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The Impact of Meditative Practices on Physiology and Neurology: A Review of the Literature

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ABSTRACT

A general awareness of meditation has grown significantly in the western world within the last fifty years yet with little accurate understanding of the nature of the practice. In addition, the broad diversity of meditative practices and their variations of physiological results make a standardized study of effects difficult. Recent advances in technology have provided an opportunity for investigators to systematize their efforts so that the body of research may be more coherent. A more accurate understanding of the physiological and neurological effects of meditation will likely reveal means of therapeutic application for both individual and social benefit as well as further insight into attentional states. The preponderance of literature points to meditation as a practice facilitating a general return to neurological and physiological homeostasis.
KEY WORDS: Meditation, concentration, attention, awareness, TM, cortisol, stress

INTRODUCTION

While the phenomenon of meditation practice is now familiar in western societies, the practice itself is poorly understood. As a result, the actual practice is often confused with its effects, which as will be explained later in this paper, are numerous and varied. In order to allow for accurate understanding of the processes involved, some distinctions need to be made.

The 1998 study by Infante and colleagues (as acknowledged in Dunn, Hartigan, & Mikulas, 1999) identifies a possible problem with the definition of meditation as a "mental stress reduction technique;" in reality it is a bit more complex. One source of this complication is the difference between cultures. The language and philosophy of the eastern cultures where such meditative practices originated differ from the western cultures where the practices are now being empirically measured. Descriptions of relevant terminology follow.

Day-to-Day Waking Consciousness

In order to comprehend what the meditative state is, it is important to establish what it is not. Neurophysiological correlates characterizing the various cognitive and affective states of normal waking consciousness have been identified by patterns of electric activity with an Electro-Encephalogram (EEG), measures of neuronal metabolism via Positron Emission Tomography (PET) or Functional Magnetic Resonance Imaging (fMRI), and measures of neurotransmitter metabolites present in the blood plasma or serum levels. The dynamic patterns of brain activity associated with these states do not readily lend themselves to rigid definition; consequently characterizations of brain states are general and often cross-referenced with other measures. The study of meditation's neurophysiological correlates may serve to provide data beneficial to a more comprehensive understanding of what mechanisms underlie day-to-day consciousness.

Day-to-day consciousness involves a number of cognitive processes including sensation, perception, memory, imagination, and abstract reasoning. Each of these corresponds to particular neurological networks involving certain brain regions and their synaptic connections. The foremost part of the brain, the prefrontal cortex (PFC), coordinates these functions in a coherent sequence and the resultant interactions between the components comprise waking consciousness. This coordination of the other mental processes by the PFC, both conscious and unconscious, is often referred to as the "executive function" (LeDoux, 2002).

Scientists have proposed two different aspects of waking consciousness: (1) consciousness of sensory world and (2) consciousness of action and the experience of voluntary control (Lou et al., 1999). Voluntary control is a key component of day-to-day consciousness wherein most activities are oriented toward the achievement of a goal. To this end, there is an active attending to relevant sensory stimuli and subsequent direction of mental and motor activity. This direction of cognition and movement is attributed to the so-called "executive function" of the pre-frontal and anterior cingulate cortices. The correlating sub-cranial activity may be observed through the different media of EEG, PET, or fMRI measurements of marked electro-chemical activity and cell metabolism. While each different cognitive process exhibits a distinctive EEG pattern, these have yet to be mapped out in detail due to the complexity of their interactions both spatially and temporally (Aftanas & Ljubomir, 1994; Lou, et al., 1999). Activity in the executive attentional system and the cerebellum appear to be characterized by normal, resting consciousness (e.g., waiting for a response after ringing a doorbell), whereas a defining characteristic of meditation is the reduction or lack of the prefrontal and cingulated activity, likely due to less volitional, motivational, and emotional control (Lou et al., 1999).

Meditative Consciousness

Meditation is an attentional practice whose dynamic nature tends to elude dichotomous classification. It can be difficult to classify simply because there are such a multitude of forms which need not require stillness. There are walking meditations, meditation of physical postures, meditation while eating, and meditation while chanting. The list of descriptions goes on. The one commonality is the application of one's full awareness to the experience of each moment. Numerous forms of meditative practice distinguish themselves on the basis of breathing method, orientation of focus, and intentional outcome. Some aim for complete blissful absorption in transcendent experience, as with many practices from India. Others, like Buddhist mindfulness practices, seek merely to notice and release any sort of intentionality or thought.

It has been established through various studies that each particular technique generates its own patterns of electrical activity and neurological activation in the brain, each corresponding to unique subjective states (Murata, et al., 2004). Generally, practice of meditation results in similar patterns of parasympathetic activation and sympathetic inhibition, although a small number of studies have noted increases in physiological measures of autonomic activity. These have largely been attributed to the specific form of meditation as well as interactions between intensity of attentional activation and the experience level of the practitioner. Monks who have been dedicated decades to their practice will have different abilities than the novice who meditates when she gets stressed (Benson, Malhotra, Goldman, Jacobs, & Hopkins, 1990; Corby, Roth, Zarcone, & Kopell, 1978).

The practices of meditation are generally categorized into two forms based upon the orientation of attention: concentrative and mindfulness. Concentrative practices focus attention inwardly. Awareness is concentrated on a particular object and sustained there. Objects may include an image, an intention, or a repeated sound (mantra). Extraneous stimuli are ignored. While concentrative techniques tighten the practitioner's focus, mindfulness meditation broadens the scope of attention to incorporate the practitioner's entire field of awareness. The practice usually begins with an awareness of the breath and is gradually expanded outward to include all cognitive, affective, and somatosensory experiences. These phenomena are allowed to permeate nonjudgmental awareness with observation that they are impermanent. This observation is reinforced through experience as new stimuli continually arise to replace the old. No stimuli are actively pushed away or ignored. Any disturbance is incorporated as the next object of attention (Kabat-Zinn, 1982). Mindfulness practice is unique in its lack of activity. It does not entail "doing" anything but rather, is more a practice of "just being" (Kabat-Zinn, 1982). Yet it is not passive in its practice. It is comprised of continual, active, effortful observation. It is the non-directed practice of noticing stimuli as they are perceived.

Much confusion surrounds meditation as it is often inaccurately assumed to be solely an exercise in relaxation. This lack of clarity likely results from the fact that most techniques effect a quieting of the practitioner's mental and physiological activity. Ambiguity also arises from the many traditions' failure to adhere exclusively to concentration or mindfulness strategies, instead employing a combination of both during different phases (Murata et al., 2004).

Meditation Forms & Descriptions

Methods of meditation vary widely in their formal practice. As previously mentioned, these are most generally classified according to their orientation, either focusing awareness onto a particular object of attention (concentrative) or incorporating the entire subjective experience into awareness (mindfulness). Within the two categories of concentrative and mindfulness are particular sub-practices based on such variables as specific attentional focus, intention, concomitant physical activity, etc. Scientific studies have generally confined their examination to six forms of practice.

Transcendental Meditation (TM) is a concentrative technique wherein the practitioner silently repeats a mantra or simple phrase and comes from the Vedic tradition of India. It is formally practiced twice a day for an average of twenty minutes. Its introduction to the West has been credited to Maharishi Mahesh Yogi, who has since established an institute based primarily on the perpetuation of TM as a simple, therapeutic practice not based on any belief or teachings as well as empirical exploration of the various effects of Transcendental Meditation in people's lives.

Tibetan Buddhist Meditation, like the Indian Yogic forms of meditation, includes numerous techniques of mental practice. These span the spectrum from Vipassana, a pure mindfulness meditation, to Metta, or Loving-Kindness, meditation. The practitioner strives to generate a state of empathy or compassion, expanding the attentional orientation outward until the subjective experience is one of complete absorption in the feeling rather than a narrower, self-focused mindset. There are also very specific concentrative techniques designed to hone the practitioner's ability to refine awareness to the point of a needle or occupy the clarity of a glass sphere.

Vipassana (Buddhist Insight) Meditation is a mindfulness practice. It entails a progressive development of the practitioner's non-judgmental attention, beginning with internal somatic experience, usually the breath, gradually expanding it outward to include emotions, thoughts, and finally external stimuli until all can be held equally in an open field of awareness.

Zen (Japanese and Korean) forms of meditation are generally simple mindfulness practices, simply observing the flow of experience as its components pass through awareness. Su-soku is one form of Zen meditation, characterized by concentrating on the counting of each breath as it passes. When one reaches 10 one begins the count anew, eliminating the tendency toward achievement (Murata, et al., 2004).

