Medical Hypotheses (2002) **58**(4), 352–358

doi: 10.1054/mehy.2001.1546, available online at http://www.idealibrary.com on IDEAL®

Impaired information processing triggers altered states of consciousness

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Summary Schizophrenia, intoxication with tetrahydrocannabinol (Δ-THC), and cannabis psychosis induce characteristic time and space distortions suggesting a common psychotic dysfunction. Since genetic research into schizophrenia has led into disappointing dead ends, the present study is focusing on this phenotype. It is shown that information theory can account for the dynamical basis of higher sensorimotor information processing and consciousness under physiologic as well as pathologic conditions. If Kolmogorov entropy (inherent in the processing of action and time) breaks down in acute psychosis, it is predicted that Shannon entropy (inherent in the processing of higher dimensional perception) will increase, provoking positive symptoms and altered states of consciousness. In the search for candidate genes and the protection of vulnerable individuals from cannabis abuse, non-linear EEG analysis of Kolmogorov information could thus present us with a novel diagnostic tool to directly assess the breakdown of information processing in schizophrenia. © 2002 Elsevier Science Ltd. All rights reserved.

INTRODUCTION

Schizophrenia is characterized by a multiplicity of signs and symptoms, no single one of which is present in all patients. Nevertheless, as this highly prevalent illness is recognized throughout the world, there must be a clinical pattern that gives the psychiatric disorder conceptual unity. Since genetic studies have led into disappointing dead ends so far, the focus of research is at present shifting back towards refining its phenotype.

MENTAL STATES

Whereas unconscious processes appear to be characterized by timelessness having no reference to time at all (1), consciousness is relevant to a person's span of awareness across time (2).

Received 1 August 2001
Accepted 26 November 2001

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Distortion of time during acute psychosis

Distortions of psychological time are fundamental aspects of altered states of consciousness (3), and the lack of goal-directed behaviour and thinking is one of the most striking clinical clues that a patient may be psychotic. Objectively, it can be observed in the disorganization of the patient's speech and actions. Subjectively, when asked about his or her future perspective, the psychotic patient often reports to have lost control over what might happen in the future (2).

With respect to dysfunctional time perception, cannabis-induced psychosis has become an interesting model for schizophrenia, because of the recent identification of a functional overlap with the dopamine systems at the physiological (4), molecular (5) and genetic (6) level. Abuse of delta-tetrahydrocannabinol (Δ-THC), the pycho-pharmacologically most active ingredient of cannabis, furthermore, stands out as an independent risk

Fig. 1 Vishnu's famous third stride transcending space and time. The bas-relief of a medieval temple near Ellora (India) depicts Lord Vishnu transcending the *kalasa* '*amrita*', the bowl of 'immortality', on the pillar to his left. Cannabis (*bhang*) was known for its hallucinogenic effects for thousands of years and thus the reason for its ritual consumption, the denomination of which was *soma* or *amrita*, an Indo–European term etymologically equivalent to ambrosia – the potion of the immortals. Loss of time sense induced experiences of 'timelessness' or 'immortality' and the disintegration of the subject–object boundary a mystic union with God. In contemporary Indian art, such ecstasy, or altered states of consciousness, are often reflected in numerous, tiny self-images of Vishnu penetrating Purusha's skin. Temples, in particular, represent Purusha, the original meaning of which – like in English pupil, Latin *pupilla* or Greek *koré* – is 'little person' whose mirror image is reflected in one's pupil. On looking at ourselves in the mirror – or a pupil – we in fact perceive the virtual, literally ecstatic, duplication of ourselves.

factor supposed to precipitate schizophrenia in vulnerable individuals or to trigger a relapse of psychotic symptoms in schizophrenic patients (7). Viewed from the perspective of the independent variables time and space, disrupted information processing points to a common psychotic dysfunction induced by Δ-THC and schizophrenia. The temporal distortions under the influence of Δ-THC are best described by the poet J. R. Anderson:

> 'The first effect – and this remained true for every subsequent occasion – was the alteration of time values. Time was so immensely lengthened that it practically ceased to exist. But this slowing-down applied only to physical events; my own movements for instance, and those of other people; it did not apply to the processes of thought. Those, on the contrary, appeared to be very greatly accelerated' (cited in 8).

