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REVIEW ARTICLE

NEUROPHYSIOLOGICAL MECHANISMS OF INDUCTION OF MEDITATION: A HYPOTHETICO-DEDUCTIVE APPROACH

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Abstract : A detailed analysis of methods of induction of meditation and meditative experience encountered therein implicates involvement of several mechanisms in inducing 'meditative effect'. 'Efferent attenuation', 'sensory attenuation' and 'cognitive restructuring' appear three possible mechanisms employed in varying degree of combinations to produce the 'meditative effect' during different types of meditations. Using hypothetico-deductive approach, it is possible to generate a neural model for explaining the 'meditative effect'. Primarily, the meditation is produced by disengaged association cortices driven by thalamus or other older group of reticular nuclei. Secondarily, there may be involvement of some more phylogenetically older structures depending upon depth and types of meditation. This model explains induction, maintenance and long-term effects of meditation.

Key words : meditation; neural model; attention; concentration; mindful meditation; reticular nuclei; association cortices; neuroimaging

INTRODUCTION

A large number of beneficial psychophysiological responses have been reported resulting from the practice of meditation (1, 2, 3). Similarly, several studies document a varying degree of clinical improvement in stress related (3) and non-stress disorders (4). In spite of widespread use of meditation, the mechanism of induction of meditation and its accompanying effects continue to intrigue the scientists. The nearest equivalent physiologic state to explain the effect of meditation is "relaxation response" as proposed by Benson (5). The immediate effects of relaxation include heightened feeling of subjective well being, decreased arousal, generalized decrease in cerebral blood flow, decreased core body temperature, decreased adrenergic tone, reduced muscle activity as recorded by EMG, reduced

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Galvanic Skin Response, reduced plasma lactate and decreased respiratory rate. These effects are considered as antidote to stress induced pathophysiological responses (6). The relaxation response is said to be common denominator of several related techniques like meditation, autogenic training, biofeedback, hypnosis, and progressive muscular relaxation. This does explain a large number of physiologic effects that lead to a physiological state defined as "wakeful hypometabolic state". The explanation as to how the state of relaxation (or meditation specifically) is induced is still far from being understood. Possibly, there appear several mechanisms that may be operative simultaneously in different set of combinations to produce a meditation effect. The following details describe the possible mechanism which may be involved in genesis of meditation effect.

Various meditative practices require definite behavioral components to produce a 'meditative state'. Most of the meditative practices employ a set of combination of many techniques viz. 'efferent attenuation', 'sensory attenuation' and 'cognitive restructuring'. The first two are adequate to give a restful state but not a psychological effect as produced by meditation. In order to produce typical psychological effect of mediation, last mechanism i.e. cognitive restructuring is a must. The cognitive restructuring refers to inhibiting or manipulating the spontaneously occurring or self induced thought process. This cognitive restructing manifests both behaviorally and electrophysiologically. Neurophysiologically such changes will present as inactivation/activation of certain neural structures and accomplished by plastic changes in the brain, thus, leading to long-term effects. Several earlier electroencephalographic studies and recent findings of neuroimaging in meditation facilitate the concept of the hypothetico-deductive model presented in this review. Besides, explaining the induction of meditative effect such model will be useful to guide future research in the field of neurophysiology of meditation.

The model proposes that association cortices are 'disengaged' to receive/output any activity other than from internal representation of memory. This disengaged association cortex (first parietal then temporal) is continuously being driven by phylogenetically older collection of neurons, which have capability to generate regular rhythms (thalamus and pontine reticular nuclei). Additionally, some more structures of lower brain may be involved depending upon depth or type of meditation. This neural model appears adequate to explain the induction and maintenance of meditative effect. The model is compatible with motor-perceptual-attentional-experiential changes, which may be responsible for meditative effect. Although the meditation is a holistic experience, a reductionist approach is used to build a concept compatible with mechanistic model for producing meditative effect.

The possible induction mechanisms

1. Efferent attenuation

For induction of meditation the conventional procedure is to adopt a motionless posture. It advises to remain calm, both physically and mentally. The motionless posture is associated with typical EEG frequency and this falls in the range of 12–16 Hz (7). We have earlier reported that the long-term meditators had higher power of sensorimotor rhythm (SMR) rhythm than non-meditators (8). Thus, the meditators had the electroencephalographic evidence of motionless posture. This motionless posture results in attenuation of motor activity, which can be described as "efferent attenuation". The term efferent attenuation (instead of motor attenuation) is used here for several reasons. Firstly, meditation is not only a motionless posture but involves active relaxation through learned autosuggestions. Secondly, there is relaxation of smooth musculature mediated indirectly through manipulation of respiration. Thirdly, by using the term 'efferent attenuation' the concept becomes applicable to situation like biofeedback where efferent attenuation is achieved in term of 'autonomic (motor) attenuation' as well. This 'efferent attenuation basically operates on effector side of control system, thereby reducing functional load on skeletomotor system. This mechanism is purely voluntary. There are several cascading changes in central nervous system that follow generalized muscle relaxation. It is apparent that gradually such efferent attenuation will unload the central nervous system. The unloading, thus, produces several beneficial effects of relaxation and may act as antidote to any kind of stress related disorder. This mechanism is also shared by several other techniques that induce relaxation. The case in point is 'autogenic training'. It consists of mental exercises, each one working to relax the patient and induce feelings of heaviness, lightness, or floating by the repetition of a text. Autogenic training is closely related to meditation, but disregards meditation's metaphysical and religious aspects, and in this respect is a precursor of biofeedback.

2. Sensory attenuation

Other common observation during practice of meditation is the use of sensory restriction to induce meditation effect. The meditation process requires reduction of sensory stimulation, either general or of selected modality/modalities. For example the classical Indian meditation requires calm and quiet place for performing meditation (the one performed with eyes closed and with repetition of word or 'mantra'). For an Indian exponent of yoga it is unimaginable to think to induce meditation in a noisy surrounding with eyes open. It is, at least impossible, for the beginners. The distraction imposed by noisy surrounding imposes further instability to already hyperactive (continuously active) mind. Any novel sensory input will render the mind vulnerable to be more active. Even the posture adopted for meditation is said to be least activating to the sensory system. The suggested posture is the posture in which the subject may remain comfortable for reasonable time, like cross-legged posture, (*padmasana*) or *vajrasna*. Some of the Indian type of meditation like *Sahaj Yoga* Meditation (as propounded/suggested by RAJYOG followers) uses the crossed legged posture with eyes open and gaze focused on one illuminated point in a featureless surroundings like dimly illuminated all-white background. The soft music may or may not be played in background. This represents a selective restriction of sensory input with leaving certain channels active. These active sensory channels receive information, which are rather non-novel and featureless using unimodal or multimodal sensory approaches. Usually visual, auditory and/or olfactory are used in the present case. Some other techniques like hypnosis also use generalized sensory attenuation with selective working of one channel like auditory or visual modalities. For inducing a relaxation effect the technique of biofeedback also requires surrounding that is devoid of large sensory inputs. The places of performing Zen Meditation are featureless natural landscapes having sand and rocks (sometimes called rock gardens). For performing Zen meditation, the meditator is supposed to keep his eyes open and meditate on these featureless large spaces. Thus, the possibility of inducing meditation with eyes open cannot be denied. The vision being a powerful sensory modality can be rendered "least stimulatory" by provision of uniform non-activating stimuli.