Yoga is an Indian spiritual practice, literally translated into English as "join," "yoke," or "union." While there are generally five different recognized yogas, the two most commonly practiced in the West are Hatha (Force) Yoga, which entails the asana or assumption of physical postures in connection with conscious breathing, and Raja (Royal) Yoga, which primarily promotes meditation. (Molloy, 1999)

Imagery meditation, while not a formal practice in itself, is can be incorporated into concentrative practice entailing active visualization. It is most often associated with yogic practices. Occipital lobe stimulation has been found with this practice and will be discussed later in this paper.

While these six predominant forms may not include all variations found within the entire array of Eastern meditative exercises, they do effectively represent the general body of practices, incorporating key shared characteristics. They are functionally identifiable by unique patterns of neurological and physiological effects. In order to characterize the various practices researchers have utilized conventional measures of brain activity and physiological responses.

Brain Activity and Functional Anatomy

EEG is categorized into frequency bandwidths. While the bandwidths are similar, there may be some degree of variation among data produced by different researchers using slightly different bandwidth parameters. This can create some complexity for inter-study comparisons if not taken into consideration (Stuckey, Lawson, & Luna, 2005).

Individually, the bandwidths represent a level of electrical activity at a specific site. What is more significant to this body of research is the relationship between multiple sites before, during, and after meditation. Understanding bandwidth requires clarifications of measures; these are (1) f*requency*, the number of cycles of brainwaves per second, (2) *amplitude*, the height of the waveform measured in microvolts, synonymous with "power" in quantitative EEG, and (3) m*agnitude*, a measure of the power of wave (the amplitude) averaged over a period of time (Stuckey, Lawson and Luna, 2005).

Bandwidths are the rhythmic frequency of electrical activity within specific brain regions and are organized into bands loosely corresponding to biological or cognitive significance. The electrical activity occurs in wave patterns whose organization starts with the slowest and largest, and proceeds to the fastest and smallest. The Delta wave (0-3 Hz) is the longest and slowest wave, typically found during deep sleep (stages 3 & 4); it is also present in brain injury and coma at the lowest level of consciousness.

The Theta wave (4-8 Hz) occurs during some sleep states, states of quiet focus (i.e., meditation), and in some instances of subcortical brain damage and epilepsy. This is also associated with the occurrences of short-tem memory, spatial learning and navigation, hippocampal ready-state, relief from anxiety (Kubota, Sato, et al, 2001). Increases have been noted during attentional orienting, stimulus expectancy, focused attention, successful encoding of new information, concentrated task performance and affective processing (Aftanas, et al., 2002).

The Alpha and Beta wavelengths are more common during daily activities. The Alpha wave (8-12 Hz) is found during periods of relaxation and visual cortex (occipital lobe) "idling" (eyes closed but awake). Also the "Mu" band (9-13 Hz, including specific bursts of 9-11 Hz) occurs with both actual motor movement and intent to move with an associated diminished activation of the motor cortex. It possibly reflects activity of mirror neurons. The Beta wave (12-24 Hz) represents (day-to-day) cognitive consciousness and active, busy, or anxious thinking. Beta activity is attenuated with sedative drugs such as barbiturates or benzodiazepine.

The Gamma wave (24 Hz and up) is the fastest bandwidth and is most infrequent during waking states of consciousness. It is associated with perception, awakening, the low voltage, fast neocortical activity (LVF) of REM sleep, and the more complex mental activity incorporating recognition of new insights and assimilation of information from multiple brain regions (Stuckey, Lawson, & Luna, 2005; Pinel, 2006).

EEG synchronization, or coherence, occurs when brainwave patterns generated from different sites move together in unison. It is the measure of informational integration or of functional coordination between separate areas of the brain and can occur between identical regions of contralateral (opposite-side) hemispheres, or between different regions within ipsilateral (same-side) or contralateral hemispheres. It is commonly regarded as underlying formation of functional networks.

Greater similarity between regional wave patterns signifies a higher degree of coherence (Stuckey, Lawson, & Luna, 2005) representing communication between cortical areas over a relatively great distance (10-25 cm apart), reflecting task-oriented cooperation among separate neural circuits (Travis & Arenander, 2006). Researchers noted that Varela and colleagues (2001) considered coherence across multiple bandwidths (broadband coherence) to represent the mechanism binding global cortical activity into the "unity of conscious experience" (Travis & Arenander, 2006). Increases in broadband EEG coherence are related to improved cognitive functioning and mental health. Coherence of EEG within the frontal lobe has been positively correlated with moral reasoning, emotional stability, cognitive flexibility, and performance on attentional tasks, while both acute and chronic anxiety have demonstrated inverse correlations (Travis & Arenander, 2006).

Processing of sensory, cognitive, and motor information can effect changes in the EEG patterns by way of event-related desynchronization or synchronization (ERD or ERS, respectively). ERD is usually associated with increased excitation and the ERS (in alpha and beta bandwidths may sometimes correlate with the deactivation of a cortical area. Synchronization can occur with decreases in arousal, internalized attention, and emotional tranquility (Aftanas et al., 2002).

EEG desynchronization represents increased neural excitation such as during enhanced cognitive activity. It can reflect externalized attention, states of heightened vigilance and expectancy (Aftanas & Golosheikin, 2003), increased arousal, and strong emotional excitation (Stuckey, Lawson, & Luna, 2005). Asymmetry is the measure of power differences in electrical activity between brain hemispheres or between designated regions within each hemisphere. It tends to reflect synchronous firing of local cortical columns (1-3 cm apart) in contrasting power to their contralateral (opposite side) counterparts. As columns fire in accord with one another, the accumulated charge of their individual waves merges into detectable power. Asymmetry is noted to emerge during affective (emotional) processing (Aftanas, et al, 2002). While asymmetry is recognized as a contrast of power between hemispheres, indicating predominance of lateralized functions (e.g., left-lateralized asymmetry could indicate a brain's active interpretation of the meaning of a speaker's words whereas right-lateralized asymmetry could indicate the perception of the speaker's intonation), Aftanas et al., (2002) identified a specific interpretation of asymmetry of cortical activity in prefrontal lobes as signifying motivational direction more than emotional valence. It is possible to have synchronization and asymmetry between multiple regions in the same way as two synchronized swimmers of different sizes may perform identical routines. Symmetry then, represents similarity of electrical power between hemispheres or regions. It signifies comparable levels of activity between functional brain areas.

Electromyograph (EMG) measures local neuromuscular activity. The activity can be an indicator of physiological responsiveness as well as a source of interference or data-contamination for EEG measures in the same area (Pinel, 2006).

Significance of EEG Activity

The brain's patterns of electrical activity have been found to correlate with varying neurological processes and subsequent states of consciousness. Both variations and sustained patterns of bandwidth may occur globally and/or locally, indicating corresponding states of cognitive or physiological function which are associated with specific levels and orientations of awareness.

Alpha activity is divided into two levels. Activity in the low alpha band is associated with vigilance and attention whereas upper alpha activity is thought to reflect task-specific processes (perceptual and cognitive). Alpha power is thought to be inversely related to activation in the awake, healthy adult such that decreases in alpha power (size of alpha waves) reflect increases in mental activation. Some researchers theorize increasing alpha synchronization signifies cognitive inactivity, termed "cortical idling." However, others suggest that alpha synchronization may represent active coordination between related brain areas, described by Cooper et al. (as noted in Aftanas & Golosheykin, 2005) to reflect "specific operations of higher brain functioning." During such tasks as attending to mental imagery, alpha wave activity appears to indicate active inhibition of sensory information (Aftanas & Golosheykin, 2005).

Internally oriented attention such as in interoception or introspection is associated with alpha synchronization while externally oriented attention is associated with desynchronization. Subjective reports of "successful" meditation experience (i.e., practitioner's attention is fully absorbed in the process) appears to be mediated by inhibition of externalized attention, as indicated by slower alpha synchronization between frontal regions of each hemisphere. Studies indicate that an increase in alpha EEG coherence may better reflect an absorbed meditative state than either power or amplitude. Transcendental Meditation (TM) for instance, has been reported to exhibit an increase in coherence across hemispheres in frontal regions (Murata et al., 2004).

Greater coherence of slow alpha wave activity (i.e., coinciding patterns of 8-10 Hz in different regions) has been interpreted as evidence for information exchange or functional coordination between brain regions. Slow alpha band (8-10 Hz) tend signify processes such as attention and expectancy in non-task-related cognition, whereas faster alpha band activity (10-12 Hz) is though to represent task-related processes (Basar, Basar-Eroglu, Karakas, & Schurmann, 2001).