When THC speeds up the physiological temporal processing system, the subject estimates the passage of physical time to be proportionally longer compared to the clock (4). This asynchrony is also experienced by patients with schizophrenia. Subjective or 'internal' time seems to be passing more quickly and physical time (clock time) more slowly than expected (9). Representations thus merge into an unreal 'timeless present':

> 'Time has stopped; there is no time . . . The past and future have collapsed into the present, and I can't tell them apart' (p. xix). 'The world had become timeless.' She knew that the 'clocks still marched onward,' but she was 'in a different realm' where 'everything is happening at once' (p. 133) (2).

One implication of the special theory of relativity is the apparent slowing-down of a moving clock, including subjective time, once it is accelerated compared to a clock at rest. This time dilation is counter-current to our subjective intuition of time, which, according to Einstein, would preclude any further analysis (10). To date, however, we are in a position to measure subjective time in the animal and human being (4). One of the major findings concerning time perception in the seconds to minutes range is the ability to accelerate the speed of subjective time with CB1 and D2 agonists, and to decrease this internal clock with typical antipsychotics and other dopamine D2 antagonists.

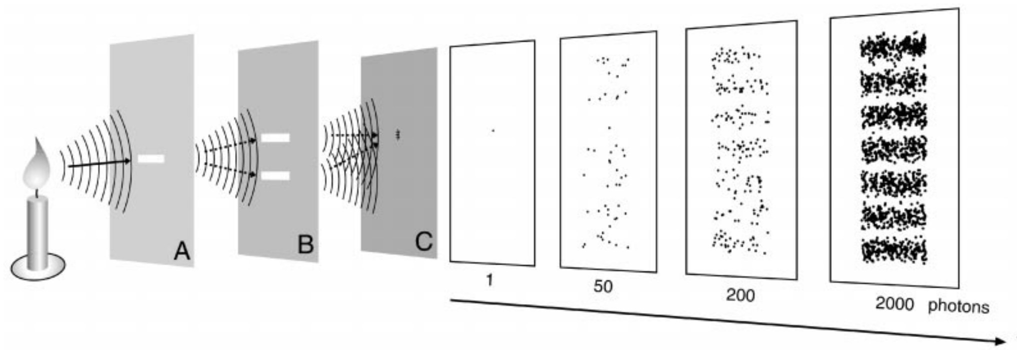

Fig. 2 Wave particle duality of light. The inherent minimal information – or choice of measuring either wave or particle – determines the complementary outcome of this experiment, which Albert Einstein used in his controversial discussion with Niels Bohr to question the observer's impact on nature (adapted from 17, 18).

Psychotic disintegration of the subject–object boundary

> 'A common hallucination induced by large doses of cannabis is time and space distortion: minutes seem like hours, small rooms yawn into caverns, and every activity is imbued with a sense of timeless grandeur . . . More importantly, in the ecstatic union of the human and the divine represented by this ritual, the sense of self is transcended by both partners. The role of cannabis in Tantric ceremony is thus to enable the worshippers to feel the divinity within and without themselves.' (11: p. 233) (Fig. 1).

Such a breakdown of the subject–object boundary, or ego-dissolution, manifesting itself as a threatening extension of external space and loss of self control is also experienced in schizophrenia, particularly by patients with delusions of alien control.

> She experienced a 'mystical awareness' in which she felt she could 'see beyond' ordinary reality. But later her sense of 'psychic powers' and revelations dissipated as she entered the 'abyss of timelessness.' Along with this, she had lost her 'grip' on who she was and felt 'pushed and pulled' by 'strange forces and voices' that made her do things against her will (2: p. 133).

