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The Physiology of Meditation: A Review. A Wakeful Hypometabolic Integrated Response

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JEVNING, R., R. K. WALLACE AND M. BIEDEBACH. *The Physiology of meditation: A review. A wakeful hypometabolic integrated response.* NEUROSCI BIOBEHAV REV **16**(3) 415–424, 1992.—While for centuries a wakeful and tranquil state or experience variously called "samadhi," "pure awareness," or "enlightenment" had been said to be a normal experience and the goal of meditation in Vedic, Buddhist, and Taoist traditions, there was little known about this behavior until recently, when the practice of "transcendental meditation" (TM) became available for study in Western scientific laboratories. Derived from the Vedic tradition, TM is unique because it requires no special circumstances or effort for practice. Based upon a wide spectrum of physiological data on TM, we hypothesize that meditation is an integrated response with peripheral circulatory and metabolic changes subserving increased central nervous activity. Consistent with the subjective description of meditation as a very relaxed but, at the same time, a very alert state, it is likely that such findings during meditation as increased cardiac output, probable increased cerebral blood flow, and findings reminiscent of the "extraordinary" character of classical reports: apparent cessation of CO_2 generation by muscle, fivefold plasma AVP elevation, and EEG synchrony play critical roles in this putative response.

Stress Hormones Behavior EEG Brain Muscle Circulation Red cell

MUCH of current basic understanding of human physiology, and of physiology in general, has been based upon study of acute states of activation such as stress, exercise, or physiological change associated with increased attentional demand. There is comparatively little known of physiological integration and regulation in acute states of decreased activation. Yet for centuries a wakeful and tranquil state or experience variously denoted "samadhi," "pure consciousness," or "enlightenment" has been said to be a common experience and the goal of meditation in Vedic, Buddhist, and Taoist traditions (1,55,58,89,90,108,109). We define meditation in general for the purpose of this review as a stylized mental technique from Vedic or Buddhist traditions repetitively practiced for the purpose of attaining a subjective experience that is frequently described as very restful, silent, and of heightened alertness, often characterized as blissful (1,41,65,79,90,108,109).

Most of the present text is about a particular stylized meditation practice known as "transcendental meditation" (TM), because a large proportion of physiological research on meditation has investigated this meditation technique (44–53, 56,84). Since the subjective description of TM as a very relaxed, blissful, and wakeful state (65,66) seems to agree generally with many classical descriptions of the goal of meditation in traditional literature, and since there is overlap of several objective characteristics, we believe meditation may be considered to be a definite category of experience.

Although meditation is centuries old, scientific study of meditation began only some 50 years ago. As early as 1935 a French cardiologist, Theresa Brosse, travelled to India to study the physiology of meditation. She reported that one of her subjects was apparently able to stop his heart (22). Some 20 years later, in an attempt to follow up and extend Brosse's original study, a team of American and Indian researchers investigated autonomic functions of yoga practitioners (5, 102). They found decreased respiratory frequency and increased skin resistance, but no consistent change of heart rate, blood pressure, or EEG, during physical and mental yoga exercise. The authors comment on the problems of obtaining and selecting expert subjects. Due to the authors' interest in phenomenal change associated with self-control (such as extreme decrease of heart rate), many of the subjects were primarily concerned with techniques of physical control, and it is possible that few of the subjects were actually experts in meditation.

Problems of precisely defining meditation in terms of its subjective characteristics, or its goals, problems of selecting subjects, and of measuring concomitants of meditation in a conventional and reproducible manner are found in most early research on yoga (13,57,71,80,81,90). Despite the numerous problems of this early research, one reported phenomenal result—markedly decreased sensitivity to ambient CO_2 noted by Vakil and Karambelkar et al. (57), among others—has a physiological basis identified in more recent studies that we will discuss in the review.

flowstate Czikszentmihalyi

In the area of electroencephalography, early studies are more consistent and, in general, show increased alpha and theta wave activity in yogic and Zen meditation techniques (2, 27,59). Other studies on Zen meditators showed such changes as significant decreases of respiration rate, oxygen consumption, and slight increase of pulse rate and blood pH during meditation (1,89).