Theta activity, occurring in the form of oscillations in response to an event, appears to represent cognitive processing and interaction between relevant cortices and the hippocampus. Distinctive increases in theta synchronization of posterior cortical regions have been observed in response to an affective challenge possibly reflecting processing of affective stimulus significance. Found to correlate with such diverse processes such as orienting, selective attention, stimulus decoding, memory processes, both anterior and posterior theta synchronization may reflect evaluation of emotional stimulus significance (Aftanas et al., 2001).

Theta activity is implicated in a number of cognitive and affective states. Short-term theta synchronization may accompany perception of emotional stimuli whereas longer lasting theta synchronization may accompany the emotional experience. Interestingly, prolonged enhancement of theta power through regular EEG biofeedback training positively correlates with creative performance (Aftanas, & Golosheykin, 2005).

Thought to originate in the prefrontal lobes and the Anterior Cingulate Cortex (ACC) theta rhythm in the frontal midline region was demonstrated to occur during meditative concentration as well as relief from anxiety. An inverse correlation was found between activation of the sympathetic nervous system and theta bandwidths in frontal areas suggesting a significant relationship between cardiac autonomic function and activity in the circuits of the medial prefrontal lobe (Kubota et al., 2001).

Incidences of gamma oscillations are less well understood. They appear to be involved with higher order integration of multiple circuits' processing rather than correlated to any specific function. Researchers have proposed their role in global CNS information processing to result from providing functional "building blocks" for communication between regions (Başar et al., 2001). Thought to originate in the limbic system, they have been found to closely associate with the cognitive component of emotional processing. (Aftanas, & Golosheykin, 2005) Increases in gamma power are correlated with internalization of attention and generation of positive emotional experiences (Aftanas & Golosheikin, 2002).

Increases in gamma rhythm within the frontal lobes have demonstrated significant correlations with heightening of orientation response, concentration of attention, and successful encoding of new information in long-term memory. There is some evidence that these originate in the attentional circuits of the ACC and medial prefrontal cortex (MPFC). Additionally, modest negative correlations between frontal midline gamma activity and intensity of experience of anxiety have appeared, but have yet to be corroborated (Aftanas, & Golosheykin, 2005).

Neuroanatomical Functions

It has been well established that particular mental functions have physiological substrates that operate in corresponding regions of the brain. These associations may be as specific as the capacity for verbal language being located within the inferior frontal gyrus of the frontal lobe or as general as the association of hemisphere with emotional valence.

The functioning of the left hemisphere is generally associated with approach-oriented behaviors and emotional processing. A number of studies have found general activation of the left hemisphere to correlate with expression of positive affect as well as approach-oriented behavior toward rewarding stimuli and co-occurence with anger-related emotions (Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2001; Travis & Arenander, 2006). The left-hemisphere also demonstrates increased activation with verbal tasks (Travis & Arenander, 2006). Aftanas et al. (2002) reported significantly greater activation of the information processing circuits within the left hemisphere in response to highly-charged negative emotional stimuli.

The prefrontal region of the right hemisphere has been found to be activated during experiences of some negative emotions. It has demonstrated significant correlation to both withdrawal-oriented disposition and behavior toward aversive stimuli (Travis & Arenander, 2006; Aftanas et al., 2002). While the right hemisphere is generally associated with unpleasant affect, posterior regions are involved in the modulation of emotion-related arousal as well as in the recruitment of anterior regions of the left-hemisphere in the analysis of others' affect (Aftanas et al., 2002).

The brain's frontal lobes house functional regions which govern the neural circuits responsible for volitional activity. The neuroanatomical correlates of higher mental functions: attention, learning, planning, working memory, language, judgment, moral reasoning, emotions, and self-concept (Travis & Arenander, 2006) are located in this region, executing the selection or inhibition of other cognitive processes as well as the preparation for, coordination and execution of motor activity. While there is still some uncertainty, findings indicate a lack of activity in the dorsolateral prefrontal cortex (DPFC) during sleep stages (Lou et al., 1999). It is also involved in the integration of working memory, cognitive aspects of decision making, coordination of working memory as well as preparation for voluntary motor activity (LeDoux, 2002). The region of the PFC located around the eye sockets, referred to as the orbitofrontal cortex, has been shown involvement in the processing of incentives and emotions. It functions in the cognitive aspects of decision making and the integration of working memory (LeDoux, 2002). Damage to this region can result in lack of interest and initiative (Kjaer et al., 2000).

The Anterior Cingulate Cortex (ACC) appears to play a critical role in motivation and resolution of conflict between competing neurological processes. An example of this might occur in an urban situation where one's attention is simultaneously drawn to both an attractive member of the opposite sex and the bizarre behavior of a street person. The ACC selects among these processing alternatives on the basis of the individual's pre-existing internal blueprint (Pardo et al., 1990 as noted by Lou et al., 1999). As an intermediate part of circuits between the executive functions of the PFC and the emotional aspects of the limbic system, the ACC regulates these regions' interactions involving cognitive processing of emotional information. During complex attentional tasks the ACC serves to evaluate probabilities of making incorrect response as well as allocating resources to attentional demands for the initiation of behavior and suppression of inadequate responses (Fallgatter, Bartsch, Zielasek, & Herrmann, 2003; LeDoux, 2002). Among its numerous reciprocal interconnections, the ACC synapses with the lateral PFC, orbitofrontal, and parietal cortices, anterior insula, as well as premotor and supplementary motor regions and provides input to autonomic, visceromotor, and endocrine systems. The ACC operates in the emotional/motivational aspect of the pain perception mechanism (Craig, Reiman, Evans, & Bushnell, 1996; Orme-Johnson, Schneider, Son, Nidich, & Cho, 2006).

The striatum is part of a circuit including the prefrontal cortices and the thalamus for regulation of cortical input serving working memory and preparation for intentional motor activity (Kjaer et al., 2000). It also functions to evaluate temporal-spatial context (Lou et al., 1999) and plays a key role in organism's reward mechanism. Divided anatomically and functionally into a dorsal and ventral aspect, the dorsal striatum processes contextual feedback while the ventral striatum is associated with predicting and anticipating outcomes of potentially risky decisions.

The cerebellum is a structure long believed to be involved solely in motor coordination; however, more recent findings concerning injury to the cerebellum have revealed various deficits in cognitive performance. Based on lesion studies in addition to functional and anatomical connectivity to cortico-subcortico-cortical loops which regulate behavior, the cerebellum has been found to play a significant role in a number of cognitive functions including attentional processes and prediction of future events (Lou et al., 1999; Pinel, 2006).

Research Technology

Advances in technology have provided unique access to neurological processes and their resultant mental phenomenon. Additionally, development of new mathematical algorithms including chaos analysis, wavelet analysis, and single trial recordings has contributed the means to interpret previously ambiguous data. With the application of these tools to recent neurological conceptualizations such as "cooperation phenomenon" and "synchronization of cell assemblies" new avenues of thought have opened for a greater understanding of the various states of consciousness. The instruments utilized in neuroscientific research have also provided a critical non-invasive means by which to operationally define the often ambiguous effects of the various forms of meditation. The primary tools used in the reviewed are briefly described here **(**Başar, Başar -Eroglu, Karakas, & Schurmann, 2001).

The EEG is a measure of electrical activity in the brain. EEG provides significant value in neurological research as it indicates patterns of electrical activity as waveforms, specific characteristics of which represent states of consciousness as well as mental activity (Pinel, 2006). (Functional Magnetic Resonance Imaging (fMRI) is a hemodynamic measure of oxygen consumption by neurons. Its ability to provide clear, detailed, 3-dimensional images of blood-flow for specific regions of the brain enables a comprehensive picture of changes in activation of functional brain structures (Pinel, 2006). The Magnetoencephalography (MEG) measures changes of the neural activity beneath the scalp which alter the local magnetic field. MEG can complement fMRI as it is a neuronal measure which can pinpoint sources of activity in basic areas such as primary somatosensory, motor, and auditory areas but is limited for mapping more complex cognitive functions such as reasoning. An additional advantage of MEG is that, with computed tomography (CT) can provide dynamic imaging in addition to static imaging (Sternlof, 2002; Pinel, 2006). Another imaging technique, Positron Emission Tomography (PET) is a hemodynamic measurement of glucose metabolism by brain cells. A particular advantage of PET is its ability to detect and record brain activity instead of merely brain structure (Pinel, 2006). Single Photon Emission Computer Tomography (SPECT) is a hemodynamic measure of detailed 3-dimensional pictures. The radioactive isotope used in SPECT scanning is less expensive and more readily available then that used for PET (Malison, Laruelle, & Innis, 2004).

