Self-Identification and Sensori-Motor Rehearsal as Key Mechanisms of Consciousness

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Abstract

The paper addresses the nature and physiological mechanisms of awareness, conscious perception, generation of thoughts and discursive and imaginative thinking. It shows that a high-frequency cyclic process of self-identification may underlie awareness and generation of thoughts. Self-identification is a collective neuronal activity process which forms an intensive specific excitation pattern in the cerebral cortex in response to external or internal input signals. This provides the best conditions for data categorisation by distributed long-term memory. The result of categorisation, a symbol or image, expresses their subjective sense. The symbolic mapping of data means the transition from the physiological (objective) level to the mental (subjective) level. Sensory awareness is produced by the processes of intensive mapping and explicit symbolic representation of the stimulus field in the sensory areas of the cortex. A thought is produced by the processes of intensive mapping and explicit symbolic representation of multiply connected coordinated neuronal activity of the brain in the higher associative areas of the cortex. Awareness and generation of thoughts have the same nature and similar physiological mechanisms.

A cyclic process of internal sensori-motor rehearsal may underlie discursive and imaginative thinking. Rehearsal is a low-frequency process and its contents are accessible to survey (introspection) by the high-frequency apparatus of self-identification which is built into the rehearsal loop. Our train of mental images, words or symbols is introspectable and controllable by means of the programming apparatus of the motor system. The interacting mechanisms of sensori-motor rehearsal and self-identification allow us form images, scenes and dialogues and watch and change them thus creating a mobile, controlled mental world.

Key words: awareness, consciousness, subjectivity, thought, thinking.

1 Introduction

There can be named a few particular problems the solution of which could shed light on the nature and mechanisms of conscious activity of the brain. The most important of such problems is finding out physiological mechanisms that produce the mentally experienced phenomenon of awareness of sensory events. The problem consists in finding out how we become aware of anything, e.g. a flash of light, a sound or a smell. Despite abundant of experimentation on conscious perception, the key aspect of the problem, and the most profound one, remains unclear, namely, how exactly does coordinated neuronal cerebral activity (a physiological process) produce the phenomenon of awareness (a mental process)?

Another aspect of conscious activity of the brain is related to man's ability to voluntarily operate knowledge. We operate knowledge in the processes of discursive thinking and imagination. Phenomenologically these processes are expressed by thoughts. What is thought and what physiological mechanisms underlie our mysterious ability to think?

In discussing these problems, we will be avoiding, where possible, going into other matters related to consciousness and attention, such as, for example, mechanisms of image recognition or the nature of short-term and long-term memory. Our efforts will be focused on establishing physiological mechanisms of awareness and volitional operation of knowledge.

2 Hypothesis of Self-Identification

As is well known, in the process of perception, a stimulus produces specific distribution of neuronal activity in one or more areas of the sensory cortex. One can assume that a specific pattern of excitation in output neurons is relayed through massively parallel feedback, returning again to neurons of the same cortical areas. The coinciding (identical) patterns of excitation, produced by the stimulus itself and by relay through back projections, are added together on the same neuronal structures, thus inducing firing in an increasing number of neurons and enhancing the intensity of excitation in these structures (Fig. 1). Such a cyclic positive- feedback process produces an "explosion" in the intensity of the specific pattern of excitation. At the same time, background excitation in neuronal structures not activated by the stimulus is of low-intensity and its frequency and phase distribution are random. Their uncoordinated interactions cannot induce a rapid increase in background noise. Moreover, intensive excitation, which is produced by the stimulus, can cause dynamic inhibition in surrounding neuronal structures (Mountcastle 1978). Therefore, the specific pattern of excitation acquires high contrast. The specificity of spatial excitation in the cortex accentuates specific features of the stimulus, thus providing adequate mapping of it.

A mechanism of enhancement of prominence of specific signals through amplification of their intensity and memorising for the duration of circulation within a closed circuit might originate in the course of evolution to map vital events, such as dangerous physical and chemical effects of the environment. The adaptive utility of this mechanism might make it subject to evolutionary selection and lead to an expanded set of physical and semantic characteristics of the signals to be mapped. Such evolutionary process might ultimately form an apparatus of intensive mapping of actually significant signals.

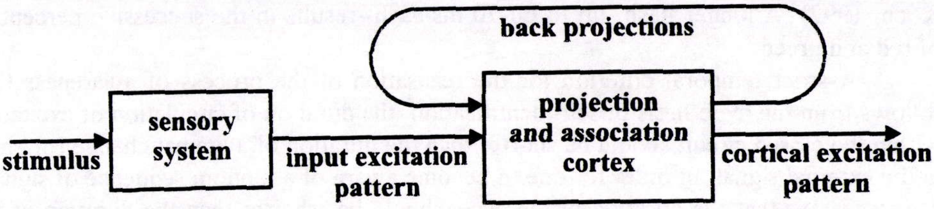

Fig. 1: Diagram of the process of self - identification.

The identification of a pattern of stimulus-produced excitation with itself by its feedback to the input is the process of self-identification. This process produces coherent neuronal activity thus forming a specific pattern and raising the signal/noise ratio for a very brief period of time. This provides the best conditions for categorisation of the pattern by distributed long-term memory. The result of categorisation, a symbol or image, expresses the subjective sense of sensory features of the stimulus. The symbolic mapping is a response of memory to input excitation and is physiologically expressed in a pattern of cortical neuronal activity. This pattern is also involved in the cycle of self-identification thus providing intensive mapping of the subjective sense of the stimulus. This event should correlate with the moment of stimulus awareness and it should be physiologically expressed in the synchronisation of oscillations in the potential in extensive cortical areas. The symbolic mapping of the stimulus means the transition of the process of perception from the physiological (objective) level to the mental (subjective) level.