Furthermore, the Indian type of mediation (word repetition) has one more mechanism to block the sensory input. This is actively blocking the sensory afferent by deliberately ignoring both external and internal stimuli (these stimuli can be termed as noises). Such induction of meditative state requires active disregard of intrusive thoughts (induced by self) or ignoring sensation if any. The beginner is taught how to induce this disregard or negation. The forgoing discussion suggests towards importance and significance of sensory attenuation in genesis of meditative effect. As a corollary, many techniques such as hypnosis, employed for inducing relaxation response (akin to meditation effect) use "sensory attenuation" as first step. The sensory attenuation leads to sensory unloading. Sensory unloading by virtue of inherent connectivity to reflex circuits will reduce afferent and consequently the efferent load. The support to this theory comes from some of the techniques used in induction of meditation and some of the studies from our department by Anand and colleagues in 1955 (1). In an elegant series of studies on expert yogis (long term meditators), they observed that during the state of meditation the yogis were oblivious of surroundings.

The two mechanisms referred above i.e. "efferent and sensory attenuation" are basically peripherally operative. The lowered efferent load and sensory attenuation lead to reduced load on central nervous system thereby leading to lowered arousal. This will impose lowered activation of central nervous system. It has been proved that such sequence of event leads to decreased sympathetic activation (5). Lowered sympathetic activation appears both a pre-requisite and necessary condition for meditation.

Some forms of the meditation are surprising. One of them is *Tai Chi Chuan* or commonly known as 'moving meditation'. During this meditation the subject continuously performs soft, smooth, effortless and natural movements. His stance remains firmly grounded on earth. He non-analytically attends to unifying sequence of movements. He focuses thoughts on series of movements in continuity. This puts him in meditative state. It is apparent that he is performing aerobic movement and long practice would render these movements as effortless. This would also induce the well-known relaxation response. The progressive muscular relaxation also induces relaxation response, however it uses intermittent bouts of strong contractions. During these practices the total energy required is less then resting state. In an elegant study, Shirley Telles and colleagues (2000) have proved a similar point by studying the effectiveness of Yoga relaxation techniques. They compared the O_2 consumption, respiratory rate and heart rate during 'cyclic activation by using yoga posture alternating with *shavasana* (the corpse posture)' and only *shavasana*. To their surprise they found more reduction in O_2 consumption during cyclic activation then *shavasana* alone (9).

From the forgoing discussion on "efferent attenuation and sensory attenuation" it is apparent that the combined effect of the two may lead to a state called "relaxation response" which is indeed true. A physical passivity with reduced sensory interference results in state of physical and mental relaxation. A large number of studies support that there are several common physiological responses observed during relaxed states (5, 6, 10).

3. *Cognitive restructuring*

A critical examination of state of meditation reveals that the effect of meditation is more than combined effect of reduction in efferent output and functional de-afferentation. The relaxation so induced by sensorimotor attenuation has different psychophysiological connotations. This has been amply argued in past and reviewed by Dunn and colleagues in 1999 (11). In the late 70s, the prevailing view about the meditation and relaxation was to put them together and consider them as one common technique. The response so induced was called "relaxation response" (5, 10). This concept has been useful to some extent. On one hand this did help a focussed research on all techniques, which induced "relaxation response". On the other hand this concept gave meditation research a wider acceptance among scientific community. Certainly there is a great deal of common variables among many relaxation-inducing techniques. However, the research in this direction did mar the research directed to look for uniqueness in different methods, if any, for example the meditation may be inducing a unique effect. In mid 80s several researchers argued that meditation might be producing a unique "effect" (12). In fact, many Indian exponents disregarded the very simplistic view of meditation, that it produces only relaxation response. In late 80s the author himself witnessed several critical questions when he used the yardsticks of relaxation to measure the effect of meditation. The question author raised was "how to measure/quantitate the state of meditation ?" The method used is described elsewhere (4). The author argued that at least in the initial phases the meditation should produce the effect similar to "relaxation response" and that might be sufficient to produce the therapeutic effect. Accordingly, the various depths will have different physiological effect. In the beginning the effect is similar to relaxation response and as the depth of meditation increases (with continued practice of meditation) the complexity of responses increases. This complexity, in fact manifests as vagueness of subjective responses (the subjective experiences are bizarre and rather unbelievable) varied physiological responses at least in terms of EEG recordings. The relaxation response does not produce such vague or complex psychic phenomena. Table I gives detailed differences between simple relaxation and meditation.

Thus, it appears that something more is happening to produce the meditation effect than simple relaxation. There are probably, some more, central mechanisms for producing the meditative state. The possible central mechanisms could be the cognitive restructuring (15). The reasons for existence of such central mechanism appear to be emanating from the instructions given for induction of meditation and the subjective responses reported by long-term practitioners. In reality the meditation may be using some complex mechanisms to induce the effect quickly and effectively.

TABLE I: The differences between simple relaxation and meditation.