Taken together, the consistent changes seen in Zen meditators and in several of the yoga meditators suggested the possible existence of a physiological pattern characterizing meditation. However, especially in the studies of various yoga practices, emphasis on manipulation of a set of physiological variables rather than study of meditation, constituted a severe limitation. Further, most meditation techniques in the past have been very rigorous and difficult, requiring isolation, special diet or lifestyle, and therefore, possible only in relatively remote circumstances such that expert subjects have often been unavailable for scientific evaluation. This situation changed in the late 1960's with the introduction of the technique known as Transcendental Meditation (TM) by Maharishi Mahesh Yogi (56,65,66,67).

This practice attracted scientific interest for several reasons. While claiming many of the traditional characteristics and benefits of meditation or yoga, it was novel in that no special circumstances for practice were required except conditions of comfortable sitting with closed eyes, and it was claimed that any normal individual capable of following simple instructions could easily become proficient without special diet or lifestyle. Also, instruction was in a highly standardized manner, resulting in large subject pool exhibiting apparently repeatable physiological effects. Regularly practiced twice daily, morning and evening for approximately 20 minutes, the technique utilizes a "mantra" or sanskrit sound (65,66). Allegedly effortless, TM is described as spontaneous perception of the mental sound or mantra without contemplation of, or concentration on it. The goal or end result of this process is a relaxed, peaceful mental state of heightened awareness.

During the past 10 years, a systematic, in-depth investigation of the TM technique has been undertaken. Evolution of research in the area has been characterized by utilization of increasingly sophisticated dependent measures and by much clearer definition of the independent variable by better control, more specific subject selection, and clearer subjective description of the meditative state.

In the review we ask whether there exists a pattern of physiological changes characterizing this behavior, what its significance may be, and what its relationship is to other states of decreased activation such as sleep and ordinary, unstylized rest. We consider in most detail acute or "state" effects of meditation, since fewer studies have been undertaken of long-term or "trait" effects.

The significance of study of this area is twofold. First, many individuals practice meditation on a regular basis, and therefore, the behavior is of intrinsic interest (56). Secondly, there is increasing evidence that beneficial medical and/or psychological effects may derive from meditation; therefore, identifying the causes of these benefits may have applied value.

For the purpose of this review it is important to define a particular subset of regular TM practitioners, the "long-term" subject. Defined as an individual who has been regularly eliciting this behavior for at least 5 years, the long-term subject usually is also an instructor of TM. This implies frequent extra meditation experience obtained at special "residence courses." Constituting an important resource in this field because of very long meditation experience, a large number of TM practitioners now fall into this category and most recent investigations have studied the long-term meditator.

OXYGEN CONSUMPTION AND RESPIRATION

In a series of early reports Wallace (92) and Wallace et al. (93,94) reported marked decrease of O_2 consumption and CO_2 elimination during 30 minutes of TM, while respiratory quotient remained unchanged. Respiration rate and minute ventilation also decreased significantly without significant change of arterial PO_2 and PCO_2. However, arterial pH declined slightly, indicating metabolic acidosis. Since plasma lactate also declined, the cause of the metabolic acidosis was unexplained. Several subsequent studies have replicated the findings of decreased oxygen consumption and respiration rate utilizing both open circuit and closed circuit techniques in intermittent (107) and continuous recording (16). The biochemical findings have also been followed up and are discussed below in a separate section.

More sophisticated studies of the respiratory concomitants of meditation became possible with increasing availability of long-term regular TM meditators, as defined in the introduction. Therefore, in a detailed study of respiration by Farrow and Hebert (33), more marked respiratory declines than reported previously were recorded during specific periods of TM, including 50% decline of respiration rate and 40% decline of oxygen consumption. They also noted several episodes of respiratory suspension and found high correlation of these episodes with subjective report of experience of pure consciousness. The respiratory suspension periods were not followed by compensatory hyperventilation in contrast with typical patterns of hyperventilation in sleep (83,86).