The process of self-identification proceeds due to coincidence (in the principal features) of the feedback pattern with the pattern of cortical excitation. Such coincidence only becomes possible in the event that no change occurs in the input excitation during circulation of output excitation within the feedback circuit. Otherwise a lagging feedback pattern will not coincide with the current cortical excitation pattern, which will make intensive mapping of specific features of the stimulus and, therefore, awareness, impossible.

For example, if two brief successive flashes of light of different colours follow each other, the feedback pattern produced by the first flash will overlap the pattern of cortical excitation produced by the second flash. The resulting distribution of cortical neuronal activity should then correspond to the blend of the colours of the first flash and the second flash. Becoming aware of these successive flashes as individual events is therefore impossible. In order to become aware of successive flashes of light of different colour, it is necessary that the duration of the flashes or the interval between them should exceed the duration of the cycle. In this case the process of self-identification is completed for each flash separately, which makes it possible to become aware of them. Indeed, it was experimentally established that two successive flashes of light, red and green, each lasting 20 ms, are perceived by a subject as a single yellow flash (Crick and

Koch, 1992). A longer flash--up to 60-70 ms each--results in the successive perception of red and green.

A strict temporal criterion for the realisation of the process of awareness thus follows from the hypothesis of self-identification: the duration of circulation of excitation within the closed circuit should be shorter than the duration of a liminal change (or shift) in the external signal. In order for one to become aware of a random sequence of signals, it is necessary that the duration of the cycle should be shorter than the duration of the signals or the intervals that separate them.

An a priori estimate of the likely duration of the cycle of self-identification is possible, based on the requirements of an organism's adaptation to the conditions of its environment. It follows from the postulated mechanism of self-identification that any signal should first circulate through at least one cycle so that the brain could be aware of it. Then the duration of the cycle should be shorter than the typical temporal intervals in environmental changes--such as are vital for the organism. Otherwise important changes will occur in the environment, but awareness will not catch up with the events. The duration of a cycle is the period of a continuous process quantisation. Representation of a continuous signal by discrete sampling requires at least two readings per period of the highest-frequency component of the continuous signal frequency spectrum. Vital events, such as animal movements (those of a predator or prey), the velocities of vortices, water currents and others, have frequency spectrums the periods of whose high-frequency components are equal to approximately 0.1 s. Then the period of quantisation should be less than or approximately equal to 50 ms, which constitutes the theoretic estimate of the cycle duration (Sergin, 1991, 1992).

The mechanism of self-identification produces discrete events at an interval of discreteness equal to the duration of the cycle. In such an apparatus of awareness, cycle duration is the shortest discriminable period of time. Successive signals falling within one cycle should therefore be mentally perceived as simultaneous. Signals falling into different cycles should be perceived as successive.

It has indeed long been established in experimental psychology that a rapid succession of a faint and a strong signal is perceived as blended. The first signal is believed to be masked by the second. This phenomenon, observed in the visual, auditory and tactile modalities, is referred to as "backward masking". The self-identification model agrees with these experimental data and explains the mechanism of "masking," which consists of fusion of the signals in accordance with their weights.

J. Hylan (1903) established as long ago as early this century that six consecutively exhibited letters seem simultaneous if they fall within an interval of approximately 80 ms. Research on this phenomenon in the decades that followed led to the establishment in psychology of the notion of the "perceptual moment" which is the longest interval of time within which successive perceptual events are perceived as simultaneous. The "perceptual moment", consequently, coincides with the timing of a cycle of self-identification, and its duration may provide an experimental estimate of the maximum duration of the cycle.

Experiments (Joliat, Llinas and Ribary, 1994) show that the subject perceives two consecutive clicks as one if the interval between the clicks is shorter than 12 msec. If the interval exceeds 12 msec., the subject detects two clicks. These experimental data agree well with the mechanism of self-identification and provide an estimate of a minimum duration of the cycle.

Signals which fall into different cycles of self-identification should be perceived as successive. Then the minimum period of time needed for discrimination between successive signals is equal to the duration of the cycle. Theoretically, there should thus be a temporal threshold for discrimination between successive events, the value of which coincides with the duration of the cycle. The temporal threshold should not depend much on the modality of signals since it is produced by a mechanism of the same type at the cortical level.

The threshold for discrimination between successive stimuli was established experimentally as long ago as the 1960s; it happens to be approximately the same for the auditory, visual and tactile modalities and for alternating stimuli of different modalities and was about 60 ms (Hirsh and Sherrick 1961; Kristofferson 1967; Efron 1973), which is close to the theoretical estimate of cycle duration. If the threshold for discrimination between successive events is produced by the duration of synchronous circulation of excitation in neuronal structures, training should change it like any other physiological process. "The striking effect of learning" (Efron 1973) has indeed been discovered. In trained subjects, the threshold for discrimination between successive stimuli is as low as 15-20 ms in the auditory, visual, tactile and alternating modalities (Hirsh and Sherrick 1961). The approximate equality of the thresholds for discrimination in different modalities, and the equal changes in them as a result of training, despite the fundamental anatomical and physiological differences between the respective perceptual organs, provides evidence for the existence of a universal signal-processing mechanism irrespective of modality. Both qualitative and quantitative characteristics of the temporal threshold for signal discrimination thus agree well with theoretical predictions.