These delusions, which Schneider included among his first rank symptoms, can be best described as actions being created, not by the patient herself, but by some outside forces. Schizophrenic patients have precisely this problem as evidenced by avolition, lack of motor awareness and related cognitive deficits to anticipate motor sequences (12). In addition to failures in task performance, error correction and memory for action at the physiological level, brain-imaging studies demonstrate increased activation in associated sensory regions where speech, as well as inner and outer space, are normally represented. Frith and colleagues (12) presume that such dysfunctional over-activity results from a lack of incoming inhibition from the frontal cortex, which normally attenuates activity associated with predicted stimuli. This is consistent with the model described by Hughlings Jackson (13). The explanation, however, that the 'positive' symptoms of schizophrenia can be seen as the consequence of a failure by 'higher' brain areas to 'regulate' lower centres leaves us with a conundrum. Cortical inhibition per se could never be demonstrated at a physiological level. Cortical inhibition and excitation rather appear to be inseparable events generated by local microcircuits (14), and this principle has been considered 'canonical' for the entire neocortex (15). The allusion to dysfunctional inhibition is ad hoc and cannot account for the disintegration of the subject–object boundary, as the authors (12) refer neither to independent variables nor to a quantifiable correlation. This, however, is indispensable for any scientific prediction with regard to the underlying psychotic phenotype.

QUANTUM STATES

The great physicist Niels Bohr (16) expressed his hope that the physical problems of quantum mechanics, particularly the impossibility of separating sharply between objective content and subjective consciousness, would advance the comprehension of the more intricate problems in psychiatry, such as ego-dissolution. 'The decisive point is here the recognition that a state of consciousness, in the description of which words like "I will" find application, is complementary to a state where we are concerned with an analysis of motives for our actions' (16: p. 971).

Quantum theory – the conceptual resolution of time and space

'God', said Albert Einstein, 'does not play dice'. This famous remark expressed his deep concern over the introduction of the new concept of probability and the extent to which the deterministic account of space-time was abandoned in quantum theory. To illustrate his attitude, Einstein referred to a simple example of a particle (photon or electron) going through a narrow slit in a diaphragm placed at some distance before a photographic plate. The apparent difficulty, which Einstein felt so acutely, was the fact that under such conditions it was impossible to predict with certainty at what point the electron will arrive at the photographic plate. If the photon is recorded at one point it is, despite the laws of ordinary wave propagation, out of question of ever observing an effect of this electron at another point. The importance of this problem was in the course of his discussion with Niels Bohr (17) illuminated by the examination of an arrangement where between the diaphragm with the slit (A) and the photographic plate (C) is inserted another diaphragm (B) with two parallel slits, as shown in Fig. 2.

If a parallel beam of photons falls from the double slit diaphragm (B) onto the photographic plate (C), we shall observe an interference pattern shown in the successive views to the right of (C). This pattern is built up by the accumulation of a large number of individual processes, each giving rise to a small spot on the photographic plate, and the distribution of these spots follows a simple law derivable from the wave analysis. The same distribution can also be found in the statistical account of many experiments performed with beams so faint that in a single exposure only one photon will arrive at the photographic plate (C). Since, as indicated by the broken arrows, the momentum transferred to the first diaphragm (A) ought to be different if the photon was assumed to pass through the upper or lower slit in the second diaphragm (B), Einstein suggested that a control of the momentum transfer would permit a closer analysis in order to decide through which of the two slits the photon had passed before arriving at the plate. At closer examination, however, the suggested assessment of the momentum transfer excludes the appearance of the interference phenomena in question.

This point is of logical importance: we are presented with a choice of either tracing the path of a particle *or* observing its interference effects. Otherwise, common sense would force upon us the contradiction, that the photon always chooses one of the two ways while it behaves as if it had passed both ways. This choice, which defines the minimum amount of information (19) allows us to escape from the paradoxical conclusion that the wave patterns of a photon should depend on the presence of two slits in the diaphragm through which it does indeed not simultaneously pass (18). In the analysis of quantum effect we are thus faced with the impossibility of drawing any sharp separation between the independent behaviour of a sub-atomic objects and its interaction with the observer. Instead, in order to be informed about its behaviour we have to make a 'choice' between the complementary conditions under which the phenomena occur (17).

Any attempt to measure precisely the velocity of a subatomic particle will knock it about in an unpredictable way so that a simultaneous measurement of its position is impossible. This phenomenon is a direct result of the particle-wave duality in the realm of subatomic dimensions. The 'particle' is most likely to be found in a location where the undulations of the 'wave' are greatest. The more intense the undulations of the associated 'wave' become, however, the more ill-defined becomes the wavelength, which in turn determines the velocity of the associated 'particle'. A strictly localized photon has an indeterminate wavelength and therefore an indeterminate diffraction pattern. A photon having a well-defined wavelength and velocity, on the other hand, is spread out almost anywhere on the screen.