Neurological Change During Meditative Practices

Lazar et al., (2000) utilized fMRI to identify functional regions of the brain activated by Kundalini Yoga meditation wherein participants concentrated attention on the breathing, silently uttering one mantra upon inhalation and another upon exhalation. Regions of the frontal and parietal cortices known to be involved in regulating attention, as well as the pregenual Anterior Cingulate Cortex (ACC), amygdala, midbrain, and hypothalamus, recognized for their roles in arousal/autonomic control, were notably activated during meditation. Lazar and colleagues (2000) also detected significant increases in activation levels of loci within the prefrontal, parietal, and temporal cortices, as well as in the precentral/postcentral gyri, and the hippocampal/ parahippocampal formation, from the early stage of meditation to the fully absorbed state toward the end of the recorded period. This demonstrated marked differences in neurophysiological states between early and late stages of meditation.

In addition to the activation of some neurological structures, a temporal effect was illustrated by increased fMRI activation throughout meditation periods. Activation occurred during subsequent scans of participants' brain regions, suggesting the effects of meditation to be "dynamic, slowly evolving during practice" (Lazar et al., 2000). This was found to parallel descriptions of experienced meditators, who reported that "subtle changes in the subjective state continue to occur throughout the duration of the meditation practice" (Lazar et al., 2000).

Orme-Johnson, Schneider, Son, Nidich, & Cho (2006) demonstrated decreased pain response by measuring cerebral blood flow in a group of inexperienced controls before they learned the TM technique and then after 5 months practice. These were compared to responses of highly experienced practitioners (mean=31 yrs practice). Pre-test results showed controls exhibiting 40-50% greater activation of the Anterior Cingulate Cortex (ACC) and regions of the Prefrontal Cortex (PFC: superior/middle frontal gyri, dorsolateral, and orbitofrontal cortices) in response to submersion of index and middle fingers in 51°C water. After the practice period, post-test results test showed controls achieving the same lowered levels of neural responsiveness as the long-term meditators with 40-50% reduction in blood flow to the pain-activated areas of PFC and ACC (Orme-Johnson, Schneider, Son, Nidich, & Cho, 2006).

In a study of practitioners of a Tibetan Buddhist concentrative meditation with at least 15 yrs experience, Newberg et al., (2001) found significant increased activity in prefrontal and orbital cortices, supporting the findings of (the other studies utilizing more advanced fMRI or SPECT) Herzog et al. (1990) and Lazar et al (2000) but not those of Lou et al. (1999). This was speculated to result from the latter study's use of audiotapes to guide the meditation. As frontal areas are associated with attention-focusing tasks, (Newberg et al., 2001) meditative practices involving these deliberate cognitive functions would be expected to stimulate the corresponding regions. Likewise, in an externally guided practice, the practitioner's role is a passive one, thereby decreasing activation of executive functions.

Although Newberg et al. (2001) hypothesized a relative decrease in sensorimotor cortices due to the motionless nature of the meditative posture, it appeared that activity in these regions increased. The authors speculated that this might be due to the tonic contraction of postural muscles keeping the meditator upright, as well as visual stimuli being provided by internal generation of images. As tonic muscular contraction seldom increases sensorimotor awareness, another possibility might consider the methodology of the experiment. Baseline SPECT scans were taken before the meditation, after participants had rested for approximately 40 minutes. Scanning itself took an additional 45 minutes. Measurements taken at this time would indicate minimal sensorimotor arousal. The next scan took place approximately 30-60 minutes after 80 minutes of meditation. Since enhanced sensory awareness is a reported result of meditation (Kjaer et al., 2002), the amount of movement was comparable. As the duration of the meditative period and the practitioners' experience was extensive, the sensorimotor areas of the brain would likely have been sensitized to sensory and proprioceptive input thereby registering greater arousal.

Citing the paradox arising from neurological investigation of meditation wherein measures demonstrate inhibition in some functional regions while excitation responses occur in others, Lyubimov (1998) documents the neurological process by which somatosensory perception is enhanced. His findings suggest that the deep resting state meditation induces in the brain serves as preparation for more precise perception. Alpha, beta, and theta oscillations are phenomenological means by which this is accomplished, functioning to organize or "prime" the brain's faculties for neural interconnectivity. This functional interconnectivity is posited to be the neural correlate for intellectual creativity, the effects of which are experienced outside the meditation session.

Neurotransmitter Alterations During Meditative Practices

In exploration of TM's effects on sympathetic adrenal-medulla stimulation, significant lowering of epinephrine (E) and norepinephrine (NE) levels were found in the morning with additional lowered levels of NE in the evening. Decreased percentages of high-affinity beta-adrenergic receptors were also found (Infante et al., 2001). Examining changes of neurotransmitter levels in 5 neural structures resulting from meditation (right and left caudate, right and left putamen, and ventral striatum), Kjaer et al., (2000) found a significant increase in the release of dopamine in the ventral striatum during Yoga Nidra (absorptive mindfulness) meditation. It appeared to inversely correlate to the function of executive control. Executive control describes a supervisory function of the brain attributed to the PFC wherein specialized task-related brain processes are regulated. This function switches between retrieval of relevant information from short and long-term memory, integration of that information for application, evaluation of options, prediction of outcomes, and the initiation and termination of each of these processes and their subsequent behaviors (LeDoux, 2002).

Kjaer et al. (2000) demonstrated a large (65%) increase in endogenous dopamine release as well as a significant decrease in dopaminergic receptor availability in the ventral striatum. The ventral striatum is a central component of three neural frontal-subcortical circuits critical to regulation of attention and behavior. Dysfunction in one of these circuits results in apathy, poverty of speech and of movement, and inhibited display of emotion (anterior cingulate syndrome). Dysfunction in the second circuit results in lack of interest and initiative (orbitofrontal syndrome). The third circuit relays through the dorsal striatum, not measured in this study, yet dysfunction of this circuit results in difficulties with preparation for volitional movement.

EEG measures showed an increase in theta activity suggesting a correlation between the increased dopaminergic tone of the ventral striatum and theta activity. What is significant about the increased dopaminergic activity and decrease in the executive function of preparedness for action is that it co-occurs with the increase in the practitioner's heightened sensitivity to his or her environment. The relationship here could likely result from a re-allocation of neural resources from active cognition to passive perception**.** The researchers posited the correlation between the reduction in readiness for action and the increased theta activity to suggest support for "regulation of conscious state at the synaptic level" (Kjaer et al., 2000).

Neurophysiological Activity During Meditative Practice

Badawi, Wallace, Orme-Johnson, & Rouzere (1984) found that periods of respiratory suspension appeared to correlate strongly with TM-induced states of pure consciousness in meditators. The authors also found EEG coherence across all bands with high coherence in alpha and theta EEG frequencies, especially in frontal areas of the brain. Although not all participants who reported experiencing pure consciousness show respiratory suspension periods, they are easily identified in a number of records. An additional finding from this study involved more general EEG patterns resulting from TM. Alpha and theta bandwidths exhibited a tendency to broaden, occupying the full spectrum of each bandwidth rather than any specific frequency.

Kasamatsu & Hirai (1969) recorded EEG patterns of Zen monks in training. They recorded the brain activity of three groups of monks according to years of experience: 1-5 yrs, 5-20 yrs, and 20+ yrs. A consistent EEG pattern emerged which demonstrated both greater regularity and increases in power as the disciples became more practiced. Shortly after meditation began, alpha waves appeared. Alpha waves are often found in an idle state in the visual cortex when eyes are closed. It is a ready, but inactive state that can be altered when eyes are opened, when active thinking begins, or when the mind becomes drowsy. The active wave patterns that then appear are the smaller, faster beta waves, or the slower, longer, irregular waves signaling transition into sleep states. Likewise, excessive alpha activity with eyes open often signifies inattention or daydreaming, such as occurs in individuals with ADD (Nash, 2000). Of note here is that zazen, the actual sitting meditation of Zen, is conducted with the eyes resting open and unfocused. Visual stimuli are thus entering the cortex, yet the visual cortices are "idling" rather than actively processing while the practitioner's attention is strongly focused inwardly. Alpha rhythms were found to persist even after meditation had ended.

Studies by Kasamatsu & Hirai, Wallace, Banquet, Fenwick et al., and Haynes, et al. (as cited in Taneli & Krahne, 1987), Newberg et al. (2001) reported a common pattern of EEG activity in both TM and Zen meditation to be characterized by the appearance of alpha activity, especially in the frontal lobes, increasing in amplitude while decreasing in frequency. Later onset of rhythmical theta trains was consistently observed toward the end of the session in more experienced practitioners. Alpha activity was detected not only during the meditative process, but was found to continue after the meditation period had ended. High-voltage alpha activity with recurrent rhythmical theta trains was also recorded in frontal and occipital regions in 70% of the participants during the period *preceding* TM practice possibly representing an anticipatory mechanism resulting from habitual practice (Taneli & Krahne, 1987).