Although the duration of the cycle limits the temporal resolution of perceptual events in the process of awareness, signals should keep their subliminal (nonconscious) temporal structure. R. Efron (1973) showed experimentally that unconscious information of the order of two or three successive microsignals, constituting a short stimulus (20-40 ms), did remain intact. Subjects are unable to report explicitly the order of microsignals in each stimulus, but can nevertheless discriminate between stimuli with different sequences of microsignals. The conservation of the temporal microstructure of signals is revealed in experiments involving the auditory, visual and tactile modalities.

Examination of extensive psychological and psychophysical data provides an estimate for the duration of the self-identification cycle of an order of several tens of milliseconds which may vary between 10 ms and 100 ms (Sergin 1994 a, c, 1998). We may therefore estimate the respective frequency band of the cyclic processes at values between 10 Hz and 100 Hz.

If the mechanism of self-identification underlies signal awareness, the frequency of its operation should be related to the frequency of events perceived, which the organism needs for adaptation to changing environmental conditions. The mechanism of self-identification should respond to an increase in the inflow of information I through any perceptual channel with an increase in the cycle frequency f_c, in order to promptly include it in the process of awareness. Therefore, $f_c \sim I$. This relation has two asymptotes. If input information is too great, the frequency reaches a value which it cannot physiologically exceed. No further increase in information input can then raise the cycle frequency. If input information flow is too small, the frequency falls to its lowest possible value which corresponds to the state of relaxation. An increasing function with two asymptotes, one at approximately 10 Hz and the other at approximately 100 Hz, may therefore represent the dependence of the cycle frequency on input information flow (Figure 2).

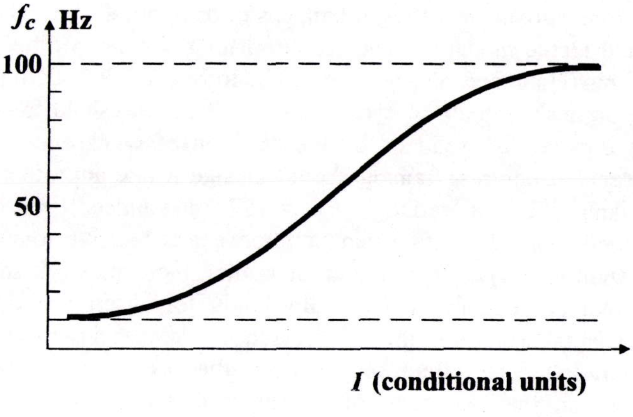

Fig. 2: The dependence of self-identification cycle frequency f_c on input information flow I.

Synchronous cyclical processes of self-identification take place in spatially distributed cortical neuronal structures of the brain and they should constitute an important part of cerebral electric activity. Indeed, in the state of wakefulness and under intense sensory stimulation, high-frequency beta- and gamma-band oscillations (14-30 Hz and 30-100 Hz, respectively) dominate cortical electric activity. In a state of relaxation and in the absence of external stimuli, with the eyes closed, cerebral electric activity shifts into a low-frequency mode dominated by alpha-rhythm (8-13 Hz). That is, cortical electric activity reveals, overall, a dependence of the oscillations frequency of potential on the rate of input information flow, which agrees, in general terms, with the frequency characteristic built on the basis of psychophysical data (Figure 2).

The process of self-identification, which proceeds by way of simultaneous circulation of signals in homogeneous neuronal structures in a limited cortical area, should produce in that area a field of spatially coherent oscillations. A stimulus containing different components, for example, boundaries, colour and motion, may simultaneously produce several fields of coherent oscillations, with frequencies of their own, in different projection and associative cortical areas. In this case, rapidly changing features may be self identified, due to high frequencies of circulation, while less mobile and stable characteristics are self-identified by low frequencies. The current spectrum of cortical electric activity may therefore contain many fields of spatially coherent oscillations differing in frequency and topographic distribution, which provide for integrated and synchronous mapping of a changing stimulus.

Recent investigation in human cerebral electric and magnetic activity has indeed discovered fields of spatially coherent oscillations (Sviderskaya and Shlitner 1990; Llinas and Ribary 1993, *etc.*). The existence of numerous very distinct fields of spatially coherent oscillations in the cortical electric activity was established in (Sviderskaya and Shlitner 1990). These fields of coherent oscillations of various frequencies are characterised by various topographic distribution. There are overlapping areas where fields of spatially coherent oscillations of various frequencies exist simultaneously. It was noted that the intensity of local activation in a certain cortical area is higher, the more fields of spatially coherent oscillations of various frequencies occur within its boundaries (Sviderskaya, Korolkova and Tishaninova 1993).

There exist numerous data on fields of coherent oscillations in the cerebral cortex obtained in animal experiments (Gray, 1994). For example, Freeman (1992) found, in an extensive program of research on olfactory processes, spatially coherent oscillations of electric activity in the olfactory bulb and olfactory cortex in the band between 20 Hz and 90 Hz. It turned out that each smell is identified by a certain spatial distribution of amplitude values of coherent oscillations in the olfactory bulb, so exposure to different smells produces different amplitude "maps" of coherent oscillations (Freeman, 1991).

