending amplitude of the alpha spindle (ALAS) at rest (NA) with a measure of focal – multifocal coherence of delta in the temporal region on the right, and coherence of similar intensity in alpha on both sides temporooccipitally. During ALDE, we can see a high degree of coherence in the left-hand frontal region, and dwindling coherence in alpha. That in itself represents a major difference between ALAS and ALDE even with the mind at rest. Series 3 and 4 illustrate coherence during calculation. ALAS shows marked delta coherence mainly in the temporal region on the left, i.e. contrateral to where it was in the resting state, with alpha coherence on the wane. In the ALDE phase, delta shows about the same coherence as in ALAS; in addition, alpha coherence has increased slightly temporooccipitally on the left. This indicates considerable differences between alpha spindles at rest and during mental effort. GF and LCF complement one another well. We can see waning coherence in the theta and “SMR” bands, thus substantiating our preference for alpha and delta activities. During mentation, there is, as a rule, increased multifocal LCF, whereas in sleep LCF is evenly and diffusely localized.*

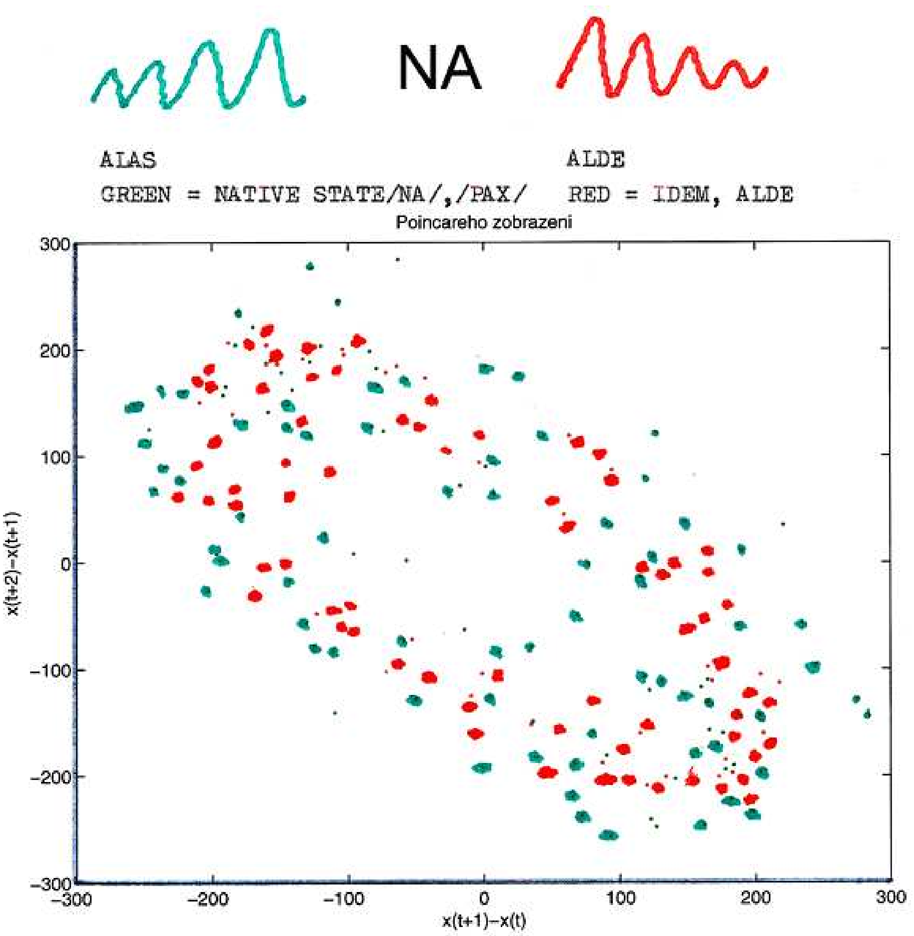

Fig. 5 *Poinceré analysis for quiet state: red dots mean ALDE, green dots mean ALAS.*

alpha spindle, we should bear in mind that not every spindle represents a successful attempt, i.e., intentionally successful iteration.