	Relaxation	*Meditation*
Level of complexity	Simple process involving skeletomotor relaxation, exhibited by animals and humans	Complex process involving specific modulation of of attentional process
The nature of activity	Induced by body immobility and minimizing sensory input (Sensorimotor attenuation)	Induction requires more than sensorimotor attenuation; neural activation of non-analytical attending along with cognitive restructuring
EEG correlates	Appearance of sensorimotor rhythm in animals (7); and SMR and α waves in humans (7)	Appearance of synchronized slowing of EEG waves: From SMR (7) to $\propto$ waves to θ waves (13) depending on depth
The possible mechanisms	Suppression of arousal mechanisms	Suppression of arousal mechanisms and activation of dedicated circuitry mainly involving parietal cortex, thalamus on right side of brain
Autonomic responses	Trophotropic response	Similar but of significantly higher magnitude (14)
Psycophysiologic arousal	Decreased	Decreased to a greater extent
Psychic experience	No specific psychic experience except vivid imagery of recent past	Distinct psychic experience usually pleasant, vague and esoteric; elaborate phenomenological description are available for different types of meditation practices
Method of ending the session	The session may be disrupted spontaneously or by external or internal stimuli or the organism passes into sleep if the need for the the same exists	De-meditation (ending the meditation session) is a deliberate process; ended by subject; never leads to sleep

The cognitive restructuring may be used in inducing meditative effect. Meditation involves the instruction like ..... *pay and maintain attention to some form of stimuli* (could be internal like breathing or could be external stimuli like a point, flame etc) or ..... *ignore the distracting stimuli* (could be internal like itch, pain, bowel sounds or could be external stimuli in form of street sounds, sound from home etc.). The verbatim used to induced meditation suggests that there is an attempt to restructure the cognitive process. There is an attempt to dissociate the stimuli or thought from actions inherent to them. Normally any stimuli is associated to multiple actions occurring in a variable temporal sequence depending on type and the context. A stimulus initiates ripples in central nervous system, thus, giving rise to sensation, feeling (pleasant, neutral or unpleasant), emotional expression, motor activation (unconscious tensing of muscles leading to increase in muscle tone) and sequences of autonomic responses, finally leading to overt motor activity (16). While sensation and manifested motor activity might die out, the autonomic, emotional and responses may take time to wane off. This system is an inbuilt one, and depending on type, characteristics and physical need and context the response could be mild to severe enough to mobilize the whole body. Nevertheless, even a series of neutral stimuli (non-provoking, non-threatening) may lead to sufficient unconscious muscle tensing and sympathetic activation resulting increased arousal. In certain situation the arousal may be out of proportion as far as the need is concerned. In our own study on the effect of autosuggestion on cold-induced pain, we observed that the pain stimulus induced less of β waves in frontal location when the subjects were under the effect of autosuggestion (17).

It is reasonable to discuss the difference between these two different types of meditations. In Indian type meditation (word repetition) the subject assumes a comfortable posture (like sitting in *padmasana, vajrasana,* or *shavasana*), concentrates on breathing, performs a word repetition (either the word given is 'OM' or other confidential mantra as suggested in Transcendental Meditation (TM), or it is a 'non-sense syllable' which is chosen from the list as used by author in his earlier study (4). The subject tries to ward off any distracting thought, and attempts to achieve the state of thoughtlessness through contemplation. In a different kind of meditation called Zen meditation, the subject makes the abdomen rise and fall during breathing, he holds attention to the breath, he widens his attention to any stimuli present in environment and body feelings. He attempts to remain dispassionately aware of whatever is going on around him but does not submerge. He keeps the body standstill and remains detached from the thoughts. The sensations of emoting that arise, should pass away during this meditation. The EEG data suggests that Indian meditation (concentrative meditation, or single point contemplation) and Zen meditation (mindful meditation) are two different forms of meditation (Table II).

TABLE II : Differences and similarities among attention, meditative concentration and mindful meditation.

	Selective attention e.g. attending a target on RADAR screen	*Meditative concentration e.g. Indian traditional meditation, TM, Raj Yoga meditation*	*Mindful meditation e.g. Zen meditation*
1. Procedure	It is a deliberate or spontaneous act to analyze a stimulus. A detailed analysis is carried out for the purpose of detection, classification, decision making, trouble shooting etc.	a. Initiated by adopting an automatic act like visualize breathing, passive counting etc. b. Attention focused non-analytically to word repetition or a point on body part, or on breathing or on imagery etc. c. Disregard other stimuli and thought.	a. Open receptivity and awareness to all incoming stimuli. b. Evaluation, analysis or classification of those stimuli is suppressed. c. It is de-atomization of perception. d. Maximize the breath and clarity of awareness.
2. Type of task(s)	Intake and/or rejection	Rejection with no analysis attached to it.	Intake with detached observation.
3. Sensory modality and source object for attention	Visual, auditory or any other. The source object is external, worldly, well defined, changing with time and space.	Mainly visual, sometimes auditory is used to initiate the process. The source object is internal, vague (During the initial phase of learning meditation, the object could be external but featureless and consistent in time.	None particular.
4. Output	a. Helps generating detailed information on stimuli, its classification and the information is stored in memory. b. Suitable action taken by motor system.	a. No information is gathered b. No motor action is implicated.	a. No storing of received information (a detached observation). b. No action implicated.
5. Autonomic changes	Involved in process with autonomic arousal	Involved in process with decreased arousal (relaxed awareness)	Involved in process with decreased arousal (relaxed awareness)
6. Purpose of procedure	Key event in acquiring worldly knowledge, defense, survival and sports.	- To achieve relaxation. - To reduce stress. - Spiritual purpose.	As in meditative concentration.
7. Physiological role	Maximize depth and clarity on focus, analyze and initiate appropriate action.	Minimize the intrusions by disregarding objects/ thoughts.	Maximize the breadth and clarity of awareness of incoming signals but remain detached to them.
8. Relation to perception	Integral part of perception-motor equation.	Disregard to perception-motor equation.	De-atomization of perception (18).
9. Behavioral correlates	Aroused, tense or hyper excited, habituating.	Relaxed calm & aware. Non-habituating (18).	As for meditative concentration.
10. EEG correlates	a. Global β waves b. Frontal midline θ at more depth of attention (19).	a. Persistent parieto-occipital α waves. b. As depth increases may be interspersed by θ and parietal leads (20).	a. Persistent global α waves. b. Frontal midline θ at more depth (21) (Some more variations reported).
11. Factors determining success	a. Context b. Motivation c. Reward/punishment factors d. Individual characteristics	a. Motivation b. Length of practice c. Individual characteristics	As for meditative concentration.
12. Pre-requisites	Certain degree of arousal (sympathetic activation) is facilitatory.	Any factor leading to sympathetic arousal will inhibit the initiation of procedure.	Like meditative concentration.
13. Periodicity and span	Periodic, 20 min. stretch.	Aperiodic, induced phenomena	As in meditation.

The question of involvement of non-local communication factors in induction of meditation remains intriguing. One study, appeared in prestigious journal "Physics Essays", reported that there are chances of communication between the two subjects isolated spatially (14.5 meter apart) using Faraday cage (22). A 100-sample average of EEG activity in both subjects showed statistical correlation between 0.700 and 0.929 occurred in the first 132 msec. One subject's 'average' showed a distinct evoked potential (DEP). The evoked potentials of similar morphology were found in the other subject. These were called transferred potentials. In control conditions, no clear transferred potential signals were found and no statistical significant correlation was obtained. Subjects were able to attain and maintain direct communication while being apart. The 'transferred potentials' demonstrate brain-to-brain nonlocal communication between brains, supporting the brain's quantum nature at the macro level. This is a conclusion that is difficult to digest.