Several reports comparing respiratory changes during TM with those occurring during ordinary eyes-closed rest/relaxed states have appeared. Farrow and Hebert found much larger respiratory changes, including number and duration of breath stoppage periods, during TM as compared with relaxation (33). Wolkove et al. in a very recent study comparing TM in long-term meditators with unstylized, ordinary eyes-closed rest in non-meditators, reported significant mean declines of minute ventilation during 10-15 minutes of TM without significant change during rest (107). These authors also found reduced ventilatory response to CO_2 during TM, perhaps related to decreased sensitivity to high ambient CO_2 concentrations commented upon in classical studies (57,91), and to marked change of muscle metabolism of CO_2, discussed below. The reduced ventilatory response to CO_2 has been replicated by Kesterson et al. (59). In earlier research Dhanaraj and Singh (30) noted significant difference of respiratory decline between TM and ordinary rest, whereas Fenwick et al. (34) reported similar declines of oxygen consumption during both behaviors. A probable explanation for the discrepancies in the magnitudes and significance of respiratory change between some of the earlier studies and later reports is utilization of more experienced subjects in later research (and in some cases, use of longer TM periods), since several physiological changes have now been found to be enhanced in longer-term TM subjects and after longer practice periods (23,46,49,91).

Based upon the respiratory measurements, the hypometabolic state induced by TM seems therefore confirmed. Questions remain as to the relationship of this hypometabolism to that of ordinary rest and that of sleep. In long-term subjects data indicate much more marked hypometabolism and a characteristic respiratory suspension pattern associated with subjective report of experience of pure consciousness. Both respiratory suspension and decreased sensitivity to CO_2 are consistent with classical reports of the existence of phenomenal change in the physiology of the advanced meditator.

CIRCULATION AND TISSUE METABOLISM

Recent studies emphasizing more basic, and probably more discriminatory, dependent measures in study of meditation have been in the areas of metabolism and blood flow (43–53). Their goals have been to understand organ, tissue, and cellular changes underlying some of the general phenomenology described in earlier research, and further to resolve similarities and differences between meditation and other states of decreased activation, including ordinary relaxation and sleep. Almost all of them have studied long-term subjects during 30–40 minute meditation periods.

One of the first of these investigations was of blood amino acid metabolism motivated by the relevance of circulating amino acids to metabolism in general and to neurotransmitter metabolism in particular (44). Of 13 amino acids measured, phenylalanine concentration increased significantly in 3–5 yr meditators, (20% during TM compared to a pre-meditation period). No change of phenylalanine concentration accompanied TM in short-term meditators (6 months experience) nor during ordinary rest in separate subjects studied as their own controls prior to learning TM. While the origin of the altered metabolism of phenylalanine was difficult to explain, it was an effect apparently enhanced by longer-term TM practice. According to the authors, it was unrelated to the occurrence of sleep during TM, which was also monitored in the study.

In dye-dilution and radioactive clearance investigation of circulation (48), a small but significant increase of cardiac output has been reported during TM (15%), coupled with significant declines of renal and hepatic blood flow; it was hypothesized that increased brain and/or muscle and skin blood flow might account for the redistributed circulation. Since blood pressure does not change acutely during TM (93), it was also observed that increased cardiac output must be due to decreased vascular resistance. Analogous measurements during ordinary rest showed comparable decline of renal circulation only.

Another result of the blood flow study was confirmation of previously reported decline of arterial lactate during TM; due to the slight increase of cardiac output and redistributed circulation, it was surmised by the authors that the lactate decline might be due to increased perfusion (notably of muscle). For the purpose of measuring possible increase of muscle and/or skin blood flow and accompanying decreases of lactate generation, relative pulsatile blood flow, and tissue lactate generation by forearm were measured for 45 minutes during and 30 minutes after TM or rest in a different series of reports (50,51). Measurement of arteriovenous difference of oxygen content also enabled determination of forearm respiration. Each subject was studied analogously as his own control on a non-TM or nonrest occasion during which he or she read. The TM subjects were long-term practitioners (4–5 years of regular TM elicitation); the rest group was comprised of normal young adults studied prior to learning TM.