This uncertainty principle, articulated by Werner Heisenberg in 1927, stipulates that the product of the uncertainties in position and velocity is always equal to or greater than a tiny physical quantity ($h/(2\pi)$, where h is Planck's constant). Although ordinary experience provides no clue of this principle, it challenges the concept of an exact description of space and time (20,21). The contribution by Heisenberg to modern physics was thus the replacement of the classical trajectory by a probabilistic description in which time-space series can in no way be determined. There are no measurements conceivable, which can give us complete information about the past of such a dynamical system in order to give us complete information as to its future (19). The concept of an exact (subatomic) reference frame for space and time has therefore no meaning in nature.

The difference between relativity theory and quantum theory is related to the level of information processing. While the principle of relativity theory is based upon perception relative to an arriving signal, quantum theory transcends perception through sensorimotor interaction – through the act of choice between two complementary aspects of that signal. In both cases we are thus confronted with the consequences of subjective observation that requires a conceptual revision of physical reality.

Since both theories have arisen from the existence of a maximum velocity of action and a minimum quantity of action, respectively, relativity theory and quantum theory possess a common logic. It is the impossibility of an unambiguous separation between time and space without reference to the observer (10), and the impossibility of a sharp separation between objects and their interaction with the observer (21).

Information theory – the missing link between subjective and objective reality

The success of classical physics since Galileo left no doubt about its objective character, in contrast to quantum theory where the need to include the subject in our fundamental description of nature has been explicitly asserted.

Time-reversible processes are described by equations of motion, which are invariant with respect to time. In quantum physics, we are confronted with the time-reversible Schrödinger equation on the one hand, and on the other, with the irreversible collapse of its wave function, or decoherence (22). If we wish to learn anything about a time-reversible object, we cannot avoid irreversibility, whether at the level of the registration device (i.e. the photographic plate; see Fig. 2) or at the level of our own memory (22,23). This irreducible duality was repeatedly emphasized by Wolfgang Pauli who wrote: 'Something only really happens when an observation is made, and in conjunction with that . . . entropy necessarily increases' (cited in 24: p. 50). Through this irreversible process we interact with a dynamical system gaining the equivalent amount of information in one dimension (Kolmogorov entropy) while at the same time decreasing the concomitant missing information or ignorance (Shannon information) about the system under observation (25). In the context of dynamics, decoherence is the ultimate cause of entropy production (26), which in turn reflects the arrow of time (see Fig. 2). There are further quantum implications of the interplay of decoherence and Kolmogorov information. Discussions of the interpretational issues of quantum theory are often conducted in a way which implicitly separates the information observers have about the state of the systems in the 'rest of the Universe' from their own physical state – their identity. Yet, there can be no information without representation, and the state of the observer's memory (Shannon entropy) determines its future actions (Kolmogorov entropy) (26).

THE DYNAMICAL SUBSTRATE OF CONSCIOUSNESS

Sensorimotor integration of subject and object

The interaction between the objects and the measuring device may be neglected in classical physics including relativity theory, whereas in quantum theory this interaction forms an irreversible part of the observation. Bohr concludes that every conscious experience corresponds to an impression in the organism, which originates from irreversible recordings in the memory of the central nervous system. These recordings, in which the interplay of numerous brain cells is involved, are essential for our reactions to subsequent stimuli and the capacity to adapt to the environment by selecting the most appropriate way to make this adjustment. The decisive point is that we attempt to predict what another person will decide to do in a given situation (23).

In order to adapt in a predictive way to dynamical environmental constraints, which is for human beings primarily social, we are constantly forced to anticipate and update information emerging from our fellows' central nervous systems. In this constant struggle, we are depending on our own brains' dynamical capacity to generate Kolmogorov information (27), whenever a choice (19) is made. This information can nowadays be objectified by dynamical electroencephalographic recording showing an increase of Kolmogorov entropy at the end and initiation of each motor act (28).