Meditation : a modified form of attention

The Neurophysiology of meditation basically refers to the modified form of attention. While paying attention to a stimulus, the approach adopted could be exploratory one to identify the signal and analyze its all-possible details. This is called "analytic attending". This follows a logical and linear approach to analyze the signal and attempts to find a meaning, correlation and interpretation of the signal. The thesis of 'focused and analytical attending' is well-accepted scientific fact. Acquisition of such kind of attention process has been essential for organic evolution. The organisms earnestly require the process of sharp attention that is able to detect, analyze and take appropriate action. Appropriate action might refer for killing a prey, search for food, avoiding motor mishaps etc. This system has been inherently linked to somatic-autonomic arousal. This would involuntarily lead to muscle tensing and rise in blood pressure through sympathetic arousal. The degree of arousal and sympathetic activation would vary depending on the associated reward/ punishment consequences. This system has been mastered during evolution and forms a pre-requisite for so called winning the 'success' in the world. Frog catching a fly or an elite soldier hitting a moving aeroplane would require the same attentional skills. This produces autonomic excitation of varying degree. The perception of stimuli may represent incogruence between implicit (behavior, physiologic response) and explicit (overt or covert form of conscious verbal report measure). Such incongruence between implicit and explicit leads to autonomic dysregulation. In this autonomic dysregulation which limb of autonomic nervous system will be involved depends on type of personality characteristics. With the same argument the congruence between the implicit and explicit would result in an autonomic effect that produce the pleasant sensation. How incongruent thought can generate motor activity is best be explained by motor theory of voluntary control (16). According to this theory all acts of will, or effort will involve activation of motor system of varying degree depending on context. This motor act could be overt or covert. Even though the person may not show external manifestation of motor action, he may have tensed the muscle along with increased sympathetic tone. The simple example would be a thought of 'getting ready to run'. It is always associated with some degree of muscle tensing, a prerequisite of preparedness. This physiologically, manifests as increase in muscle tone, rise in blood pressure and accompanied by appearance of prolonged stretches of β waves. Engaging in a state of analytical attention creates a similar situation. Some scientists prefer to call it as selective attention, active attention or 'outer' attention. When organism is not involved in active attention, it assumes a relaxed attitude with absence of focused attention (Table II).

Going one step further, it is possible to execute voluntary attending to a stimulus non-analytically. It can only be developed provided organism has very highly developed cognitive functions with great degree of neural plasticity. The natural evolution of attention has followed a teleological course. From the point of view of evolution, there might have been no compulsion on the part of organism to sharpen the skill of non-analytic attending. It is only human who realized the potential of such development with reference to the following considerations :

- counteract the ill effect of chronic over-arousals
- gain control over certain involuntary process including thoughts
- indulge in mind manipulative techniques
- discovering the potential of body and self

There are several ways a state of non-analytic attending can be achieved. Physiologically there are two important ways the non-analytic attending may be achieved :

1. Initiate the following sequence of changes :
   - neglecting a novel stimuli
   - suppression of any thought
   - denial of significance attached to stimuli
   - attenuating the receiving and perceiving processes.
2. Let all incoming stimuli be sensed but with least possible perception and without any further consequence. The incoming stimuli could be of external origin i.e. 'street sounds' or of internal origin (an active thought).

During this the person attends to a set of stimuli (visual, auditory or internally created signals like word repetition). By doing so the person shifts attention from active-analytical attention (arousal response) to passive-non-analytical attention (lowered arousal). A state of non-analytic attention yields entirely opposite physiological effects. We have earlier reported this phenomenon (4). We have been successful in recording long stretches of non-analytical attention interspersed with phases of active-analytical attention by using electroencephalography (Fig. 1). With practice of meditation the total duration of non-analytical attending enhances.