The appearance of various theta wave activity is often recorded during meditative sessions. Intermittent theta trains were observed to occur toward the end of the meditative session in highly experienced practitioners, correlating with levels of elevated consciousness. (Kasamatsu & Hirai, 1969; Taneli & Krahne, 1987) Hebert & Lehmann reported very high amplitude theta bursts during TM (as cited in Jevning, Wells, Wilson, & Guich, 1987). Arambula, Peper, Kawakami, & Gibney (2001) recorded participants' self-reports and noted an increase in theta wave activity to be associated with pleasurable feelings following the meditation. Aftanas & Golosheykin (2005) found theta wave activity to correlate positively with subject's scores of their emotional experience. Yet subjective scores of thoughtless awareness correlated negatively with both theta and alpha power. This was interpreted by the authors to indicate that greater power (larger wavelengths) equals greater mental silence.

Hormonal Changes During Meditative Practices

TM (if not all) meditators may be less responsive to acute stress. While the exact mechanisms are not verified, researchers have discovered consistent patterns regarding the effects of meditative practices on known processes and agents of the stress response. The stress response itself is a function of stimulation of the sympathetic nervous system, preparing an organism to respond to a threat with fight (approach) or flight (avoidance) by mobilization of bodily resources through the Hypothalamic-Pituitary-Adrenal (HPA) Axis. The response occurs from a neuroendocrinological cascade of internal events: When threatening stimuli are perceived, the hypothalamus is stimulated to release Corticotropin-releasing hormone (CRH), Growth hormone-releasing hormone (GHRH), and Thyrotropin-releasing hormone (TRH). This effects stimulation of sympathetic nerve impulses to the viscera and muscles, causing the measurable physiological responses associated with stressful states: deactivation of the non-essential organ functions such as digestion, excretion, and reproduction. Blood vessels to the skin and viscera are constricted while those to the heart, lungs, brain, and skeletal muscles are dilated, increasing blood pressure and thereby flow of oxygen and nutrients in case of action and/or injury. The adrenal medulla, directly activated by the sympathetic nervous system, is likewise stimulated to release epinephrine and norepinephrine, which also prepares the body for increased activity.

CRH, GHRH, and TRH activate the anterior pituitary which then releases respectively, adrenocorticotropic hormone (ACTH), human growth hormone (hGH), and thyrotropin-stimulating hormone (TSH). These then initiate responses in target organs. hGH stimulates the liver's production of glucose for muscular consumption. TSH stimulates the release of thyroid hormones which assists the body's utilization of the increased glucose. ACTH stimulates the adrenal cortex to release the glucocorticoid, cortisol, which in turn facilitates the catabolism of proteins into amino acids, synthesis of glucose, metabolism of fatty acids, and production of glucose for repair of and energy supply to muscles and other tissues. There exists a vast body of literature devoted to the identification of cortisol as the critical component contributing to the adverse effects of stress, especially its suppression of the immune function (Tortura & Grabowski, 2003).

The stress response is an evolutionary adaptation designed for survival in threatening situations. This includes negative feedback mechanisms to shut off the response when the danger has past. If the organism remains in a constant state of perceived threat, the negative feedback mechanism is undermined. Well-suited to short-term threats, a sustained stress response has been found to exhaust the body's resources, thereby creating at best, uncomfortable mental states and at worst, potentially life-threatening disruptions to homeostasis (Benson & Klipper, 1975; Tortura & Grabowski, 2003; Pinel, 2006). Many studies focus on meditation's mitigation of the stress response.

While this is a study of neurological changes resulting from meditative practice, the physiological effects noted in studies included within this paper and elsewhere must also be considered as these states in turn interact with neurological responses. These include typical signs of parasympathetic stimulation such as decreases in heart rate, respiration rate, blood pressure (Kasamatsu & Hirai 1969; Werner et al., 1986; Jevning, Wells, Wilson & Guich, 1987; Mills, Schneider, Hill, Walton, & Wallace, 1989; Sudsuang, Chrentanez, & Veluvan, 1991; Infante, et al., 2001), and reduced hepatic metabolism (Jevning, Pirkle, & Wilson, 1977; Jevning, Wilson, & Davidson, 1978).

Based on previous findings that significant increases of plasma arginine (O'Halloran et al., 1985), acute reduction of blood cortisol, and increased prolactin secretion (Jevning, Wilson, & Davidson, 1978) influence decreases in the metabolic state of TM practitioners (6-10 years of experience), one study sought to evaluate the contributions of insulin and/or thyroid-related hormones to said decreased metabolic state. The authors found a modest decrease in Thyroid Stimulating Hormone (TSH) whose significance lay in the immediacy with which it occurred as well as the fact that practitioners' concentrations were already significantly lower than those of the control group. This was considered salient as decreased TSH is usually associated with increased cortisol, yet TM practitioners displayed lower rates of both cortisol and TSH. Normal concentrations of plasma TSH concentration are relatively stable, resisting modulation even by acute stressors. That T3, T4, and insulin concentrations remained stable during TM indicates reduced possibility of their roles in regulating either TSH or cortisol. It was suggested that the lower level of TSH in the experimental group was due to long-term TM practice chronically altering neural modulation of TSH secretion (Jevning, Wells, Wilson, & Guich, 1987).

In exploring the changes in sensitivity of epinephrine (adrenaline) receptors due to TM practice, Mills et al. (1989) found significant decreases in beta-adrenergic receptors, high-affinity receptors that function in the presence of high levels of epinephrine. This study was supported by Hoffman et al., (1982) (as cited in Mills et al., 1989) which revealed significantly heightened norepinephrine responses to orthostatic and isometric stressors in participants practicing a concentrative technique inducing the relaxation response as compared to resting controls, even though the two groups displayed nearly identical heart rates and blood pressure.

In their study of TM's effects on some hormonal aspects of the stress response, Infante and colleagues (1998) suggested that TM (concentrative) practice affects the negative feedback mechanism, sensitizing hypothalamic GABA receptors as well as cortisol receptors of the anterior pituitary, which then regulate release of the hormones ACTH and beta-endorphins. Noting significant changes in the neuroendocrine axis researchers found not only a decrease in ACTH production, but in blood plasma levels of beta-endorphin, a potent analgesic released in accord with the stress response in order to deal with potential pain of tissue injury (Infante et al, 1998).

In examination of the adrenal-medulla's role within the sympathetic nervous system Infante et al., (2001) found significantly lower morning levels of epinephrine and norepinephrine, evening levels of epinephrine in TM practitioners, and reductions in the percentage of beta-adrenergic receptors. This was theorized to contribute to reductions in high blood pressure (Infante et al., 2001). Jevning, Pirkle, & Wilson (1977) compared plasma concentrations of the amino acid, phenylalanine in long-term TM practitioners (3-5 yrs experience) to controls practicing the technique for the first time. Phenylalanine is utilized by the brain for protein synthesis and serves as a significant precursor for catecholamines. While no significant differences were found for short-term practitioners, the more experienced practitioners exhibited a marked increase in plasma concentrations. Citing previous works identifying metabolism of certain amino acids to behavioral states, the authors interpreted this change to result from a decline in brain utilization, suggesting a streamlining of neurological metabolism.

Though decreases in chronic cortisol levels seem to be ubiquitous with meditative practice, not all studies have found the same differences in cortisol responsiveness. For example, MacLean et al., (1996) performed a study of inexperienced participants. These were divided into two groups: one who learned and practiced TM technique and the control group who learned and practiced Stress Education Control (SEC), a stress education and management for 4 months. They found the expected lowering of both basal and average levels of cortisol in the new TM practitioners. However, they also displayed an increased cortisol response to acute stressors. This was interpreted as a "more adaptive, low-stress profile" which matches Sapolsky's findings of identical patterns in successful male baboons in the wild (as cited in MacLean et al., 1996). It also matches patterns of streamlined cortisol responsiveness to chronic and acute stressors exhibited by PTSD patients in Yehuda et al's study (as noted in MacLean et al., 1996).

Interestingly, for each of the variables measured, cortisol, TSH, GH, and testosterone, a unique pattern emerged. Overall, TSH and GH exhibited slight increases in the SEC group in response to stressors, and slight decreases in the TM group, but neither of these was significant. Greater testosterone levels in response to acute stressors were found in the TM group, also a pattern found by Sapolsky (as cited in Maclean et al., 1996) to be associated with successful male baboons in the wild, while lesser increases were found in the less successful baboons.