The action perception cycle – the remembered future

Anticipatory and goal-directed actions transcend purely sensory and motor processes by co-ordinating motor acts with sensory inputs that have occurred in the past and are supposed to occur in the future. Being of fundamental significance, this has become the implicit or explicit topic of a vast literature dealing with the neural mechanism of sensory–motor interaction (29). From the simplest and most automatic to the most deliberate, motor action is not only initiated by sensory signals, but also regulated in the course of time by inputs that action itself induces by its movement through the environment. This pattern of interaction between the organism and the world is also called the gestalt cycle (Gestaltkreis) by Viktor Von Weizäcker (30), who established the principle of the indissoluble union of perception and movement, subject and object, space and time.

Consciousness and its independent variables

William James (31) expressed the temporal aspects of self-awareness clearly, dissociating the consciousness of the immediate present from the consciousness that enables a personal history and an anticipatory vision of the future. Antonio Damasio (32) describes how consciousness has evolved from a 'core-self' into a higher faculty providing us with an elaborate sense of self, richly aware of the lived past and anticipated future. The stream of consciousness is furthermore, as James (31) observed, selective. Conscious control is exerted only, when a definite choice or selection has to be made – a feature that has led many to conclude that consciousness has limited capacity.

However, since it is the process of choosing among many alternatives that is the real bottleneck, this reduction considerably speeds up action. According to Edelman and Tononi 'the occurrence of a given conscious state selected among billions of others represents information, in the fundamental sense of reducing uncertainty among a large number of choices' (33: p. 147). The stream of consciousness follows a single trajectory, 'and what may appear as "decisions" or "choices" can occur only one at a time' (33: p. 151), corresponding to a large amount of information generated over a short time. It is astonishing how close, and without the explicit knowledge of the physical principles involved, these scientists have come to an objective description of consciousness by insight.

Irreversible processes, which lie at the heart of the so-called time vector (24,26), can be defined as Kolmogorov entropy (25) or a finite object (34) in one dimension. On the other hand, the 'choice' from a probability distribution ('uncertainty', 'missing information') (25) over a class (34) or a multidimensional set (35), can be defined as Shannon entropy. Through a 'choice' from such a set of probable expectations we gain actual information (Kolmogorov entropy) during an observation while at the same time decreasing the missing information or ignorance (Shannon information) (25). Furthermore, Shannon (**H**) and Kolmogorov (**K**) entropy constitute independent variables in Zurek's ensemble entropy equation ($\mathbf{S} = \mathbf{H} + \mathbf{K}$), defining the total amount of information in the whole (subject–object) system (25,26). It is well known that the total amount of entropy (**S**) or information inherent in any system never decreases. Otherwise, Maxwell's demon would – in defiance of the second law of thermodynamics – cause havoc by devising the prohibited perpetual mobile (25,26,36). In medicine, too, the consequences of impaired information processing are therefore inescapable.

Prediction

When Kolmogorov information (inherent in the processing of time and action) breaks down in acute psychosis ($\mathbf{K}\downarrow$), Shannon information (inherent in the processing of space and higher dimensional perception) will 'explode' ($\mathbf{H}\uparrow$), provoking altered states of consciousness. In schizophrenia and cannabis psychosis, positive symptoms will then 'impose' themselves upon the subject as 'external' 'representations' or as a pathological overlap of 'internal' and 'external' space. Schizophrenic patients with delusions of alien control have precisely this problem, showing in brain imaging studies concomitant shifts of over-activation to the cingulate gyrus and right parietal cortex, where 'inner' and 'outer' space is normally represented (37). This conclusion can be verified as well as falsified. It is falsified if non-linear EEG analysis of psychotic individuals demonstrate an undiminished Kolmogorov entropy during an act of choice (28) along with an absence of increased Shannon entropy (i.e. by functional MEG clustering, 38) over those brain areas that exhibit pathologic over-activity during hallucinations (12,37,39).

Psychiatric research is at a crisis, since numerous linkage studies have yielded unconvincing evidence for the involvement of multiple candidate genes. The correct definition of the phenotype is therefore a fundamental question in schizophrenia in order to ask the even more fundamental question: what at the genetic level correlates with what at the phenotypic level? Information, it is conjectured, constitutes the independent variable to render this search more tractable – in both human subjects and animal models (6).