Marked decline of forearm oxygen consumption and decline of blood lactate accompanied TM without significant change of these parameters during rest; control occasions were unaccompanied by significant change in either TM or rest subjects. Neither forearm blood flow, nor forearm lactate generation, was altered significantly in any of the experiments, although forearm blood flow increased and forearm lactate production declined slightly during TM; increased cerebral blood flow was therefore hypothesized to account for the earlier observation of redistributed blood flow. Total sleep and sleep stage percentage were almost identical in TM and rest subjects, amounting to approximately 10% stage 1 without correlation with forearm respiratory change. In a followup to this study (106) an extraordinary alteration of intermediary metabolism as well as change of metabolic rate has now been demonstrated; cessation of CO_2 generation by forearm occurs after 20–30 minutes of TM, an effect that the authors believe is due to a shift toward increased fatty acid utilization and beta oxidation by muscle in the hypometabolism induced by meditation.

It was inferred from these data and an independent study (52) that since forearm lactate production changes little during TM, decreased muscle or skin lactate generation during TM cannot explain the rather large decline of serum lactate in this behavior. However, a significant fraction (30–50%) of total body oxygen consumption decline may be accounted for by the decrease of muscle respiration.

Recent studies suggest that the decrease in blood lactate may be due to changes in erythrocyte metabolism (52,53). Rapid decrease of whole blood and red cell glycolytic rate has been reported during TM, with slight increase accompanying rest. Since the red cell contributes a major proportion of total blood lactate content in man, it was concluded in these reports that decreased red cell glycolysis probably accounts for TM-induced decreased blood lactate. These studies also demonstrated that decreased red cell metabolism was probably plasma mediated and could not be explained as an epiphenomenon of blood gas changes. Since red cell gas transport is sensitively dependent upon its metabolic status, the authors concluded that this effect is unique and important for physiology in general, and for metabolic control in meditation in particular. Based upon the red cell investigation and blood hormone changes (discussed below), it was hypothesized that the metabolic effects of TM are modulated to significant degree by circulating plasma factor(s). Finally, decreased red cell metabolism and the shift toward increased fatty acid and utilization by muscle have been hypothesized to be components of an integrated response to spare glucose for increased cerebral activity during meditation [(43); and see "Meditation as an Integrated Response" below].

In summary, marked metabolic and circulatory changes accompany TM, especially in the long-term practitioner; virtually none of the effects can be accounted for by sleep and many do not accompany unstylized eyes-closed rest. The metabolic changes are probably mediated by circulating plasma effectors, and comprise an integrated "meditation response."

ENDOCRINE AND NEUROTRANSMITTER EFFECTS

Several research groups have investigated hormones and neurotransmitters or their metabolites during TM; additionally, some studies have compared meditation with other states of decreased activation. Adrenocortical activity has been particularly well-studied. Acute and marked decline of adrenocortical activity seems to be a confirmed accompaniment of 30 minutes of TM in long-term practitioners (19,20,46,70). However, Jevning et al. (46) and Bevan et al. (19,20) found no acute change of cortisol in either short-term meditators (less than 8 months experience) or during stylized or unstylized relaxation.

Longitudinal studies have reported decreased cortisol secretion in subjects practicing meditation, although the data are less clear than acute studies. In normal subjects Subrahmanyam and Potkodi reported significant decline of urinary-free cortisol levels in both novice and long-term TM subjects in a 6-month period (88); Bevan et al. (19) found significant negative correlation between urinary-free cortisol and length of TM experience, but levels were not significantly lower at the end of 8 months. Very recently, plasma cortisol and ACTH were found to decline significantly after 16 weeks of TM in comparison with blood levels in each subject studied as his own control prior to TM instruction (103). In a very interesting study of several clinical populations, Subrahmanyam and Potkodi (88) found that free cortisol declined from abnormally high levels in hyperaggressive patients, whereas in mental retards urinary-free cortisol increased from abnormally low levels. This later finding is one exception to generally decreased cortisol secretion with the TM technique.