The energy level of our neuronal networks often gets stuck in a "local minimum" or is unable to find even the direction of problem solution. Consequently, our mind teems with unanswered questions both professional and everyday-life ones, not to speak of emotional problems. It is only occasionally that our iteration helps us reach the "global minimum", the point where we have come to understand the problem, where the energy function trajectory has reached the minimum, and when the resulting attractor has reached a minimum of energy in the neuronal structure, the end of neuronal selection and cognitive automation, when the optimized neuronal networks have been fixed in memory traces.

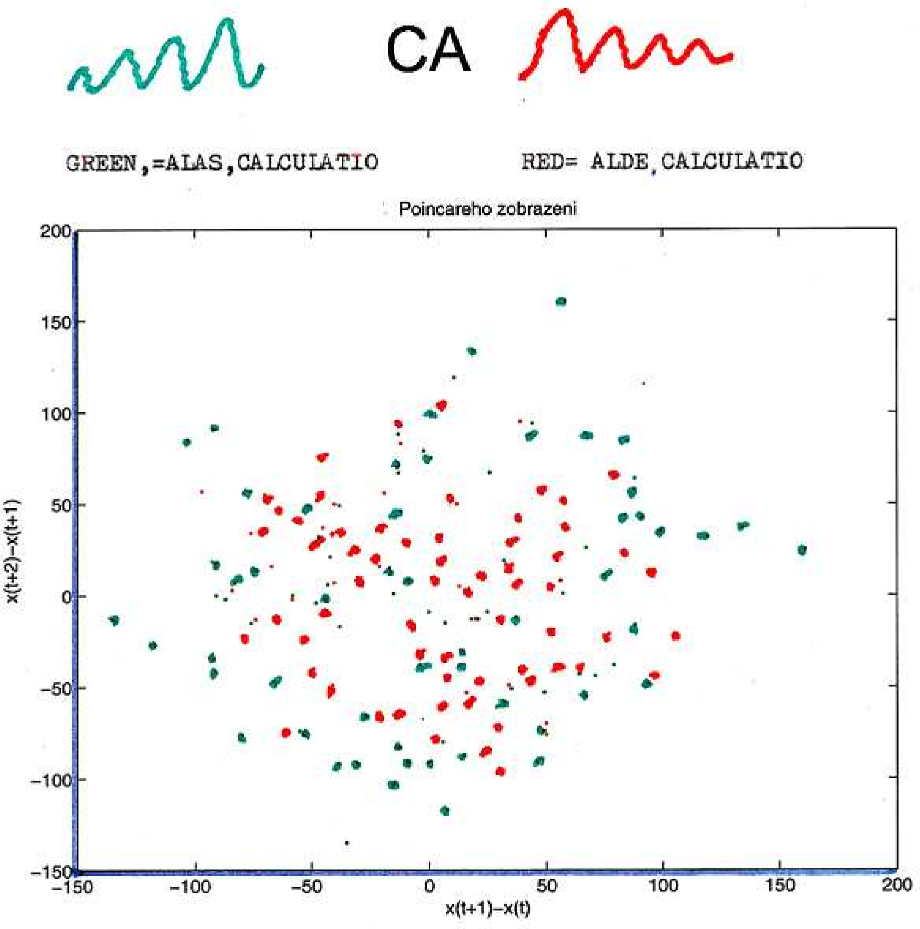

Fig. 6 *Poincaré analysis for state when tested persons were loaded by calculations: red dots mean ALDE, green dots mean ALAS.*

Let us emphasize the great differences between the first and the second halves of the alpha spindle also because they are not discernible to the naked eye. More differences exist between the resting and "working" spindles of alpha activity which, in this case too, are quite considerable interindividually. These analyses may be useful not only for the detection of brain relaxation and activity but also for the detection of some character changes. In particular, society at large would welcome prediction of potential aggressors' behavior in everyday life and behind the steering wheel. All the more so, considering that the analyzed section is very short.