In schizophrenia, only the Lyapunov exponent has been investigated by means of dynamical electroencephalography, so far: compared to normal controls, it was significantly lower in schizophrenic patients (40). However, since the Lyapunov exponent can be viewed as a dynamic measure of the rate of diverging trajectories, it reflects the rate at which Komogorov entropy is generated by the brain (see Pesin's theorem, 27). Non-linear EEG investigations have furthermore correlated the processing of volition (28) cognitive (41) and emotional information (42) with Kolmogorov entropy in normal subjects. A reduction of this objective measure would thus presents us with a novel diagnostic tool to assess the breakdown of information processing in schizophrenia, namely, the 'break of thought and emotion' (43) directly. Based on the first commercially available non-linear EEG program, a preliminary assessment of Kolmogorov Entropy and other dynamical parameters in schizophrenia appears to confirm this assumption (44). Preventive assessments could then hopefully protect those individuals who are at an increased risk (7) of developing a devastating psychosis upon the consumption of cannabis.

REFERENCES

1. Freud S. The unconscious. 1915. In: Strachey J., ed. *Complete Psychological Works, Vol. 14*. London: Hogarth, 1964: 159–215.
2. Melges F. T. *Time and the Inner Future. A Temporal Approach to Psychiatric Disorders*. New York: Wiley, 1982.
3. Ludwig A. M. Altered states of consciousness. *Arch Gen Psychiatry* 1966; **15**: 225–234.
4. Meck W. H. Neuropharmacology of timing and time perception. *Cogn Brain Res* 1996; **3**: 227–242.
5. Glass M., Felder C. C. Concurrent stimulation of cannabinoid CB1 and dopamine D2 receptors augments cAMP accumulation in striatal neurons: evidence for a Gs linkage to the CB1 receptor. *J Neurosci* 1997; **17**: 5327–5333.
6. Fritzsche M. Are cannabinoid receptor knockout mice animal models for schizophrenia? *Med Hypotheses* 2001; **56**: 638–643.
7. Johns A. Psychiatric effects of cannabis. *Br J Psychiatry* 2001; **178**: 116–122.