Plasma catecholamines and/or urinary catecholamine data are conflicting with regard to the acute effects of TM. Michaels et al. (69) found a nonsignificant acute decrease, while Lang et al. (61) report *increased* plasma adrenaline in long-term subjects during TM, despite decreased heart rate. The latter authors hypothesize that the autonomic effects of TM may reflect a coupled modification of both sympathetic and parasympathetic activity rather than simply reduction or increase of sympathetic activity alone. In this regard, it may be important that Michaels et al. (70) reported significant increase of plasma renin during TM, since part of plasma renin's control is by renal sympathetic nerves.

The urinary metabolite of serotonin (5-hydroxyindole-3-acetic acid, 5-HIAA) was found to increase significantly after 30 minutes of TM (23,98). 5-HIAA levels were also higher in meditators than they were in rest subjects studied comparably throughout the experiment. These studies are examples of several which have reported apparently persisting or delayed effects of an acute TM period. Another example is the rapid increase of plasma prolactin immediately *after* 40 minutes of TM in both long-term and 6-month TM subjects (49); and also very recently (73) a 2-hour period of fivefold increased plasma levels of arginine vasopressin (AVP) has been associated with the usual morning TM period of the long-term subject. Unstylized rest was unaccompanied by changes of either prolactin or AVP.

Many other hormones have been reported unchanged in either chronic or acute studies of TM, including testosterone, growth hormone, insulin, thyroid hormones, T3 and T4, and luteinizing hormone (LH) (46,103). However, thyroid stimulating hormone (TSH) has been reported to decrease chronically and acutely (103).

As we have described, many hormone/neurotransmitter studies comparing meditation with either stylized or unstylized rest/relaxation practices have found differences between these procedures; differences were clearer when long-term meditators were studied. However, in conflict with the findings of Jevning et al. and Bevan et al., Michaels et al. reported a nonsignificant difference in the acute declines of plasma cortisol during TM and rest (70). The conflicting data of Michaels' investigation may be due to the failure of these authors to take into account the confounding effect of large circadian decline of cortisol in the morning when their study was conducted. It is possible that the magnitude of this decline made it impossible to distinguish statistically between the smaller differences found between TM and rest. They also did not include in their study a specific long-term practitioner group that was present in other cortisol studies.

With respect to the relationship of meditation to sleep, the rapid increase of plasma prolactin after cessation of TM is informative, since napping is accompanied by increased prolactin during the nap period with rapid decrease immediately after awakening (49,64). Also, acute decline of cortisol during meditation is distinctive since, despite the diurnal rhythm of cortisol, there is no specific relationship between sleep onset and cortisol secretion. Finally, with respect to contribution of sleep to observed hormonal changes, total sleep and sleep stage percentage during TM have been found uncorrelated with either plasma cortisol or prolactin variation.

In summary, most reported acute effects on cortisol and catecholamine secretion in normal individuals are consistent with decreased activation during meditation in the long-term subject. Chronic decrease of level of activation also seems to occur. An exception to this general characterization was the report by Lang of increased plasma catecholamine concentration during TM. Of other hormones studied, extraordinarily high concentration of arginine vasopressin associated with meditation is probably the most interesting effect; it is hypothesized by O'Halloran et al. (73) to play a role in mediation of TM's reportedly positive effects upon learning and memory. High levels of AVP in a condition of lessened activation is also of significance for basic understanding of control mechanisms of AVP secretion, since it has been previously thought that increased activation due to osmotic, psychological, or positional stress was the primary mechanism of increasing AVP secretion.

With respect to the relationship of meditation to sleep and unstylized rest, patterns of AVP, prolactin, and cortisol secretion during meditation in the very advanced subject seem distinctive; data comparing catecholamine effects between TM and rest are conflicting.