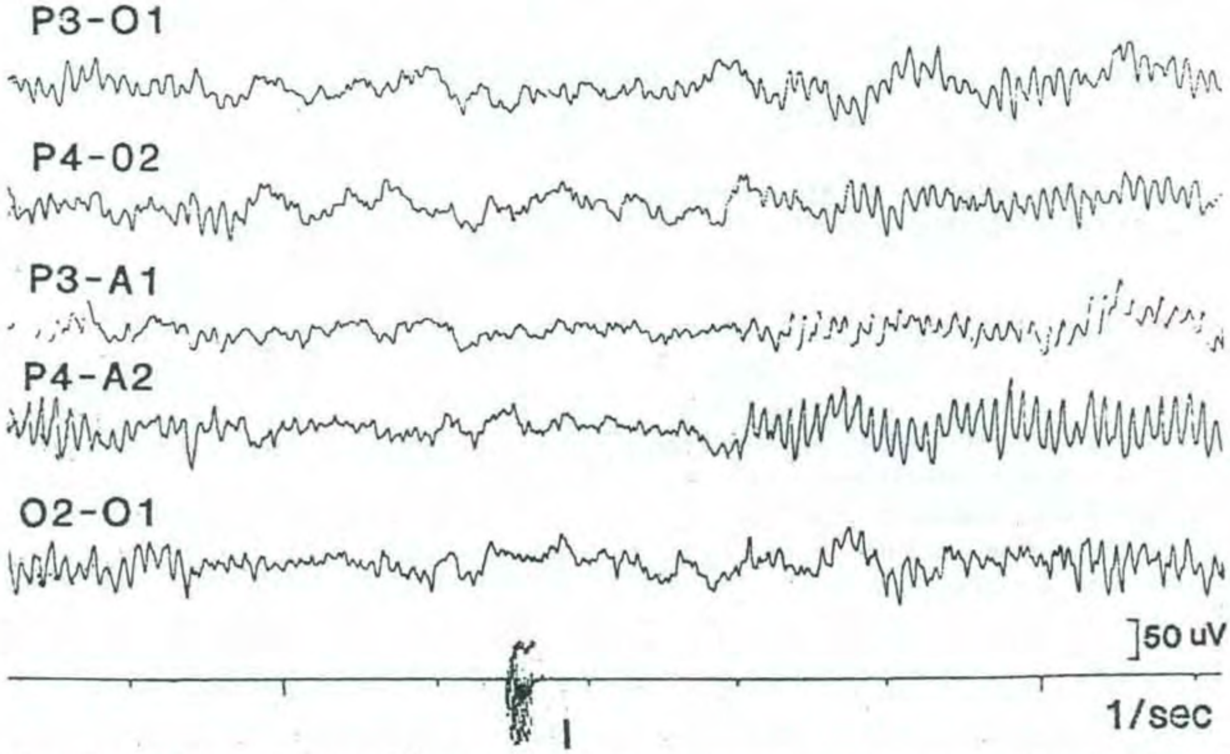

Fig. 1: The record shows EEG changes before, during and after occurrence of 'intrusion' observed during meditation. The five traces represents EEG records from five scalp locations- left and right parieto-occipital regions (P3-O1, P4-O2), left and right parietal areas (P3-A1, P3-A2) and bilateral occipital areas (O1-O2). The intrusion (shown as 'I' on the record) is recorded on the time tracing. Several of such intrusions were encountered during meditation of 20 min duration. To record the intrusion, the subject was given a hand-held microswitch and was advised to press the microswitch whenever he encountered an intrusion or drift in the word repetitive process (meditational task). He was advised to resume the meditation process soon after the encountering the intrusion. Typically, the EEG became desynchronized prior to the intrusion occurrence. The EEG changes were best represented over right parietal area (channel 4). In the present case, the occurrence of intrusion was noticed two seconds after the appearance of EEG changes. This latency varied from 0.5 to 8.7 seconds. These EEG changes outlasted the event marking by the subject. The latency gradually decreased with practice. The long term practice of meditation resulted in decrement in total number of intrusions during a 20 min meditation session. These decrements were found to be significantly correlated to neuropsychological indicators of relaxation and clinical improvement in cases of drug-resistant epilepsy patients (4).

Localizing neural structures in meditation

Several researchers have argued a definite involvement of neural structures during meditation. The structure may be involved in producing a non-analytical attention state as opposed to analytical attending state. Extensive research has been carried out to investigate neural basis of selective attention. There are definite structures involved in executing selective attention (23, 24). The brain structures involved in non-analytic attending processes still remain far from clear. Some support to neural mechanism has come out from the studies of brain during meditation of different types. Several electroencephalographic, MRI, SPECT (single photon emission computed tomography) and PET (position emission tomography) studies have been carried out to find out the neural substrate (4, 11, 26–31). The following is brief description of some of these studies.

Electroencephalographic studies

A large body of evidence supports the presence of persistent high amplitude alpha during meditation. There are reports that at certain increased depth of meditation much slower frequencies like theta and sleep like delta frequencies appear in EEG. (13, 20). The EEG studies suggest appearance of synchronous activity is not uniformly distributed over scalp. The meditation initiates comparatively more synchronizing EEG activity, particularly on posterior and right side of hemisphere (13). This activation of right hemisphere conforms to non-analytical function of right hemisphere and consequently expresses relaxed alertness. A similar finding has been confirmed for hypnosis (13). There is also slowing of EEG with prolonged practice of meditation (20). The consensus that emerges from various studies is that the meditation is a right brain function. However, the structures involved in inducing meditation are varied. These various differences pertaining to areas activated during meditation in above mentioned studies could be because of various reasons: namely the type of meditation, the stage of meditation, the type of stimuli, the number of stimuli and expectations out of meditation.

One of the recent electroencephalographic study logically concluded that the different types of meditation may be different and they may be different from simple form of relaxation. Dunn et al (11) carried out a well-designed study to find out differences among the Indian type of meditation, Buddhist type (Zen) meditation and simple form of relaxation in college students. They concluded that the both forms of meditation differ from simple relaxation in terms of EEG activity (11). The two types of meditations also show differential distribution of EEG activity over scalp. Thus, there appears an existence of different neural subsets responsible for these differences.

Deepak et al (4) attempted to find out the brain event(s) during meditation especially when the subject's meditation process is interrupted by stray thought by using electroencephalography (4). The author carried out these investigations in both normal subjects and in patients of drug-resistant epilepsy. When the subjects were performing Indian type of meditation (word repetition), they were asked to report the break in continuity in meditation by pressing the microswitch. The subject resumed the meditation after pressing the switch. The EEG was recorded from the areas overlying rolandic fissure and posterior parietal areas. The EEG showed clear-cut episodes of desynchronization, corresponding with interruptions reported by subject/patients (Fig. 1). These breaks in the process of attention were called 'Intrusions of drifts'. The intrusions are common during any sustained mental process. These can be defined as "drifting away from non-analytic attention". We analyzed and categorized them on the basis of EEG features (32). These reflect inner mental changes. These appear important indicator of success of meditation and represents activity in some specific neural substrate for meditation. We also found dominance of ∝ EEG waves on right hemisphere during meditation.

Neuroimaging studies

Recent neuroimaging studies by using functional MRI suggest a generalized decrease in cerebral blood flow with focal increases in blood flow to the dorsolateral prefrontal and parietal cortices, temporal lobe, hippocampus/parahippocampus, pregenual anterior cingulate cortex, striatum, and septal nuclei during simple form of meditation (31). Global fMRI signal decreases were also noted, although authors assigned their activity probably secondary to cardiorespiratory changes. The results indicated that practice of meditation activates neural structures involved in attention and control of autonomic nervous system (31).

A SPECT study describes the findings during Tibetan Buddhist meditation (28, 29). By SPECT one can locate the areas, which show increase activation by increasing blood flow. It is assumed that more the blood flow in the area, more active the area is. The frontal area showed increased blood flow and parietal area demonstrated less activity on the right side of hemisphere suggesting that the Buddhist meditation is a process that requires high degree of concentration without any input from cognitive or any other sensory stimuli (perhaps Newberg and colleagues referred to a set stimuli that require excessive attention in the beginning of meditation that may be analytic attending). Lou et al (1999) measured the cerebral blood flow (CBF) distribution using the PET technique in nine young adults, during the relaxation meditation (Yoga Nidra), and during the normal resting state (27). Spectral EEG analysis was performed throughout the investigations. In meditation, differential activity was seen, with the noticeable exception of V1 (primary visual sensory area no. 17), in the posterior sensory and associative cortices known to participate in imagery tasks. In the resting state of normal consciousness (compared with meditation as a baseline), differential activity was found in dorso-lateral and orbital frontal cortex, anterior cingulate gyri, left temporal gyri, left inferior parietal lobule, striatal and thalamic regions, pons and cerebellar vermis and hemispheres (structures thought to support an executive attentional network). The mean global flow remained unchanged for both subjects throughout the investigation (39+/–5 and 38+/–4 ml/100 g/min, uncorrected for partial volume effects). It was concluded that CBF distribution reflects characteristic patterns of neural activity in the meditative state as well as during the resting state of normal consciousness. The above mentioned studies suggest that the meditation is a complex mental state involving a set of neural circuity. The complete elucidation of circuity is yet to be investigated.