8. Hicks R. E., Gualtieri C. T., Mayo J. P., Perez-Reyes M. Cannabis, atropine, and temporal information processing. *Neuropsychobiology* 1984; **12**: 229–237.
9. Wahl O. F., Sieg D. Time estimation among schizophrenics. *Percept Mot Skills* 1980; **50**: 535–541.
10. Einstein A. *The Meaning of Relativity*. Princeton: Princeton University Press, 1922.
11. Aldrich M. R. Tantric cannabis use in India. *J Psychedelic Drugs* 1977; **9**: 227–233.
12. Frith C. D., Blakemore S., Wolpert D. M. Explaining the symptoms of schizophrenia: abnormalities in the awareness of action. *Brain Res Brain Res Rev* 2000; **31**: 357–363.
13. Jackson J. H. In: Taylor J., ed. *Selected Writings of John Hughlings Jackson*. London: Hodder & Stoughton, 1932.
14. Douglas R. J., Martin K. A. A functional microcircuit for cat visual cortex. *J Physiol* 1991; **440**: 735–769.
15. Churchland P. S., Sejnowski T. J. *The Computational Brain*. Cambridge: MIT, 1992.
16. Bohr N. Medical research and natural philosophy. Address delivered at the Second International Poliomyelitis Conference in Copenhagen 1951, pp. 65–78. In: Kalckar J., ed. *Collected Works, Vol. 10*. Amsterdam: Elsevier, 1996.
17. Bohr N. Discussion with Einstein on epistemological problems in atomic physics. In: Schilpp P. A. (ed). *Albert Einstein: Philosopher-Scientist. The Library of Living Philosophers, Vol. 7*. Illinois: Evanston, 1949; pp. 201–241.
18. Rae A. I. *Quantum Physics: Illusion or Reality*? Cambridge: Cambridge University Press, 1986
19. Wiener N. *Cybernetics: or Control and Communication in the Animal and the Machine*. Cambridge: MIT, 1948
20. Heisenberg W. Ueber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. *Zeits Phys* 1927; **43**: 172–198.
21. Bohr N. The causality problem in atomic physics. Address delivered at the Conference on New Theories in Physics in Warsaw 1938. In: Kalckar J., ed. *Collected Works, Vol. 7*. Amsterdam: Elsevier, 1996; pp. 299–324.
22. Zurek W. H. Einselection and decoherence from an information theory perspective. *Ann Phys* 2000; **9**: 855–864.
23. Bohr N. The unity of knowledge, 1954. In: Kalckar J., ed. *Collected Works, Vol. 10*. Amsterdam: Elsevier, 1996; pp. 79–98.
24. Prigogine I. *The End of Certainty. Time, Chaos, and the New Laws of Nature*. New York: Free Press, 1997.
25. Zurek W. H. Algorithmic randomness and physical entropy. *Phys Rev* 1989; **40**: 4731–4751.
26. Zurek. W. H. *Personal Communication*, 1997.
27. Elbert T., Ray W. J., Kowalik Z. J., Skinner J. R., Graf K. E. et al. Chaos and physiology, deterministic chaos in excitable cell assemblies. *Physiol Rev* 1994; **74**: 1–47.
28. Popivanov D., Dushanova J. Non-linear EEG dynamic changes and their probable relation to voluntary movement organization. *Neuroreport* 1999; **10**: 1397–1401.
29. Fuster J. M. *The Prefrontal Cortex. Anatomy, Physiology, and Neuropsychology of the Frontal Lobe*. New York: Raven, 1989.
30. Von Weizäcker V. *Der Gestaltkreis. Theorie der Einheit von Wahrnehmen und Bewegen*. Stuttgart: Thieme, 1950.
31. James W. *The Principles of Psychology*. New York: Dover, 1890.
32. Damasio A. *The Feeling of What Happens. Body and Emotion in the Making of Consciousness*. New York: Harcourt Brace, 1999
33. Edelman G. M., Tononi G. *A Universe of Consciousness. How Matter Becomes Imagination*. New York: Basic Books, 2000.
34. Leung-Yan-Cheong S. K., Cover T. M. Some equivalences between Shannon entropy and Kolmogorov complexity. *Trans Information Theory* 1978; **24**: 331–338.
35. Yockey H. *Information Theory and Molecular Biology*. Cambridge: Cambridge University Press, 1992.
36. Szilard L. Ueber die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen. *Zeits Phys* 1929; **53**: 840–856.
37. Spence S. A., Brooks D. J., Hirsch S. R., Liddle P. F., Meehan J., Grasby P. M. A PET study of voluntary movement in schizophrenic patients experiencing passivity phenomena (delusions of alien control). *Brain* 1997; **120**: 1997–2011.
38. Tononi G., Edelman G. M. Schizophrenia and the mechanisms of conscious integration. *Brain Res Brain Res Rev* 2000; **31**: 391–400.
39. Silbersweig D. A., Stern E., Frith C., Cahill C., Holmes A., Grootoonk S., et al. A functional neuroanatomy of hallucinations in schizophrenia. *Nature* 1995; **378**: 176–179.
40. Kim D. J., Jeong J., Chae J. H., Park S. An estimation of the first positive Lyapunov exponent of the EEG in patients with schizophrenia. *Psychiatry Res* 2000; **98**: 177–189.
41. Micheloyannis S., Flitzanis N., Papanikolaou E., Bourkas M., Terzakis D., Arvanitis S., Stam C. J. Usefulness of non-linear EEG analysis. *Acta Neurol Scand* 1998; **97**: 13–9.
42. Aftanas L. I., Lotova N. V., Koshkarov V. I., Pokrovskaja V. L., Popov S. A., Makhnev V. P. Non-linear analysis of emotion EEG: calculation of Kolmogorov entropy and the principal Lyapunov exponent. *Neurosci Lett* 1997; **226**: 13–16.
43. Bleuler E. *Handbuch der Psychiatrie. Dementia praecox oder Gruppe der Schizophrenien*. Leipzig: Deuticke, 1911. (Translated by J. Zukin New York: International Universities Press, 1950.)
44. Fritzsche M., Mayorov O., unpublished data, 2002.