AUTONOMIC EFFECTS

Many reports of autonomic effects of meditation indicate decreased activation, including marked increase of galvanic skin resistance (GSR), decreased spontaneous electrodermal response (EDR), and decreased heart rate (38,42,73,74,93,94, 105). In comparing autonomic effects of different rest states, some studies have shown differences and others have not. For example Morse et al. (72), in a complex study, looked at four separate experimental groups (trained in the TM technique but not hypnosis, trained in autohypnosis, but not the TM technique, trained in both, trained in neither) over six different conditions including alert, meditating, relaxation, and hypnosis. Meditation periods were of 8 minutes duration. Subjects were not distinguished on the basis of meditation or relaxation experience. The autonomic indices measured were unable to distinguish among the different behaviors. On the other hand, GSR has been reported to increase much more during meditation than rest in many studies (73,74,105,107); and Farrow et al. (33) have found marked GSR increase (along with respiratory suspension) to characterize subjective report of experience of pure consciousness, the goal of meditation. It is probably important that studies finding differences between meditation and rest have in general used practice periods varying between 10 and 30 minutes.

Good agreement exists in comparison between different procedures with respect to their effects upon recovery from stress. Therefore, Orme-Johnson (74) reported significantly faster habituation of GSR fluctuation to a noxious tone stressor (100 dB, 0.5 s, 3000 Hz) in meditators than in non-meditators, and he also reported fewer multiple fluctuations in skin resistance during the recovery cycle. Goldeman and Schwartz (38), using measures of heart rate, phasic skin conductance, self report and personality scales, compared meditator and relaxation group response to stressful stimuli. Subjects either meditated or rested, after which they viewed a film depicting woodworking shop accidents as stressors. Increased heart rates returned to pre-stress levels more quickly, and phasic skin conductance response to stressor presentation habituated more rapidly in meditators than non-meditators. Finally, Michaels et al. (70), in study of adrenocortical response to venipuncture, reported no significant change of plasma cortisol in experienced meditators, in contrast with significant increase in non-meditators.

In a meta analysis of comparative effects of TM and ordinary rest on several autonomic variables, Dillbeck et al. (32) report no significant difference between the effects of these behaviors on heart rate or EDR, while, in agreement with several other findings, these authors report significantly larger effects of TM on GSR, oxygen consumption, and blood lactate.

In summary, the most distinctive autonomic effects of TM seem to be enhanced recovery from stressful stimulation measured by a variety of autonomic indices, including EDR, GSR fluctuation, and heart rate; and marked increase of GSR during TM.

EEG

Initial EEG studies of TM reported increased intensity (mean square amplitude) of slow alpha activity (8–9 Hz) in central and frontal regions, occasionally interspersed with high voltage frontal theta activity (93). Beta (12–14 Hz) and delta (2–4 Hz) waves either decreased or remained constant during meditation. Subsequent studies have in general replicated and extended these findings (6,7,9,10,39). Banquet et al. (6), in particular, reported three distinct stages of meditation: Stage 1 is characterized by frontal alpha which slowed in frequency and increased in intensity during TM; stage 2 is characterized by high voltage theta bursts; and in a few subjects, a period similar in description to that reported by Das and Gastaut (27) was observed, characterized by fast beta spindle bursts most predominantly in anterior channels, alternating with alpha or theta rhythms. Third stage activity correlated with subjective report of "deep meditation" or experience of pure consciousness and was accompanied by disappearance of tonic EMG (electromyograph) activity and very slow and shallow breathing. Behaviorally, subjects could respond readily and accurately to questions. Both theta activity of stage 2 and beta activity of stage 3 were unresponsive to click stimuli. Abundant high voltage theta burst activity has also been reported by Hebert and Lehman in a study of a large number of long-term subjects (36,40).

One of the most interesting and sophisticated areas of EEG research has been computerized measurement of phase coherence (2,4,29,33,39,63), or "synchrony," a related measure, in the EEG measured from two separate derivations. In brief, synchrony or phase coherence measures the degree to which EEG amplitude increase or decrease is occurring simultaneously from different spatial locations on the scalp of the subject. Its importance derives from numerous reports of markedly increased phase coherence or synchrony during meditation, especially in long-term subjects and particularly in alpha bands (2,4,14,31,33,39,63). Also, EEG coherence is a likely predictor of other behavioral or physiologic accompaniments of meditation. Therefore, Haynes et al. (39) and Orme-Johnson and Haynes (76) found significant correlation between EEG coherence, clearer experience of pure consciousness, and higher scores on the Torrance Test of Creativity; and Farrow and Hebert (33) and Badawi et al. (4) correlated increased EEG coherence with respiratory suspension and subjective reports of clear experience of pure consciousness.