Hypothetico-deductive reasoning about brain structures involved during meditation

A state resulting from efferent and sensory attenuation can be called as pre-meditative state and this will be akin to simple relaxation. During this the primary sensory and motor cortices will be silenced. In such state, earlier we observed appearance of sensorimotor rhythm and alpha rhythm on scalp area overlying rolandic tissue (4). Possibly, the inhibition of cortical and subcortical areas associated with selective attention (executive attentional system) and voluntary motor activity is important in initiating the pre meditative state. The depth is increased either by actively absorbing attention to a focus (non-analytic attending to word or object) or altering perception under the influence of suggestions (hetrosuggestion or autosuggestion). Those who have undergone TM or hypnosis would assert that on first day such depth relaxation produces a unique feeling in the limbs (heaviness, perception of increased size of limbs and then a feeling of detached limbs). Such symptoms, probably, are generated because of absence of normal sense of self-awareness. Considering the role of posterior parietal cortex in perception of self-awareness (33), the brain structure responsible for this phenomenon appears to be posterior cortex. The role of posterior parietal cortex appears to explain two functions, one altering the perception to limbs and body, secondly, initiating repeated 'disengagements' from active thinking. Disengaging from attentional task is an important function of the parietal cortex (34, 35). Lesions of parietal lobe interfered with the ability to shift attention in humans (25). At certain more depth of meditation, the parietal cortex may lose its function and the activity may switch over to temporal cortex. This may engage a person in vivid imagery involving spatial perception.

During the initial stage of meditation, cognitive restructuring plays important role. A will is generated which initiates withdrawal of senses (withdrawal of senses means disregarding any interrupts and noise). The area of brain involved in producing 'will' is uncertain; perhaps it is either in pre-frontal area (36) or posterior parietal cortex. The will is executed by adjusting the posture, disengaging from any sensory input and engaging in passive sensorimotor task like modulating breathing. This conforms to "Top down model" of attention where powerful influences from top i.e. association cortices influence to optimize the use of its processing resources, by allowing us to concentrate on a very small proportion of incoming information (23). It has been amply proved that attention modifies the way in which sensory information is processed (37). During induction of meditation one learns to reduce the information processing of input stimuli. The initial stage requires active effort. We do experience the allocation of attention as effortful, but the extent to which it restricts processing seems to escape intuition, as demonstrated by our inability to detect even large changes in visual scenes as long as they occur outside the focus of attention (38). By similar analogy, the initial stage of meditation is not effortless. Simultaneously the person surrenders the effortful attentional activity to the natural rhythm, this would mean letting the natural frequency to take over attentional regulatory controls. This stage defines transition from effortful stage to effortless one. The meditator enters into the phase of "sustained attending to the "word or mantra"/imagery/or detached observation of input stimuli. For processing such information the posterior parietal cortex is implicated. Earlier, based on several studies on monkey and clinical reports in humans it was firmly believed that posterior parietal cortex is performing the spatial function. Recently the role of superior temporal lobe has been implicated in perception of space of humans (39). During meditative state, the meditator reports perception of peculiar spatial events. The meditator may visualize object with static features, open spaces and even a void. The superior temporal cortex appears responsible for these experiences. One more possible reason of involvement of temporal cortex may be the fact that many yogic literature reports listening of various internal sounds during deeper levels of meditation. Close approximation of superior temporal cortex to primary and secondary auditory cortices may be responsible for genesis of these internal sounds.

Basis and implication of EEG slowing during meditation

At the outset it may be made clear that spontaneous EEG activity mostly reflects processes taking place in the reticular core rather than local changes in the area of recording. The local component can be altered, however, when excitability of the local circuits is changed by various inputs. Thalamo-cortical circuits have been known to generate alpha waves (40). It is clearly known that thalamic neurons have pacemaker property and capable of generating frequencies around 10Hz (corresponding to $\propto$ waves). Thalamus has tendency for generating alpha waves especially when no input is present. Just closing of eyes or relaxed attitude with open eyes is sufficient to induce them. There is large number of reports available that the alpha produced during meditation is persistent and can be enhanced with practice. Such changes indicate that brain has neural plasticity to modify its function. With the practice, the depth of meditation increases as confirmed by subjective reports both during TM and Zen meditation and presence of θ waves in EEG has been reported (21). The genesis of θ waves during mediation poses a peculiar problem. It may be having its origin in subcortical structures. At least three structures are known to generate θ rhythm. These are anterior cingulate cortex, hippocampus and pontine reticular nuclei (41). Anterior cingulate cortex is involved, when organism is engaged in active attention task and it is responsible for appearance of frontal midline theta waves (42). Hippocampal θ waves may not be responsible for θ waves recorded from scalp during meditation for three reasons, first, the memory output from hippocampus is not continuous one, secondly, hippocampus does not have a tonic discharge and thirdly, there are very weak connections of hippocampus (including other structures of limbic system) with neo-cortex. The pontine reticular nuclei appear responsible for generation of θ waves during depths of meditation. It is surmised that for further slowing of EEG in δ range, older reticular nuclei of brain stem may be responsible (41). Thus, during meditation it is hypothesized that, as the depth increases, older and older core reticular nuclei are involved to generate the rhythm to drive cortices. In part, this point of view draws support from the study carried to localize sources of alpha/theta/delta activity in the brain during spontaneous mentation (43). The authors used multi-channel field EEG data to find out presence of single oscillating dipole sources by determining the phase angles. During different mentation efforts different equivalent source locations were found for the different spectral components of the EEG. It implies the different neural generator populations generate the different frequencies. The possible locations of these slow wave generators appear in the brain stem (44).

The alpha waves are EEG correlates of relaxed awareness. They represent non-analytic attending to stimuli. The θ waves are associated with reverie and said to be EEG correlates of 'creative thinking'. During this stage the activity moves back and forth in memory stores and association cortices (temporal and posterior parietal areas), thus, producing a reverie consisting of a combination of new concepts, images, events etc. There is a possibility to enhance this skill either through meditation or θ EEG brainwave biofeedback (45, 46). Through this mechanism, it is possible that non-sense images/thoughts are produced. These may appear creative because a person will not be able to create such combinations during wakeful state. Perhaps this is the explanation for 'vague' thoughts or images observed during deep meditative state. Maintaining meditative state of mind requires continuously active core structure(s). These core reticular nuclei (either thalamic or pontine reticular nuclei or further lower down in brain stem) idle at natural frequency without being interrupted by any external or internal input. In these structures there is a natural tendency to shift activity to neurons with lower frequencies. These frequencies drive cortices and/or memory structures having least threshold values for activation. During this the meditator remains 'disengaged' with reference to external and internal inputs. Presumably, this state requires participation of only small number of brain structures. Earlier also a similar view has been opined (47).