Sudsuang, Chrentanez, & Veluvan (1991) conducted a study of serum cortisol and total serum protein levels, blood pressure, pulse rate lung volume, and reaction time in 52 males with no prior meditation experience as they learned Buddhist Dammakaya meditation, a concentrative technique focusing on the mental image of a smooth, clear, glass sphere. The training program consisted of 4 hours of meditation per day for the first three weeks with a reduction to two hours per day for the remaining three weeks. This reduction in hours meditating was reflected in some of the measures taken.

The authors found serum cortisol levels to be reduced significantly after 3 weeks of training. By the sixth week, it had risen incrementally, but remained significantly lower than pre-training. The rise was attributed to the reduction of hours meditated. The authors found serum protein levels increased insignificantly after 3 weeks of training but rose significantly after 6 weeks. Blood pressure was found to be significantly reduced after 3 & 6 weeks of training although it was lowest after 3 weeks. The slight re-increase at 6 weeks was attributed to the reduction in hours meditated. Pulse rate declined significantly throughout the 6 weeks of training. While not definitive, an interesting self-reported measure of this study points to the potential for an individual proficiency for "effective" meditation, implying that some individuals may derive greater physiological benefit than others. (Sudsuang, Chrentanez, & Veluvan, 1991).

While the majority of studies have focused on the inhibitory effects of concentrative meditation on sympathetic stimulation not all practices entail decreased arousal. Some studies of absorptive meditation have reported signs of autonomic activation in experienced yogis. Corby, Roth, Zarcone, & Kopell (1978) assessed meditators' autonomic orienting responses to tones during the meditation period. The control group consisted of meditators who silently repeated a mantra while the experimental group practiced an intensive Tantric yoga technique practiced by spiritual group, Ananda Marga. Practitioners in the experimental group exhibited increased heart rate (although not significant), respiratory volume, and EEG measures (as noted in previous *EEG: Brain Activity* section).

Reviewing the growing body of literature suggesting meditation's contributions to a mediation of the stress response, Walton et al. (2004) sought to apply the findings to a similarly growing body of literature on susceptibility to a secondary effect of stress in post-menopausal women, cardiovascular disease (CVD). Noting the potential for TM practice to reduce stress response, the authors found that TM significantly reduced metabolically-induced elevations in cortisol with amount of time practicing the technique inversely correlating with measures of both intensity of heart disease and number of symptoms. The extended implication is that TM practice can reduce chances of CVD in this at-risk population.

There appears an additional possibility of arousal via a neuro-immunomodulation mechanism. It is well known that stress and cortisol in particular adversely impact functioning of the immune system. Conversely, lowered amounts of stress appear to support enhanced immune functioning. Kamei et al. (2000) observed an inverse correlation between cortisol levels and increases in temporal exhibition of frontal alpha wave activity during and after practice of yogic movements, postures, and breathing meditation. Citing a previous study correlating frontal alpha activity with increases in natural killer cells of the immune system, the authors proposed the possibility of a relationship between alpha wave activity and immune function.

Endocrine and Immune Systems in Meditative Practices

Secretion of Arginine Vasopressin (AVP) serves to regulate the pressure and volume of blood as well as other bodily fluids through its functions as a vasoconstrictor for the smooth muscles of the circulatory system. Additionally, it appears to play a role in the acquisition of new behavior patterns in states of stress. O'Halloran et al. (1985) tested a number of TM practitioners (5-10 yrs. experience) and found greatly increased levels of AVP with no corresponding increases in blood pressure.

With the large body of evidence pointing to meditation's beneficial physiological effects, both pre-emptive and remedial, it seems reasonable to conclude that efforts would be extended to capitalize on this. Orme-Johnson (1987) identified evaluated rates of utilization of claims of one health insurance group in comparison to the other such groups under the same carrier. The group, SCI, required members to have practiced TM for at least 6 months prior to application and to continue the practice in order to maintain benefit eligibility. Claim rates of SCI and the control, deemed Group Business (GB), were analyzed according to 18 categories. The results indicated SCI claims were significantly lower in 17 of the 18 categories, excluding only obstetric admission services. The categories and their percentage differences showed significantly decreased utilization of both inpatient and outpatient services. Lower rates were found in the following categories: (1) Intestinal by 49% (2) Nose, Throat, Lung by 73% (3) Heart by 87.3% (4) Genital/Urinary by 37% (5) Injuries by 63.2 % (6) Tumors by 55.4% (7) Bone/Muscle complaints by 67.6% (8) Ill-Defined conditions by 76% (9) Mental Disorders by 30.6% (10) Nervous System by 87.2% (11) Metabolism by 65.4% (12) Infectious Diseases by 30.4 % (13) Services Covered by Medicare by 100% (14) Congenital Disorders by 50.6% (15) Blood by 32.8% (16) Other by 91.2% (17) Skin by > 60%.

Overall, SCI's records demonstrated 63% lower utilization of inpatient medical care, 71.5% lower inpatient surgical care 58.8% lower outpatient medical care by TM practitioners. Combined inpatient and outpatient payout was 26.5 - 67.4% less for SCI than Group Business across each of the five years examined. Practitioners of the technique spent significantly fewer inpatient days in the hospital by: (1) 50.2% for children, 0-18 (2) 50.1% for adult, 19-39 (3) 68.4% for adults 40 and over. Outpatient visits (per 1000) were also found to be lower: (1) 46.8% for children 0-18 (2) 54.7% for adults 19-39 (3) 73.7% for adults 40 and over. The difference in health care utilization for those 0-18 and 19-39 was around 50 % less for SCI; whereas normally increased utilization made by the 40 and over group was 68.4% less for inpatient services and 73.7% less for outpatient services (Orme-Johnson, 1987).

Subjective Experience in Meditative Practices

The experience of pain carries with it intense emotional component, activating a pattern of related functional areas of the brain and driving the organism to escape the pain's immediate source. The thalamus, primary somatosensory cortex (SI), secondary somatosensory cortex-insula (SII-insula), the Anterior Cingulate Cortex (ACC) all activate in response to heat stimuli. The thalamus receives the signal from the spinal cord, directing it to the somatosensory areas responsible for bodily perception and to the ACC, which is associated with the characteristic urgent emotional component (Craig, Reiman, Evans, & Bushnell, 1996).

Kakigi et al., (2005) sought to identify patterns of neural activation within the brain of a highly experienced Yogi purported not to experience pain when in a meditative state. Brief laser stimulation was used to induce thermal pain on top of the hand and foot. Both subjective report and objective measures (fMRI, PET & MEG) identified the stimulus as inducing a high level of pain during the non-meditative state while no sensation at all or only one of light-touch was self-reported with fMRI showing a negligible increase in activation of SII-insula and ACC, but an incremental decrease in thalamic activity during the meditation. While there is insufficient data on such highly experienced practitioners to draw firm conclusions, it was speculated that the pain perceiving properties of the SII-insula and ACC may have been tempered by a plasticity resulting from the extensive training causing a “low signal-to-noise ratio” (Kakigi et al., 2005).

In their study exploring the more general neurological effects meditation has on the pain response, Orme-Johnson and colleagues (2006) recorded significant reductions in cerebral blood flow in the PFC and ACC in novice (control group) and highly experienced TM practitioners. While the control group achieved the same decreased levels of neural responsiveness as the long-term meditators, subjective reports indicated that the controls experienced greater intensity of pain than their counterparts although their neurological responses were highly similar. This suggests that the sensory experiences were equivalent, but the more practiced group was less disturbed (Orme-Johnson et al., 2006).

While this report attempts to confine the scope of its review to studies of neurological effects, it is impossible to speak separately of these and the cognitive/behavioral functions which they engender. Operational definitions such as Total Mood Disturbance represent the affective aspect of the neurological changes in question, in this case, chronic pain. Ambiguous and often idiopathic in nature, chronic pain is difficult to operationally define. Having formerly been characterized as pain lasting 6 months or more, it was more recently redefined as pain lasting longer than the expected duration of the natural healing process for that particular form of disease or trauma (Shipton & Tait, 2005).