Complex as it is, the EEG curve appears to contain a spectral mix of regular and harmonic as well as stochastic components. An alpha spindle also contains both components, what is more, differently correlated in ALAS and in ALDE, and differently again at rest (NA) and during mentation (CA).

Going by clinical experience, we know that many diseases exhibit changes in the frequency, form, phase and other parameters of alpha activity, while still remaining within norm. Hence the difficulty in defining the difference. For instance, the milder forms of the ADHD syndrome (attention deficit-hyperactivity disease affecting up to 10% of the young population) or incipient Alzheimer dementia have no clear-cut pathognomonic changes in the EEG curve. This would also facilitate the detection of worsened concentration and imminent sleep onset, in general, attention changes prediction. That is where the above analyses could be of help. No doubt, the study calls for further mathematical programmes for more sophisticated analysis of the EEG curve, cooperation with psychologists, and more probands to be examined with new diagnostic techniques, such as positron emission tomography (PET) or transcranial magnetic stimulation (TMS) and the like.

5. Hypothesis and Expected Consequences

We have put forward our hypothesis of dual iteration in data processing in the thalamo-cortical reverberation system (TCRS) of the brain:

- MIA (multilayered iterative algorithm) according to A. G. Ivakhnenko,

and

- "ordinary" iterative with convergence to the target solution in the second phase of data processing. In vigilance, the brain's electric activity comprises primarily the alpha rhythm (8 – 13 Hz) of variable amplitude responsible for the fusiform spindle-like shape of those alpha waves – described as the alpha spindle.

As a rule, the general assumption is that the ascending part of the alpha spindle (ALAS) is the same as the descending part (ALDE).

Our aim was to find out whether our hypothesis of differences between the ALAS and ALDE phases is acceptable. To that end, we examined 24 persons by means of EEG and simultaneous short psycho tests. We then compared ALAS and ALDE in the alpha spindle of all the probands both at rest and in a state of psychic activity (mentation), and found a preponderance of alpha in ALAS, which might correspond to a hypersynchronous recruitment of alpha and to the situation evolving in the MIA regimen. There was little change in delta which retained similar values in ALAS as much as in ALDE, probably a reflection of constantly present iteration. Interindividual differences were considerable apparently due to the role played there by psychological and stochastic processes. In our opinion, thanks to these and other sophisticated analyses and to the short EEG curve interval, the above method could be of use not only in the detection of mentation, relaxation, attention disorders and incipient sleep onset, but also for the identification of anomalous types of personality, such as impulsive or even aggressive psychopaths and the like.

We can express the expectation that the presented interrelations between the EEG alpha spindle and tested person's psychic state will also be proved by a further larger set of measurements, and that their existence can open the way for further improvement of many application cases, in which human subject interacts with considerably complex and complicated artificial system or system alliance and in which the reliability of such interactions plays crucial role for operation safety, like e.g. in railway (see [41–44] e.g.) or road (see [45] e.g.) transportation.

References

[1] Adams P., Cox K.: A new interpretation of thalamocortical circuitry. Philosophical Transactions, 2002, **357**, 1428, pp. 1767-1779.

[2] Anand B. K., China G. S., Baldev S.: Some aspects of electroencephalographic studies in Yogis. Electroenceph. Clin. Neurophysiol, 13, 1961, pp. 452-456.

[3] Andersen P., Andersson S. A.: Thalamic Origin of Cortical Rhythmic Activity. PP 2C-00-118. In Handbook of EEG. Clin. Neurophysiol., Ed.: D. Creutzfeldt, **2**, Part C, Elsevier, Amsterdam, 1974.

[4] Andersen P., Eccles J. C.: Inhibitory phasing of neuronal discharge. Nature, 196, 1962, pp. 645-647.

[5] Andersson S. A., Holmgren E., Manson J. R.: Synchronization and desynchronization in the thalamus of the unanaesthetized decorticated cat. Electroenceph. Clin. Neurophysiol., 31, 1971, pp. 335-345.