3 Perceptual and Operational Consciousness

The spatial distribution of long-term memory means that the memory of specific features of a stimulus, such as its boundaries, motion or colour, may be located in respective specialised cortical areas, and the memory of binding the features into objects or images, is located in the associative cortical areas of different levels (Damasio, 1989). Therefore simple unimodal stimuli may be categorised in the posterior areas of the sensory cortex, while more complex stimuli, will involve intermediate areas. Complex scenes, multimodal events or their temporal sequences may be categorised and symbolically interpreted in the frontal associative areas of the brain, as well as the temporal area of the cortex and the hippocampal system. Then, in response to input excitation, memory produces a pattern of neuronal activity in the same cortical areas as are involved in the perception of the stimulus. If the memory response corresponds at least approximately to the stimulus, memory produces a pattern close to the pattern of sensory excitation (similar in principal features). Identical components of these patterns add together in the same neuronal structures, accentuating the most significant features of the stimulus. The resulting pattern of neuronal activity is again subjected to categorisation, which produces a new pattern of symbolic interpretation. This cyclical process ends in a pattern of sensory excitation becoming approximated by the best version of symbolic interpretation which the subject's memory has at its disposal (Sergin, 1998).

Mapping of the stored data of memory by a neuronal activity pattern in the sensory cortex, that is, *functionally in the same manner* as external signals are mapped, is the representation of internal data in the explicit form. Data stored in long-term memory in an *implicit* form are thereby converted into an explicit form. Explicit representation of internal data allows their categorisation and symbolic interpretation in the same manner as applies to external signals. Therefore mapping of symbolic data by a neuronal activity pattern is its representation to the subject as an external world description element. As a result, the external world is represented to the subject in his own terms (or symbols, or images), which is the most specific experience of subjective perception.

Awareness is a form of secondary processing of signals, the purpose of which is explicit representation of actually significant data. The operation of the system of awareness forms a selected multimodal flow of explicit knowledge, apparent, and represented to the subject ("the self"). Similarly, there is a flow of information of which the subject is unaware (implicit, concealed knowledge). The universal system of explicit representation of data reaches its maximum efficiency in visual perception, thus producing the mental phenomenon of vision. Awareness imparts to the process of perception a new quality in terms of the *mental dimension*, allowing us not only look and respond adequately, but also look and see, and not only listen and act, but also listen and hear.

We shall refer to the system of awareness of signals arriving from the environment and from our own body by massive parallel multi-modal signalling routes as perceptual consciousness. Fig. 3 shows its block diagram. The lower level represents the organism's functioning in situations where we quite adequately respond to stimuli without being aware of either the stimuli or our own actions. The upper cognitive level includes awareness of stimuli and actions which enables us to survey the current situation. Typically, both levels are working and, depending on internal motivation and external conditions, functional load is continually redistributed between them.

The principal function of sensory awareness is explicit integrated representation of sensory events. The non-specific activating system of the brain may simultaneously activate the cyclic processes of self-identification of sensory characteristics relating to different cognitive levels and different modalities (or sub-modalities), thus binding them by pattern simultaneity. The *non-specific system* which includes the reticular formation of the stem and thalamus has projections into all cortical areas and, in turn, is controlled by the cortex of the cerebral hemispheres through descending projections (Kratin, Sotnichenko, 1987; Newman, 1997). The cortex selectively and differentially governs its own activity through the non-specific system.

Llinas and Ribary (1993), proceeding from observations derived from different sources, arrive at the conclusion that the specific system provides contents and the non-specific provides temporal binding of the contents into an integral cognitive experience (awareness). Since processes of self-identification are expressed in simultaneous fields of spatially coherent oscillations in the potential at various frequencies, their triggering from the state of relaxation should look as "de-synchronisation" in the EEG. One experimental work (Sviderskaya, Korolkova and Tishaninova 1993) shows that the phenomenon of "de-synchronisation" in the slow high-amplitude EEG rhythm actually consists in its replacement with a multitude of fields of spatially coherent oscillations of various frequencies.

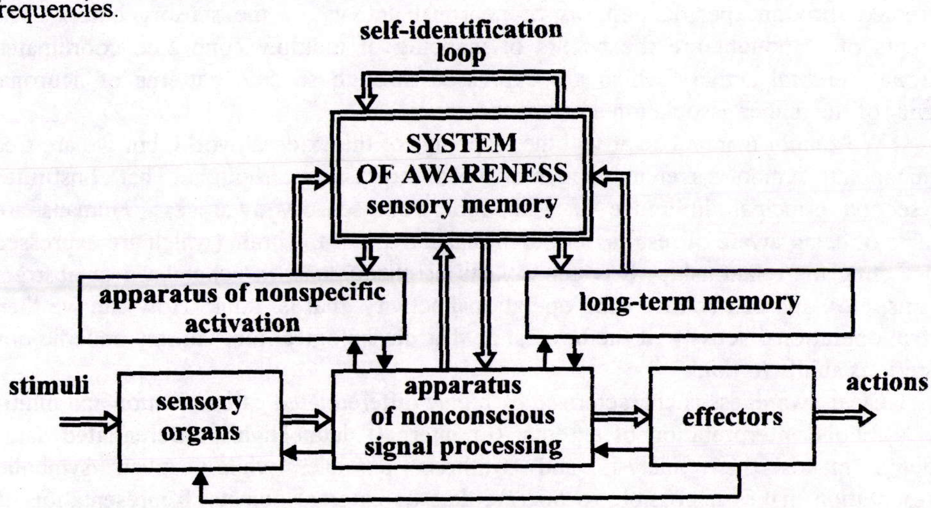

Fig. 3: The block diagram of the model of perceptual consciousness. Double arrows show the principal loops of signal transmission.