One study of chronic pain utilized a ten week program to teach patients who had not responded to traditional medical care to apply mindfulness techniques to focus non-judgmental attention on their sensory experience of pain, effectively reducing the cognitive and affective dimensions of their pain experience. Kabat-Zinn and colleagues conducted three cycles of this program with follow–up questionnaires: at the end of the program, after 2.5 months, 7 months, and 11 months. The results were highly significant with greater than 50% of patients reporting at least 33% reduction in both present pain (PRI) and general body problems (BPPA). Approximately 50% were categorized as “moderate to great improvement.” Between 35% and 50% of each cycle’s patients rated themselves having undergone a more than 50% reduction on both PRI and BPPA. In each cycle, the average number of medical symptoms continued to lower from 29% to 46%, even after 10 weeks. For the first cycle, the reduction in symptoms increased with time to a level of 56% at the 7 month follow-up. In all three cycles, 55% of the patients reported symptom reductions 33% or greater at the end of the 10 week program and 33% reported 50 % reductions or higher. Measures of psychological symptomology were reduced in 57% of the patients of all cycles by 33% or more, while more than 50% of this symptomology were reduced in 32% by 50% or more. These were outstanding changes by even the most conservative measure.

Largest average reductions of the affective measure Total Mood Disturbance (TMD) occurred in the dimensions of depression, anxiety, obsessive-compulsive behavior, and somatization (Kabat-Zinn, 1982). Also reported were qualitative changes harder to quantify yet key indicators of the efficacy of mindfulness practice to improve quality of life. Growth was found in areas of self-esteem, communication and ability to cope with adversity. Supporting Kjaer et al.’s (2002) findings of meditative practice’s effects harmonizing neuronal circuits, participants reported increased occurrence of profound insights, patience, and a “willingness to live more in the present moment.” (Kabat-Zinn, 1982)

Longitudinal records of the participants, kept up to 18 months following the program, indicated not only perpetuation of these experiences but continued improvement as well.

Vietnam veterans participating in Brooks & Scarano's (1985) study of TM's effects on PTSD reported significant reductions in felt sense of rage, tension, and guilt. Many described their experience, "as if a huge burden had been lifted" (Brooks & Scarano, 1985).

Cognitive Functions and Meditative Practices

In response to uncomfortably loud tones, meditators exhibited higher physiological responsiveness to the stimuli, yet displayed fewer symptoms of cognitive anxiety with greater cognitive relaxation as indicated by the overt anxiety subscale of the IPAT, the State and Trait scales of the STAI and a post-experimental questionnaire (Lehrer, Schoikett, Carrington, & Woolfolk, 1979).

In their study of Zen monks, Kasamatsu & Hirai (1969) noted EEG records and subjective reports matched in participants' responses to constant audible clicks sounded throughout the meditations sessions. Normal alpha wave patterns appearing shortly after meditation began to be slightly disrupted by the click stimulation (referred to as alpha blocking), returning after a period of 2-3 seconds. The duration of alpha blocking steadily decreased in control subjects as their brains habituated to the clicks. Experienced priests (over 20 yrs practice) exhibited no habituation. Subjective reports indicate the perception of "clearer" awareness of stimuli and were neither "affected" or "disturbed" by it but were still free to respond (Kasamatsu & Hirai, 1969).

Long Term Changes and Meditative Practices

Lutz et al. (2004) examined brainwave synchronization in Buddhist practitioners (15-40 yrs experience) in order to examine the effects of extensive practice. Brain regions displaying the most distinctive patterns from controls were located over the medial frontoparietal cortices. Activity consisted of high gamma wave oscillations which are associated with higher-order integration of widely distributed neural assemblies regulating attention, conscious perception, working-memory, or learning. The gamma oscillations were relatively high even for this fast frequency, indicating widespread distribution of synchronizing neurons with an accelerated temporal precision. There is evidence that these synchronizations represent cumulative synaptic plasticity and coordination (Lutz et al., 2004).

Readings of fast gamma oscillations, distinct from activity recorded in the majority of meditation literature, were thought to result from the lack of analysis of other researchers for these faster rhythms. Additionally, the form of meditation practiced herein is likely significant: metta, or unconditional loving-kindness mediation, lacks a specific object of concentration. Rather, mental efforts are devoted to the general cultivation of a compassionate state of being. Lutz, et al. (2004) suggest that due to different mechanisms of cognitive activation involved, the two different meditative forms, object-focused (concentrative) and objectless (mindful), may produce correspondingly different EEG patterns.

Banquet (1973) observed a commonly identified pattern of meditators incurring more rapid anteriorisation of alpha rhythms during the meditative period in correlation with accrued experience. Of particular note was the maintenance of these wavelengths after the meditation had concluded and eyes were opened, in addition to the spreading of large amplitude alpha waves to the occipital region. Alterations in the quality of normal consciousness were reported in the findings of Corby, Roth, Zarcone, & Kopell (1978) noted in conjunction with the sustenance of theta power waves into daily activities.

Kasamatsu & Hirai's (1969) study of Zen monks showed a distinctive progression in both amplitude and immediacy of onset of specific brain states in correlation to years of training. Alpha wave patterns appeared earlier in the period of practice in addition to increases in alpha wave power and the appearance of rhythmical theta trains toward the end of meditation sessions. A study of highly experienced Tibetan Buddhist meditators displayed significantly lower thalamic laterality index than controls. Their practice entailed one hour a day, five days a week for over 15 years (Newberg et al., 2001).

An advanced form of the TM technique is TM-Sidhi, utilized only by more advanced practitioners. Studies of these individuals tend to support evidence of long-term effects of the technique. In one such study investigating the long-term effects of this technique on the endocrine system, Werner and colleagues (1986) found significant declines in hormones whose release is initiated by the stress response TSH, GH, & prolactin. The authors suggested the meditation effected a change in circadian secretion.

Lazar et al. (2005) documented changes in cortical thickness in experienced practitioners (Mean = 9 yrs) of Buddhist Insight meditation. As this is not a hierarchical or schedule-oriented process, the foci of awareness may be widely varied, potentially confounding researchers' attempts at establishing correlations between attentional experience and cortical changes.

A common focus of all practitioners is the sensory experience of the breathing process. Accordingly, the right anterior insula, associated with awareness of internally generated stimuli including respiration and the viscera, was found to exhibit the most significant differences between the control group and the practiced group. Increased volume of the inferior occipitotemporal visual cortex also correlated with physiological measures of experience though this was not explained. Additionally, cortical thickness in the dorsolateral and frontopolar regions of the prefrontal cortex (PFC) was found in the 40-50 yr old participants to closely resemble thickness of those regions in both participants and controls in the 20-30 yr old range. The authors suggested that this indicated an effect of meditation is to slow age-related neural degeneration.

The authors noted a more global pattern of cortical change when it was observed that most of the identified regions were within the right hemisphere, described by Posner and Peterson (as cited in Lazar et al., 2005) to be acutely responsible for sustaining attention. Furthermore, the dorsolateral prefrontal cortex and frontopolar regions of the PFC are associated with "the integration of emotion and cognition" (Lazar et al., 2005). This cognitive awareness of sense stimuli is suggested to increase practitioners' overall awareness, thereby facilitating a more adaptive approach to potential stress arising from daily encounters. Davidson et al. (2003) observed greater meditative experience to effect significant changes in anterior activation symmetry, suggesting a lasting benefit of meditation to increase communication between hemispheres.

DISCUSSION

Limbic stimulation of the frontal cortices, as with emotional arousal from a mental posture of anxiety or self-protection, induces desynchronization of regional EEG. This state of defensive vigilance, monitoring one's environment for threats, is mediated by meditation, allowing the limbic system to quiet and the cortical regions to become synchronous. The accompanying subjective state correspondingly transitions from a more intense, contracted experience to a more relaxed, open one. This state persists after the practice period, allowing the practitioner to navigate life's daily hurdles with flexibility.

From Lazar and colleagues' (2005) investigation of the effects of the cognitive and behavioral practice of meditation on cortical thickness, we can see its potential for top-down regulation of neurophysiology. Meditation itself is the practice of directing attention which, through repetition, facilitates cortical plasticity. An interesting implication here is that the intentional direction of cognitive processes influences the physical size of neural tissue.

When examined together, the correlational findings from Kamei et al. (2000), Carrington, & Woolfolk (1979), and Davidson et al. (2003) suggest that meditation-induced frontal lobe activation facilitates increases in positive affect as well as enhanced antibody-mediated immune response. In addition as demonstrating benefits of meditation, these findings support the relationship between positive mood and heightened immune response.

Meditation has numerous long term effects. While there may not exist conclusive data as to causality, the body of evidence points to definitive trends in inhibiting or resisting some age-related declines in endocrine function, motor reflex response, hypertension, loss of cognitive and perceptual faculties, and autonomic recovery following stressful stimuli, all serving to assist homeostatic return (Werner, 1986).