[6] Berger H.: Das Elektrenkephalogramm des Menschen. Nova Acta Leopoldina. Halle, Saale, 1938, p. 139.

[7] Brodmann K.: Feinere Anatomie des Grosshirns. In: Handbuch der Neurologie. Ed.: M. Lewandowsky, Berlin. Springer, 1910, p. 1184 (in German).

[8] Dusser de Barenne J. G., McCulloch W. S.: The direct functional interrelation of sensory cortex and optic thalamus. J. Neurophysiol., 1, 1938, pp. 176-186.

[9] Faber J., Tošovský J., Taichmanová Z., Tuháček M., Měšťan J.: A method of averages and functions applied in differentiating subclinical and clinical petit mal paroxysms. Čes. Neurol., 36/69, 1973, pp. 108-113 (in Czech).

[10] Faber J.: Vigilance, sleep, petit mal and EEG as manifestations of programmed brain regulation. Acta Univ. Carol. Med., Monogr. LXXXVII, Praha 1978.

[11] Faber J.: Associative Interneuronal Biological Mechanism. Neural Network World, 1, 1991, pp. 13-31.

[12] Faber J.: Electroencephalography and psychophysiology. ISV naklad, Praha, 2001, p. 170 (in Czech).

[13] Faber J.: Isagogé to non-linear dynamics of formators and complexes in the CNS. Acta Universitatis Carolinae Medica, Monogr. CXLIX, Praha 2003.

[14] Faber J.: QEEG (Qualitative and quantitative EEG analysis), Galén, Praha, 2005, p. 191.

[15] Faber J.: Neurocybernetic analogies, Triton, Praha, 2008, p. 113.

[16] Faber J., Novák M., Tichý T., Svoboda P., Tatarinof V.: Driver psychic state analysis based on EEG signals. In: Neurodynamic and neuroinformatics studies, Second book on microsleep. Ed. M. Novák, ČVUT, Praha 2005, p. 265.

[17] Farley B. G., Clark W. A.: Simulation of self organizing systems by digital computer. Trans., IRE, PGIT-4, 1954, pp. 76-84.

[18] Freeman W. J.: Messoscopic neurodynamics. From neuron to brain. J. Physiol., Paris, 94, 2002, pp. 303-322.

[19] Fuller P. W.: Computer estimated alpha attenuation during problem solving in children with learning disabilities. Electroenceph. Clin. Neurophysiol., 42, l977, pp. 149-156.

[20] Gibbs F. A., Gibbs Erna L.: Atlas of Electroencephalography. Addison – Wesley Press Inc. Cambridge, 42, Mass. 1940, 1952, pp. 221.

[21] Grünnewald-Zuberbier E., Grünnewald G., Rasche A., Netz J.: Contingent negative variation and alpha attenuation responses in children with different abilities to concentrate. Electroenceph. Clin. Neurophysiol., 44, 1978, pp. 37-47.

[22] Howard R. C., Fenton G. W., Fenwick P-B-C.: Event-related brain potentials in personality and psychopathology: a Pavlovian approach. Research studies Press. John Willey, Chichester, New York, 1982, p. 112.

[23] Jones E. G.: Thalamic circuitry and thalamocortical synchrony. Philosophical Transactions of the Royal Society, **357**, 2002, pp. 1650-1674.

[24] Kandel E. R., Schwartz J. H.: Principles of neural science. Amsterdam, Elsevier, 1985, p. 981.

[25] Kolda T., Faber J., Svoboda P., Dvořák M.: A model of artificial neuronal networks designed according the natural neuronal brain structures. Neural Networks World, 3-4/2004, pp. 233-246.

[26] Lion K. S., Winter D. F.: A method for the discrimination between signal and random l noise of electrobiological potentials. Electroenceph. Clin. Neurophysiol., 5, 1953, pp. 109-113.