The apparatus of awareness allows explicit representation of both external and internal signals. The physiological mechanism of survey (explicit representation) of one's own thoughts and mental images--that is, the mechanism of introspection--may therefore be quite similar to the mechanism of sensory data awareness.

A thought emerging under the influence of some motivation is a response of memory of the association cortex to input excitation, which response is expressed physiologically through a specific pattern of neuronal activity. A thought may be dim and almost indistinct, but if motivation that has generated the thought holds on, the feedback pattern adds to the pattern of input excitation on the same neuronal structures of the association cortex thus enhancing the intensity and contrast of the specific pattern of excitation. By accentuating the specificity of the pattern, this cyclical process of self-identification forms a clear, distinct thought (a symbol, an image or a word). A continuing motivation implies a continuing involuntary interest in the subject or topic, or requires an effort of will that evokes selective activation of neuronal structures. If motivation changes, the feedback pattern would not coincide with the current pattern of input excitation and the original thought would disperse.

Sensory awareness is produced by the processes of intensive mapping and explicit symbolic representation of the stimulus field in the sensory areas of the cortex. A thought is produced by the processes of intensive mapping and explicit symbolic representation of multiply connected coordinated neuronal cerebral activity in the higher association areas of the cortex. Awareness and generation of thoughts have the same nature and similar physiological mechanisms. Sensory awareness and thought differ in their contents. The contents of sensory awareness are the results of mapping of the stimulus field, which are expressed through specific patterns of neuronal activity of the sensory cortex. The contents of a thought are the results of mapping of multiply connected coordinated neuronal cerebral activity which are expressed through specific patterns of neuronal activity of the higher association areas of the cortex.

We cannot manipulate at will the mappings of the external world, but we are free to manipulate symbols, sketchy images or words expressing a thought. That constitutes the second principal difference of a thought from sensory awareness. Humans are capable of being aware of results of operational activity of the brain (which are expressed in detecting the relationships between objects or phenomena, in generalised or abstract notions, etc.) and can control such operational activity, that is, think. How can we then control operational activity of the brain and what physiological mechanisms underlie our mysterious ability to think?

Clear awareness is characterised by highly differentiated categorisation and multi-level symbolic interpretation of external (or internal) data. Highly differentiated data-mapping makes their analysis and synthesis possible, while explicit symbolic representation makes it possible to operate data as external objects. Representation of data in terms of the subject's knowledge base (by means of words, symbols or images) makes them accessible to control. Verbal rehearsal provides a good example of volitional control: the subject utters a word, hears and memorises it, which extends the time of its storage in working memory. This is the cyclic verbal process of sensori-motor rehearsal. It is unnecessary to utter words out loud; the subject may repeat them silently, which constitutes the process of internal sensori-motor rehearsal.

External rehearsal--verbal rehearsal or finger-tapping--is expressed through the actions of effector and receptor organs. Coordinated schemes and programmes for volitional movements are formed in the pre-frontal cortex and association motor cortex. They are expressed physiologically in specific patterns of neuronal activity which are transmitted into the primary motor areas of the cortex, basal ganglia, cerebellum and spinal cord. At the same time, still before they evoke a movement, these specific patterns are transmitted via feed-back to the higher (parieto-temporo-occipital) association areas of the sensory cortex thus adjusting the sensory systems to the proposed actions. This central feed-back closes the loop (Fig. 4) which makes internal rehearsal possible.

The auditory and visual systems have multiple inputs to the pre-frontal and association motor cortices and receive back projections from there, which makes internal verbal and visual rehearsal possible. The pre-frontal and association motor cortices have no modal-specific zones and consist entirely of apparatuses of the motor type. Therefore inter-relationships of the motor and sensory systems of other modalities have the same scheme, which makes internal sensori-motor rehearsal possible in any modality.

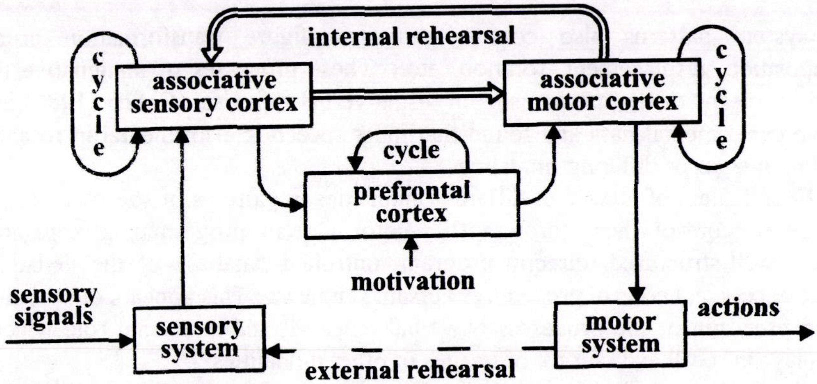

Fig. 4: Diagram of sensory-motor rehearsal. Internal rehearsal is shown by double arrows. Cycles of self-identification are shown by closed loops; the activating system is not shown.