While much of the human brain's specific functions are not clearly understood, much of the specific nature of meditations' many varied neurological effects are also not understood. Yet the recurrent theme throughout all of these studies seems to be that meditation, whatever the form, provides a state of lowered arousal, a seemingly necessary antidote to the imbalanced and incessant stimulation inherent in our modern world. Innumerable studies illustrate the ways the chronic environmental stress most of us endure is destructive to our physical and mental well-being. An appropriate measure of this might be "quality of life." While we may not be certain yet of how and why, it is safe to conclude that meditation is beneficial for the body and its brain as evidenced by the myriad of physiological measures and beneficial for one's mental well-being, as evidenced by a vast body of subjective reports.

Research on meditation as an altered state of consciousness provides insight into neural correlates of cognitive processes such as attention, intentionality, and consciousness itself. It provides evidence of the malleable nature of cognitive and affective processes, provoking questions regarding new possibilities for therapeutic intervention in pathologies previously thought only remediable by psychopharmaceutical application.

While activation and de-activation of neuronal activity in specific regions seems to vary according to the particular focus of the meditative practice, frontal regions appear to be a common denominator in such fluctuation. Although most forms of meditation are relatively passive forms of consciousness, there is invariably volitional direction of the attention to the practices. Actions are sustained through intentionality and a practice which requires the practitioner to refrain from the habitual pull of unceasing stimulation, both internal and external, facilitates continual inhibition of the myriad impulses which vie for attention. Meditative practice appears to develop the capacity for sustained attention, regulation of mental faculties, enhance lowering of the autonomic stress response concomitant with an enhanced availability of both neurological and physiological resources, cultivation of emotional self-regulation and increased tolerance for both mental and physical discomfort.

With the vast majority of meditation literature describing a general pattern of reduction in cortisol and other stress hormone levels in conjunction with decreased physiological arousal, the appearance of some findings of heightened sympathetic response to acute stressors (Sinha et al., 1978; Sudsuang, Chrentanez, & Veluvan, 1991; MacLean et al., 1996) would seem to contradict this. The disparity is further complicated by reports of decreased habituation to acute stressors (Kasamatsu, 1969; Williams and West, 1975). Taken into consideration with self-reported experiences of mental calm and heightened awareness, the evidence suggests a higher potential for responsiveness resulting from a stable pool of bodily resources for allocation toward physical reaction to a stimulus. At the same time, a calmer state of mind, meaning lowered utilization of neurological resources, provides lowered reaction times with fewer perceptual errors. This suggests that meditation functions to lower the general "noise" level within the brain, allowing greater flexibility for fuller response to incoming stimuli. This would seem to serve an evolutionary benefit of having more neurophysiological and cognitive resources available to deal with novel situations. Social interaction may be facilitated as individuals respond to one another more empathically. Inverse correlations between meditative experience and diminished executive functioning of the prefrontal cortex suggest possible decreases in neural metabolism. This may contribute to the subsequent sense of restfulness accompanied by heightened awareness and increased concentrative ability. Decreased metabolism provides an opportunity for neurons to regenerate depleted resources and return to homeostasis.

A distinction may be found between concentrative techniques and mindfulness techniques in regards to receptiveness to stimuli. Those in occupations which require a vastly wider spectrum of response with less room for error, such as police officers or soldiers, requiring patience and diplomacy while maintaining the capacity for intense, immediate and forceful action, might benefit more from mindfulness techniques than from concentrative techniques which appear to generally decrease responsiveness. Their personal lives may benefit as well as meditation appears to enhance the ability to return to pre-arousal levels. This carries broader implications for individual interactions as well as society at large if component members are able to enter novel social situations free from stress accumulated from previous experiences.

From the pain perception experiment by Kakigi et al. (2005), some specific details may lead to more general application. The pain threshold of the Samrat Yoga Master was high enough to necessitate increase of the stimulus intensity by about 40%. Incorporation of this with evidence from other studies examining highly experienced practitioners (minimum 20 yrs practice) of other disciplines may reveal that extensive regulatory abilities result more from the length of practice than any particular technique.

One of the most significant cognitive aspects of the meditative experience is the facilitation of compulsive motivations into conscious awareness. Addiction to a particular avoidant behavior: ingesting cocaine, shopping, indignant rage, is neither ignored nor inhibited, but allowed to come forth into the neurological mechanisms providing for conscious awareness, allowing the felt sense of urgency to dissipate. Allowed to diffuse into the flow of neural circuitry like a spoonful of poison dropped into a river, the neurological patterns of compulsion disperse in the electro-chemical currents while neurotransmitters and neuromodulators otherwise expended in the synaptic substrates of these habitual responses may be conserved for more productive behaviors.

Much of the meditation research is documenting correlations between physiological phenomena and psychological phenomena, but still has yet to identify the actual causal relationships therein. In light of this, meditation research serves not only to explicate the neurophysiological substrates of meditation, but to provide an additional window illuminating brain function's role in consciousness and the ability of the individual consciousness to influence the anatomy and physiology of the brain.

Limitations of Current Research Methods

EEG has proven an invaluable tool for translating the brain's electrical impulses into visible records. Yet it is susceptible to contamination by local electrical activity at neuromuscular junctions (EMG) which can interfere with recording of neurological activity. EMG waves exhibit distinctive size and patterns so are usually recognized as such, but their presence may mask more subtle brainwaves.

While great technological advances have been made in observation capabilities each particular mechanism bears unique functional limitations. For example, fMRI may indicate increased activity in a particular region but may not be able to distinguish synaptic excitation from inhibition (Casey et al., 1994). Likewise, researchers' utilization of varying EEG sites in order to examine different neurological effects serves to complicate comparisons of brainwave activity.

Direction for Future Research

The large body of research conducted in the 1960's, '70's, and '80's was both exploratory and extensive. The data gathered from that period was hindered by a lack of the technology currently propelling neuroscience into new dimensions of scientific understanding. The data is now if not obsolete, at minimum incomplete and insufficient for integration into current models of neurophysiology and consciousness. A reinvestigation of previous findings will further refine current understanding of the neurological mechanisms of cognitive processes.

A greater number of comprehensive studies are required for more meaningful statistical analyses including contrasts between significant numbers of advanced and less proficient practitioners. This might also necessitate establishment of a standard of meditation experience. As was suggested by Arambula et al. (2001) some significant development may only take place after subjects attain high levels of proficiency. Obtaining an accurate understanding of the various forms of practice and their particular effects relies upon constructing a conceptual framework of meditation as a developmental trajectory, rather than just a particular state. Individual practices are going to interact with individual practitioner's physiological, psychoemotional and temperamental characteristics. This requires a dynamic model rather than a static list of causes and effects.

Different forms of meditation yield different effects on somatic physiology and neurophysiology. Different foci of attention correspond to activation of particular cerebral regions. These require diagramming. Certain meditative forms found to increase metabolism and states of arousal suggest that advanced meditation practices may yield different alterations in metabolism. The mechanisms involved in producing these effects remain unclear and invite further investigation.

Review of the literature uncovers a definite need to systemize findings on the basis of form or type of meditation, including such factors as intention (e.g., mindfulness vs. concentration or relaxation vs. arousal), physiological effect, brainwave activity, neurological effects, endocrinological effects, subjective experience, etc. and then place them on a temporal continuum.

Lineage of the nature-nurture question remains in the form of concerns regarding an innate physiological predisposition for meditative facility or whether the potential benefits rendered from the practice apply to all individuals equally. Concerns have been raised that if there exists a natural propensity for certain physiological of neurological effects, the validity of empirical data is threatened. Factors such as subjects' expectancy, belief systems, motivation and suggestibility may influence outcomes. These too need to be accounted for. Such concerns may be suitably addressed by utilizing larger populations in longitudinal studies whose duration is a matter of decades instead of months. Assessment of the subjective experience cannot be emphasized enough as this can provide critical background which establishes a matrix of neural correlation. It seems that future research on meditation would benefit from greater consultation with experienced meditation instructors in order to integrate this information.

Particular research can be done to follow up unresolved questions of previous findings. Insight into actual physiological interactions carries great potential for understanding neural development as well as profound implications for the treatment of traumatic brain injury. This highlights the most significant potential for meditation research in the discovery of therapeutic application for conditions which are presently not treatable due to limitations of current technology and understanding or which are simply limited in access by individuals who do not possess the resources to obtain such treatment.

Guidelines for eliminating confounds could be established, minimizing redundancies and incomparable data. Most studies do this for EEG or vital signs, but not for fMRI, PET, MEG, or SPECT. If these data are recorded only in individualized studies, they cannot be as useful as if they were in a centralized database. Consistency of meditation measures and methodologies across studies would likely necessitate the establishment of a specific institute or organization to coordinate the investigations. This organization could also serve as a storehouse of all related research gathered to date and provide access to that for researchers.

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