[27] Mazziota J. C., Toga A. W., Frackowiak R. S. J.: Brain Mapping. The Disorders. Academic Press, Sand Diego, San Francisco, New York, London, 2000, p. 669.

[28] Moruzzi G., Magoun H. W.: Brain stem reticular formation and activation of the EEG. Electroenceph. Clin. Neurophysiol., 1, 1949, pp. 455-473.

[29] Novák M. et al.: The artificial neuronal networks, theory and praxis. C. H. Beck, Praha, 1998, p. 382 (in Czech).

[30] Petrovický P. et al.: Nervous and Clinical Aspects of Anatomy. Triton, Praha, 2008, p. 628 (in Czech).

[31] Posner M., Raichle M. E.: Image of mind. Scientific American Library. New York, 1994, p. 257.

[32] Raichle M. E.: The Brain's Dark Energy. Scientific American. March 2010, pp. 28-33.

[33] Reinis S.: Some principles for decoding local neuronal systems in the mammalian central nervous system. Neural Network World, 7, 1997, pp. 205-225.

[34] Saunders M. G.: Amplitude probability density studies on alpha and alpha-like patterns. Electroenceph. Clin. Neurophysiol., 15, 1963, pp. 761-768.

[35] Šimek J., Stein J.: How to read the electroencephalogram. SZN. Praha, 1969, p. 450. (in Czech)

[36] Šnorek M.: Neuronové sítě a neuropočítače. (Neuronal Nets and Neurocomputers.) ČVUT, Praha, 2004, p. 156 (in Czech).

[37] Svítek M.: Dynamical systems with reduced dimensionality. Edice monografií NNW, ČVUT, Faculty of Transportation Sciences. Prague, 2006, p. 161.

[38] Timsit M., Koninckx N., Dargent J. et al.: Variations contingentes négative en psychiatrie. Electroenceph. clin. Neurophysiol., 28, 1970, pp. 41-47.

[39] Votruba Z.: The information power in the mass, energy and organization unity. In: The information power. Ed.: J. Vlček et al., ČVUT, 2002, p. 109 (in Czech).

[40] Walter W. G., Cooper R., Aldridge V. J., et al. : Contingent negative variation, electric sign of sensori-motor association and expectancy in the human brain. Nature (London), 203, 1964, pp. 380-384.

[41] Fábera V., Leso M., Poláček I.: Testing electrotechnical laboratory FTS CTU (in Czech: Zkušební elektrotechnická laboratoř FD ČVUT). Věda o dopravě 2004. Praha: Vydavatelství ČVUT, 2004, pp. 329-331. ISBN 80-01-03047-4.

[42] Leso M., Votruba Z.: Reliability Estimator. In: Neural Network World. **9**, 3, 1999, pp. 235-245. ISSN 1210-0552.

[43] Brandejský T., Leso M.: Risk analysis of railroad safety systems (in Czech: Analýza rizika ve schvalovacím procesu železničních zabezpečovacích zařízení z pohledu hodnotitele bezpečnosti). In: 17. Medzinárodné sympózium "Zvyšovanie konkurencieschopnosti európského železničného systému" EURO – Žel 2009. Zborník prednášok. Žilina: Žilinská univerzita, díl 1, 2009, pp. 185-192. ISBN 978-80-554-0024-2.

[44] Brandejský T., Leso M.: Evaluation of railroad systems according EU standards (in Czech: Hodnocení železničních systémů podle evropských standardů). EURO – Žel 2010. Žilina: Žilinská univerzita, 2010, pp. 29-32. ISBN 978-80-554-0197-3

[45] Novák M., Votruba Z., Matoušek V., Přenosil V., Faber J., Bouchner P., Hrubeš P., Svoboda P., Novotný S., Piekník R., Pěkný J., Sýkora O., Tichý T.: Road Accidents Reduction, Aracne, Roma, 2010, ISBN: 978-88-548-3332-6

[46] Ivakhnenko A. G., Müller J.-A.: Selbstorganisation von Vorhersagemodellen. Verlag Technik, Berlin 1984 (in German).