The verbal system has the most powerful apparatus of sensori-motor rehearsal which includes specialised cortical areas that make the receptive selection of words (Waernicke's area) and form speech (Broca's area). Discursive thinking is immediately related to coding information in speech motor system patterns. The rehearsal procedure makes reasoning consecutive, continuous, coherent and unambiguous. These properties of discursive thinking reveal demonstrably characteristic features of the motor system which functions by accessing a single necessary command from a potential set, consecutively execution of commands, and strict cohesion of successive actions. The programming apparatus of the motor system makes it possible to form, from an enormous reserve of potential micromovements brought forth by a virtually endless number of degrees of freedom of the peripheral motor system, small yet coordinated sets of movements. A strict sequence of multitudes of simultaneous, coordinated movements makes a purposeful action possible. The programming apparatus which forms a linked sequence of acts of movement forms likewise a linked sequence of thoughts. Sketchy, rigidly determined and logical discursive thinking appears to be a result of a motor system programming apparatus. Discursive thinking proves to be mechanistic by nature. That imposes restrictions on its creative capacity and explains the ease with which the computer performs discursive procedures.

Visual rehearsal is a cyclical process of sensori-motor reproduction of visual images. Images generated in the higher association areas of the cortex are bare of detail; they are mere sketches of real objects and events. However, such simple images of objects and sketches of events are convenient for control and processing. Words express many visual images, and their attributes and properties and operations performed on them, which are thus coded in patterns of the speech motor system. Naming an image silently or aloud is enough to visualise it. By uttering a word, we activate the speech motor system which accesses respective visual information in long-term memory. Speech motor system patterns also control geometric figure transformation procedures (decomposition, displacement, rotation, etc.). These processes of imaginative thinking proceed by means of the mechanisms of visual-verbal rehearsal. Cohen (1986) analysed extensive experimental data and found that inner speech is instrumental in recalling and controlling images of different modalities.

Encodement of images of different modalities in patterns of speech motor system allows us to control them through the motor system programming apparatus. An extensive, well-structured, directly program-controlled database of the verbal system make the access and control procedures versatile and easy. This appears outwardly in the ease and precision of the processes of verbal rehearsal and in special role which inner speech plays in recall and control of images of other modalities.

The formation of mental images or logical constructions must invoke motor and sensory activity patterns of corresponding modalities. It does so indeed (Cohen, 1986). For example, mental images and visual thinking invoke reafferent signals from eye muscles. Discursive thinking is linked with patterns of neural activity of the verbal motor system. The voluntary imaging of tastes or smells may be accompanied by covert oral or nasal adjustments. Cohen (1986) points out that no thought nor image is possible without specific activation patterns in the motor system

We will refer to the system of operation of knowledge which performs such higher functions as discursive thinking, imagination and reflexion, as operational consciousness. (A tentative outline of operational consciousness can be found in the works (Sergin, 1994, a, b, c). The mechanism of sensori-motor rehearsal is a basic tool of operational consciousness. Experimental findings set the upper limit of verbal rehearsal frequency at 3-6 Hz (Klatzky, 1975). The frequency of rehearsal is the clock frequency of operational consciousness as a data-processing system. Processes of discursive and imaginative thinking are thus carried out by cyclic mechanisms with a clock frequency of several hertz. To compare, the clock frequency of the awareness apparatus is several tens of hertz.

Our proposition is that the basis of discursive and imaginative thinking is the physiological mechanism of internal sensori-motor rehearsal. If this is indeed so, any process of rational thinking should evoke in the cortex of the cerebral hemispheres three source spots of intensive activation: in the pre-frontal area and in the association sensory and motor areas. In those areas of maximum activation, there should simultaneously take place oscillations of the potential corresponding to the frequencies of sensori-motor rehearsal (several hertz) and of cyclical processes of self-identification (several tens of hertz). The more difficult the task, the more distinctly this triangle should be pronounced. In case of simple tasks and routine work this triangle may degenerate into a functional axis connecting the association areas of the sensory and motor cortex. These theoretical predictions are accessible to experimental verification by electroencephalography.

The procedure of sensori-motor rehearsal is introspectable and controllable. It is physiologically possible because rehearsal is a low-frequency process and its contents is accessible to survey by the high-frequency apparatus of consciousness which is built into the rehearsal loop (Fig 4). Therefore the mechanism of review of thoughts and mental images by operational consciousness could be quite similar to the mechanism of review of images of the environment by perceptual consciousness. A train of mental images, words or symbols is introspectable by means of the self-identification apparatus and is controllable by means of the programming apparatus of the motor system. The interacting mechanisms of controlled sensori-motor rehearsal of thoughts and images and their introspection constitute the apparatus of reflexion. This apparatus allows us form images, scenes and dialogues, watche and change them, thus creating a mobile, controlled mental world.

The duration of fixation of a look or duration of one inhaling, 200 to 300 msec each, is just the time of activation of high-frequency cyclical processes of self-identification in neuronal structures involved in the process of sensory awareness. Then activation is transferred to another (partially coinciding) set of neuronal structures, which constitutes the process of spontaneous readjusting of consciousness. When we freely look and hear and sense the sun and wind and inhale the smells of grass and flowers, we are not tired. Free perception and free thinking do not tire because the time of activation of neuronal structures does not extend beyond the time of spontaneous readjusting of consciousness. Retaining of a phenomenon or an image within the field of consciousness for a period which is far longer than the time of spontaneous readjusting requires extra energy for high-frequency activation of a certain set of neuronal structures. That is why long reasoning work is tiresome. The sense of effort and will which is associated with discursive thinking or operating mental images is brought forth by the work done to activate massive neuronal structures of the sensory and motor systems. Efforts required to operate symbols, words or images are just the efforts that are made to maintain long synchronous activation of the neuronal structures performing such operations.