Earlier neurophysiological models

In the recent past some attempts have been made to propose neuropsychological models for explaining the 'meditative effect'. Wallace and his colleagues have carried out large number of studies to investigate the autonomic and electroencephalographic effects during TM(2). Travis and Wallace (48) proposed a hypothetical neural model to explain the phenomena of TM (48). According to this model the frontal areas inhibit thalami activity through GABA-rich nuclei of the nucleus reticular thalami. This initiates (phasic control) the meditation. The meditative state is maintained by tonic control from subcortical structures. Cortical-basal ganglia-thalamo-cortical loops may serve this maintenance function through feedback control. These circuits involve projections from all cerebral cortices to globus pallidus then to the mesencephalic reticular formation. This loop maintains tone in the thalamo-cortical circuits. This model has two strengths. First, enunciation of the role of prefrontal cortex to produce a will to inhibit both sensory and motor activity through thalamus and secondly, the role of thalamo-cortical circuits in maintaining meditative state. The model, however, presents certain conflicting concepts with regards to current knowledge of neurophysiology.

1. Considering the well-documented role of basal ganglia in planning and execution of motor activity, it is unlikely that basal ganglia are involved in genesis of maintenance of the 'motionless' posture. Furthermore, none of the studies on relaxation/meditation have reported activity in basal ganglia.

2. The model proposed feedback inhibition of reticular neurons of thalamus. If these are inhibited it will be difficult to explain the presence of enhanced α activity in EEG.

3. The model does not explain the genesis of slow EEG activity (θ and δ waves) reported in several TM studies (21).

4. The model suggests that negative feedback maintains low excitability of cortical neurons. This does not appear to be the case. In fact, theoretically, the feedback circuits are not designed to generate a frequency at steady state and maintain it for long time. The feedback loops are ideal for controlling perturbations in a steady state function. Moreover, the feedback circuits are involved to maintain a controlled variable in a given limit, which is not definable here. The nature has endowed the steady state function to pacemakers.

Recently, Newberg and d'Aquili proposed a comprehensive model to explain religious and spiritual experiences associated with meditation prayer and rituals (49). This model is suitable for explaining the hyperergotropic state (generalized excessive arousal due hypersympathetic stimulation). When we apply it to 'meditative state' there are certain problems such as the following :

1 The model is not applicable to meditative state leading to wakeful hypometabolic state.

2. The meditative state and 'hyper-excited' state (hyperergotropic) are neither similar, nor their methods of induction are similar.

3. The hyperexcitable state of Yogis can be explained only by hypersympathetic state (hyperergotropic), there is no need of simultaneous existence of hyperparasympathetic (hypertrophotropic) condition along with it. Since the two are antagonistic, for augmented effect at one point of time one would require changes in opposite direction which can not be explained by 'spill over' hypothesis as proposed by Newberg and d'Aquili (49).

In the forgoing discussion only neural models have been described. The meditation models can be based on phenomenology

TABLE III : Proposed neural structures involved in the present model and their functions during meditation with eyes closed.

Neural Structures	*Activity during meditation*
Prefrontal cortex	- Generates 'will' to initiate meditation - Detects the 'intrusions'/'drifts' in attention. - Controls shift in attention required as a part of meditative procedure - When not actively involved in processing, it is driven by thalamic/pontine reticular neurons
Posterior parietal cortex	- Disengagement for active attention (arrest the intrusive thoughts) - Altered kinesthetic perception (relaxed & heaviness in limbs) - Requires a driving rhythm - When not actively involved in processing, it is driven by thalamic/pontine reticular neurons
Superior temporal cortex	- Scans the memory presented to it - Perceives the form, space and void - Perceives the internal sounds - Responsible for emotional and autonomic expression encountered at times - Enlarges the perception of personal space - Required a driving rhythm
Thalamus	- Rhythm generator for driving cortices ($\propto$ waves) - Blocking sensory input (Gating mechanism)
Pontine reticular nuclei	- Rhythm generator for lower EEG frequencies (θ) - Blocking sensory input
Hippocampus	- Memory traces

(50,51), or psychological, philosophical or spiritual considerations. These are out of scope of present discussion.

The Present model

Certainly the previous models have paved the way for the model proposed in this article. This model proposes that the prefrontal cortex initiates the first step of meditation. It generates the "will" to initiate sensorimotor attenuation by inhibiting the primary sensory and motor cortices and restricting the involvement of concerned association cortices concerned with stimulus processing (Table III). The inhibition of cortices is also achieved by providing minimal stimuli for analysis (Fig. 2). It is proposed that thalamus engages in natural idling mode and remains active to produce basal rhythm. Thus, functionally speaking the cortices become less and less active; and are surrendered to thalamic driving (Table III enlists detailed functions various proposed neural strutures implicated in this model). As the depth of meditation increases, lower reticular nuclei i.e. pontine reticular nuclei may be involved to produce θ activity in posterior parietal cortex which is reflected as θ waves in EEG. The involvement of pontine reticular nuclei is supported by the fact that these are capable of generating frequencies in θ range (41). The analysis of meditation effect suggests that, in fact, there is a feedforward activation of large number of cortical neurons by thalamic discharges. Since the thalamic rhythm is natural and spontaneous it does not contain any information to process. Thus, the activation does not impose a task on cortices. As the meditation process continues, the inherent neural