The muscle system relaxes in default of arbitrary effort. The programming apparatus of the motor system which determines the consistency and rigid coherence of the process of thinking, ceasing to prevail. In this event, thoughts are not controlled by the central apparatus of the motor system, and they are formed in accordance with free associations. Phenomenologically, this could manifest itself in a train of spontaneous, loosely connected thoughts, inconsistent representations, polysemantic images, etc. Spontaneous readjustment of consciousness makes arbitrary thinking mobile, sensitive to the emotional state and unpredictable. The influence of motivation and the role of the pre-frontal cortex and limbic system should increase. Such phenomena as insight and intuition, appear to be related to processes of arbitrary thinking. Many literary sources in psychology testify that fundamentally new ideas sometimes come, or difficult problems find their solutions, at rest, e.g. during a walk, or in the morning, without obvious effort, as if spontaneously. Free (intuitive) thinking is related to the function of cognitive structures of the non-conscious and is likely to account for most of creative findings and non-trivial solutions (Sergin, 1992). A distinct border separates intuitive thinking from discursive and imaginative thinking which are connected with the mechanism of sensori-motor rehearsal and the programming apparatus of the motor system.

Note also, that deep inner concentration on a subject of research is a special mental state in which there is no irrelevant thoughts in the field of consciousness. That means that the influence of motivation prevails and the dominating source spot of excitation shifts into the pre-frontal area. Long steady concentration is awarded with impressive results and is perhaps another way to intuitive comprehension.

4 Altered Consciousness States

The proposed model of consciousness is based on universal physiological mechanisms of self-identification and sensori-motor rehearsal. On the other hand, human mentality includes many phenomena of conscious activity ranging from perception and discursive thinking to still mysterious hypnosis and meditation. If the proposed model could explain from the single position intrinsic mechanisms underlying these dissimilar mental phenomena without recurring to extra assumptions for every particular case, it would be a substantial evidence for corroborate the model's adequacy.

"Altered consciousness states", such as hypnosis and meditation, are intriguing characteristics of human mentality. Subjects in deep hypnosis can neither be aware of the situation and his own behaviour, nor critically perceive extrinsic sensory signals, nor adequately sense even physiological influences. Hypnotic analgesia, for example, kills pain (Bul, 1975; Kihlstrom & Hoyt, 1988). Partial or total interruption of self-identification and sensori-motor rehearsal plausibly explains a broad range of hypnotic phenomena. The interruption of rehearsal makes discursive thinking impossible. The absence of self-identification prevents awareness (sensation) of even basic physiological influences, such as heat, pricking, smell or taste. If this is indeed so, suggested blindness, deafness or insensibility to pain must be concurrent with the absence of high frequency synchronous oscillations in the corresponding specialised areas of the sensory cortex, which could be tested by electroencephalography.

Hypnotism should include techniques which suppress or disorganise the activation of self-identification and sensori-motor rehearsal. This results in a suppressed consciousness. A hypnotised subject's subconsciousness could immediately perceive the hypnotist's instructions as a program quite similar to a program which would normally arrive from the subject's own consciousness, and therefore it is executed likewise.

A human brain with a suppressed consciousness cannot reason or critically evaluate extrinsic messages, so it accepts the hypnotist's instructions as authentic information, which evokes immediate adequate behavioural or physiological responses. Verbal suggestion thus possesses an exceptional power and, somatically, could override even real physiological influences (Bul, 1975).

The hypnotist controls the subject's subconsciousness verbally. The subject's subconsciousness receives programmes from his own consciousness also in a verbal form. Inner speech, as was mentioned above, is the main means of calling representations and images of different modalities. A situation where one individual's consciousness could in principle control another's subconsciousness can only arise from the versatile communication channel, speech.

The hypnotist can call an image from the hypnotised subject's long-term memory verbally, thus activating self-identification in respective cortical areas. There is awareness, that is, secondary processing, of the information which does not exist in the primary structures of perception. The subject hallucinates, perceiving an object absent from the stimulus field. The technique of this "suggestion" is simple. Information is called from the subject's long-term memory and included in the self-identification process (the image is visualised) quite in the same way as in the process of imagination, when the subject calls a respective image by the word from his own memory. In the state of hypnosis, the subject's own consciousness is replaced by the hypnotist's consciousness, which arbitrarily calls images stored in the subject's long-term memory.

It follows from this theory that a hypnotist who does not speak the language of the hypnotised subject, cannot induce arbitrary hallucination in him. On the other hand, even using the same language for communication, the hypnotist cannot induce hallucinations in a subject in terms of representations and images absent from the hypnotised subject's long-term memory.

Consciousness has the features of an artificial system, it is controllable and is relatively independent from the rest of mentality. Meditation is practice which uses the apparatus of awareness for penetration into one's own inner world. A precondition for the state of meditation is isolation from extrinsic events while a high degree of arousal is maintained. The brain in this state is totally introvert, and all its resources are aimed at perceiving intrinsic signals. Another important condition for meditation is profound relaxation of the motor system and muscular relaxation which minimises the flow of signals from one's own body. Profound relaxation of the motor system allows one to interrupt the procedure of rehearsal, which stops inner dialogue. The interruption of the procedure of rehearsal means interruption of the sensori-motor rehearsal of images and sets of data, which leads to "vacuity" of consciousness. The brain, being activated and free of intensive routine operation, is more sensitive and produces a low noise level. Therefore weak signals of the subconscious which are normally subliminal, can activate the apparatus of awareness. There is a possibility of awareness of signals from the abyss of the non-conscious and of realising the utmost capacities of the apparatus of awareness as a system of inner vision.

Meditation techniques combine conflicting requirements the subject must meet. On the one hand, there must be profound muscular relaxation, cease of inner dialogue and turning off the extrinsic events, which reduce signal input and therefore inhibits cerebral activity; on the other hand, perceiving faint signals sent by the subconscious requires a very active brain. The high level of activation is achieved through by using special techniques. There is, for example, respiratory techniques (Katsuki, 1993) which induce in the body a critical state, perhaps similar to hypoxia, which highly activates the brain non-specifically. This sophisticated and essentially counter-natural, technique is hard to master and is hazardous; it requires an expert guru to instruct in it, and is not for everyone to master at all. Nevertheless, it activates the brain to a high degree, while the individual experiences unusually clarity, inner strength and power.

Proceeding from theoretical notions, we may predict some mental phenomena that should take place if the usual conditions of meditative practice are met: they will be deafness to inputs from the environment and one's own body, interrupted inner dialogue, and a highly active brain.

The frequency of self-identification processes represents the intensity of an individual's inner life and sets the pace of subjective time (Sergin, 1994 a). This is local time, or the experienced present. Though the awareness apparatus allows us to detect the new and discriminate between previous and subsequent events, it does not contain any means of comparing the present with the past and future on a large scale. Discursive thinking and imagination which are based on the procedure of rehearsal have these means. Meditation in an advanced phase lacks rehearsal, so the brain cannot compare the present, the past and the future. Current events should drop out of the general course of time and turn into a continuous present. Events may either begin or end, strange as it may sound, always in the present.

Spatial thinking, depending on the character of a specific task, creates a functional space and spatial relationships based on the experience of perceiving the environment and one's own body. That is, we perceive and construct space. In an advanced phase of meditation, there is neither perception (because of self-reclusion from both extrinsic reality and sensations of one's own body), nor imagination (based on the procedure of rehearsal). Therefore, there can be no habitual space with its attributes. Events do still take place, but, surprisingly, they must occur "outside any space."

If in the advanced phase of meditation there is neither time nor space, the mind is incapable of discrimination based on temporal and spatial comparison. And since there is no reasoning as well, there is no operational discriminatory means whatsoever. This condition could create a weird world without differences, a world of "unity of all things".

We determine the cause and effect by reasoning. The absence of discursive thinking takes out causality from our mental world during meditation. Events occur, but they occur all by themselves. The absence of causality makes all things totally free and independent from each other, resulting in an unusual world dominated by "total independence."

Such mental phenomena are indeed reported by those who practice meditation and are extensively covered in literature. "Time totally disappears in the absolute samadhi, and so does space. Causality also disappears. Only a string of events exists." "[The] usual way of consciousness falls apart. Suddenly, we become aware of a world, where there is no conflict, and we experience the unity of all things." "[Only] the present is coming and going at every moment; there is just a continuous stream of the present." "[Life] in the present is totally independent, and this is just our true existence" (Katsuki, 1993).

Meditation in its advanced phase interrupts rehearsal, and eliminates discursive thinking and reflexion; "thoughts vanish," There are no means for self-observation or control over the process of awareness. The mind surveys its inner world directly and unaccountably, and takes it in just as it is: without comment, query, analysis or reasoning. One comprehends his own being, his own true nature.

Low input from the environment and from one's own body, along with suppressed rehearsal, result in low input to awareness apparatus. Physiologically, it should be expressed in a drop in the frequency of cyclic processes of self-identification to its lowest limit (10 Hz or lower), and in a slow subjective time. Experiments confirm the dominance of low-frequency alpha- and theta-rhythms in the meditating brain (West, 1982). Subjects involved in experiments report the subjective sensation of slower thoughts and slower time, up to a full stop of both.

5 Conclusion

There is therefore an impression that processes of self-identification which form specific patterns of cortical neuronal activity underlie the awareness of external and internal signals. Distributed memory categorises specific patterns of excitation thus revealing the subjective sense of incoming signals. These universal physiological mechanisms may generate such mentally experienced phenomena as sensory awareness and thought. The compatibility of the mechanism of self-identification with independent psychological, psychophysical and electrophysiological data provides evidence for its reality.

Internal sensori-motor rehearsal perhaps underlie discursive and imaginative thinking. The programming apparatus of the motor system is the principal operational means of controlling thoughts and images at will. The interacting mechanisms of sensori-motor rehearsal and self-identification allow us to create a mobile, observed and controlled mental world..

Our concept is built on the basis of well-known physiological mechanisms and allows us to predict immediately measurable macroscopic characteristics of brain functioning in the processes of sensory awareness and discursive and imaginary thinking. Precisely formulated theoretic consequences provide a possibility for experimental disproval or confirmation. Moreover, the concept which is built on mechanisms accessible to verification allows us to explain from a single position the nature of a broad scope of mysterious mental phenomena, from awareness and thought to imagination, hypnotism and meditation. This makes a serious argument in favour of its adequacy.

Nevertheless, this work is not a finished research. This is rather a substantiated plan for broad theoretic and experimental research in physiological mechanism of human mentality on a new conceptual basis.

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