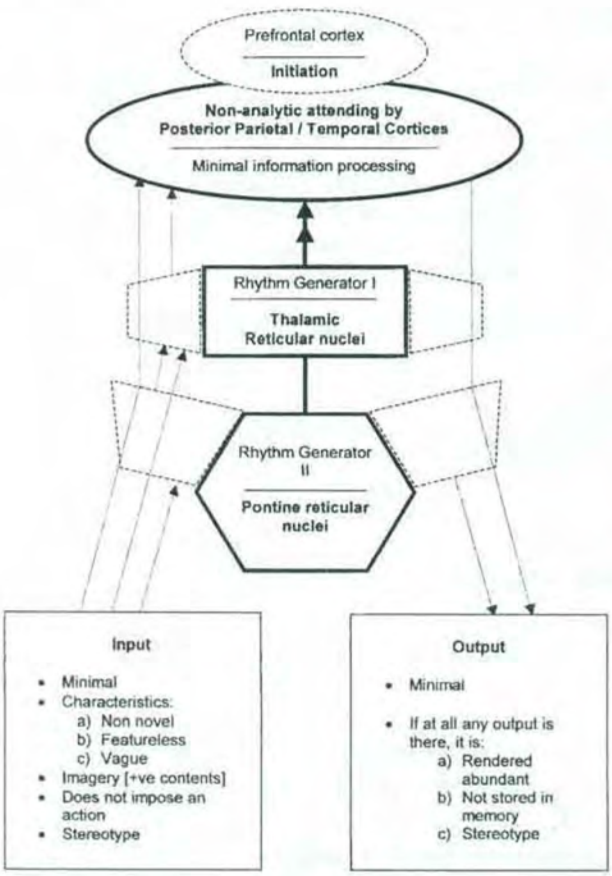

Fig. 2 : Characteristics of input and output, and neural structures involved in processing them during initial and sustained stage of meditation. The thin arrows represent the input/output pathways along which the activity is minimized. The dashed lined boxes are involved in initiation of meditation. The thick lined boxes contain core structures involved in maintaining sustained meditative state. The thick lined arrows indicate the pathways along which idling rhythm is generated during sustained meditation. There are several other structures involved during initial phase (pre-meditation or inductive phase) and others, which are spontaneously active during sustained stage. Refer text and Table III for further details.

activity in the cortices reduces substantially even through sporadic activity (driven by prefrontal lobe) keeps on taking place since the input from memory is difficult to prevent. The inherent neural activity arises somewhere in cortices, shifts from cortex to cortex, gets analyzed, gradually reduces and dies out. This progression appears to be non-linear and not in logical order. For quite a while it may not be detected by conscious perception. Once detected it is labelled as an "intrusion" or a "drift". It is proposed that the "intrusion" is detected by prefrontal cortex. During the steady state of meditation, the suppression of unwanted thought/stimulus would require recognition of the stray thoughts. After recognition the unwanted thought/stimulus is suppressed and replaced by a meditational task (like attention on breathing and attention on object or word). Since it is a rejection task requiring analysis, the prefrontal cortex is involved. The meditator is advised, as the first cognitive step, to learn to avoid them. Perhaps a long-term practice gives rise to formation of new connections in the cortices. Thus, prefrontal cortex helps in rejection of stray and unwanted thought/stimulus and commands selected neurons in posterior parietal/temporal cortex in the right hemisphere to switch over to non-analytical state, which manifests as appearance of α waves in EEG. In favour of this view, PET studies show strong activity in parietal cortex, pulvinar and frontal areas during attentional shifts (24, 34). The second important cognitive restructuring during meditation is dissociating the significance and consequences attached to thought/event. This dissociation is responsible for de-linking autonomic effects from thought process. This is achieved by decreasing the total time made available for stimulus processing in the association cortices. Hence, it deletes the perceptual processing that occurs as delayed processing of stimuli. The initial processing is intact and it is responsible for producing feeling of sensation. This assumption is supported by a report on reduction in amplitude of middle latency auditory evoked responses (52). Thus, the meditation controls the later part of stimulus processing so as to allow sensing but not perceiving of a stimulus. There are two implications of this. After receiving the stimulus no meaning is attached to a stimulus and it may explain the de-linking with autonomic responses. Secondly, it may explain the concept of "detached observation", "sensed awareness" or "relaxed awareness" commonly used to explain the meditative state. The cortical receptivity becomes higher in such a situation as evidenced by fast and high amplitude of initial (early) components of cortical evoked responses during mediation and reports of increased critical flicker frequency after meditation practice (53,54,55). Several other researchers have reported alteration in information processing (56,57,58). Logically, such a state of cortices will be called "easily excitable". This gives the state of "enhanced alertness" reported during various meditative states. Here the alertness is defined by high receptivity of stimuli. When no stimulus is being received, the activity in cortices is low. It should not be confused with low excitability of cerebral cortex (Fig. 2 depicts the proposed scheme of information processing, brain structures and their corresponding functions concerned with the present model).

Conclusion

Currently a lot of interest is being shown by medical scientists to discover underlying mechanisms of yogic sciences and their application (59). The meditation is a Yogic technique which has at least four potential uses. First, it can be used as a counter measure to a large number of ill effects of chronic over-arousal situations. Secondly, it can be used as a pleasure inducing (bliss) technique and to discover unusual human potentials. Thirdly, it can be used as a technique to exercise extraordinary fleet of control over involuntary consequences of meditative effect i.e. control over attention, heart rate etc. Fourthly, it can be used as a technique to explore physiological basis of attention, relaxation and associated autonomic responses.

Meditation is a sustained non-analytic attention without any arousal component in it. The attention is focused to internally cued non-novel stimuli. A substantially reduced sensory motor activity along with a shift of the information processing system to internally turned receptive mode is expected to decrease the activity of neurons associated with externally directed action. The information processing neurons idle without further consequent action. Primarily, the meditation is produced by disengaged association cortices ('disengaged' refers to not engaged in any active analytical attending) driven by thalamus or other older group of reticular nuclei. Secondarily, there may be involvement of some more phylogenetically older structures depending upon depth and types of meditation. Thus, the beginning of meditation essentially means dynamic shifting between the non-analytic mode (minimum information processing) and meaningful analysis of internally/externally presented stimuli. The process continues to strive attaining the non-analytical state. The present model suggests a shift in neural activity to - (a) right brain, (b) older association cortices like from frontal to parietal to temporal cortex and (c) rhythm generator like thalamus to older slower rhythm generator situated in lower brain. This explains the shift from desynchronized high EEG frequency to synchronized low frequencies (frequencies form β to SMR to α to θ range) during meditation. The model is able to explain the behavioral effects associated with meditative state like-reduced levels of arousal, reduced motor excitability, enhanced sensory excitability along with non-processing of input signals, decreased autonomic arousal and shutting down of complex analytical processing. The hypothetical model presented here is simplistic, comprehensive and involves less number of active neural circuits. This can be used to explain the observable phenomena during meditation to a greater extent. The model is essentially based on reductionism and it will be difficult to explain the whole range of consciousness implicated to meditation, as envisaged by early workers (60). Future studies using PET combined with radiotracers for markers of various neurotransmitters in proposed neural structures may reveal clear picture of brain functioning during meditative state.

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