Several EEG studies have compared meditation to sleep and/or relaxation. Banquet and Sailhan in a statistical analysis of the EEG (10) reported significant difference between meditation and eyes-closed rest and between meditation and light sleep with respect to the following parameters: depth of sleep coefficient, wakefulness coefficient, and relative proportions of alpha, beta, theta, and delta activities. Banquet and Sailhan also found significant difference between night sleep of meditators and non-meditating controls with respect to both total sleep and sleep stage duration (9). Theta burst activity, prevalent during meditation of long-term TM subjects, may be unique to meditation, since it is absent during relaxation and sleep in non-meditating subjects (40). EEG coherence has been reported by Levine (63) to decline markedly during drowsiness or sleep in meditators. Dillbeck and Bronson (31), Badawi et al. (4), and Levine (63) report greater EEG coherence intensity and coherence, particularly in frontal channels over a wider frequency range, during meditation than during eyes-closed relaxation. Badawi et al. (4) reported an apparently unique relationship between breath stopping and EEG coherence during meditation, in that intentional breath holding in relaxed controls was not accompanied by variation in the degree of coherence.

Probably the most controversial area of EEG research on meditation is in the relationship of meditation to sleep. Pagano et al. (77) reported that 40% of a TM period was comprised of sleep stages II, III, and IV. This study appears to be alone in its findings, however, since of the very many measurements of sleep content of a meditation period (6,7,9, 46,49,52,87), most have reported alpha and with some stage I drowsiness. In another exception amongst EEG studies, Fenwick et al. (34) reported that EEG patterns during TM were essentially identical with those of drowsiness and sleep stage I onset.

While many investigators have noted increased frontal alpha activity during TM, Stigsby et al. (87) reported no difference between meditation and relaxation in frontal alpha, although they corroborated earlier reports of alpha slowing. Morse et al. (72) and Stigsby et al. (87) reported no increase of EEG synchrony during meditation. Since these authors utilized visual examination of EEG records only, the relationship of these reports to previous computerized measures of EEG coherence or synchrony is unknown.

In summary, probable distinguishing features of the EEG of meditation include high voltage theta burst activity, and increased frontal alpha coherence which spreads to other frequencies. Fast beta and disappearance of tonic EMG in advanced stages of meditation has also been reported in a variety of studies. Behaviorally and physiologically, increased EEG coherence may be most significant in that this phenomenon correlates with subjective experience of pure consciousness and may be a predictor of other behavioral and physiological concomitants of meditation. Sleep or drowsiness may accompany meditation, but is unlikely to account for most of its reported electroencephalographic characteristics. Nowhere more clearly than in the area of understanding the EEG of meditation has been illustrated the importance for progress of 1) utilization of more sophisticated dependent measures, 2) study of long term subjects, and 3) correlation of dependent measures with subjective experience.

EVOKED POTENTIALS AND SENSORY AND MOTOR RESPONSES

Group differences and acute changes of sensory evoked potentials have been reported in studies of meditation. Visual and auditory evoked potential latencies have been reported to be shorter and, in the case of the visual evoked potential, the amplitude of response has been found to be larger in meditation, as compared with non-meditation control groups (8, 60,99). McEvoy et al. (68) reported brain stem auditory evoked potential changes in acute studies of meditation in long-term subjects, while Barwood et al. (11) found no change during TM in less experienced subjects. In related studies, alpha blocking due to visual stimuli was significantly different between meditation and non-meditation subjects (104), although alpha suppression by click stimuli was not different between rest and meditation states (12,100,101).

In sensory and motor studies decreased reaction time (3, 8), decreased latency and related measures of normal and Jendrassik patellar reflex responses (96), and faster recovery of paired Hoffman (H) reflex (39,95,96) have been reported in association with TM. Rapidity of recovery of the paired H reflex has also, in more detailed study of this parameter, been correlated with increased EEG coherence, subjective report of experience of pure consciousness, and several measures of creativity and academic performance (39,62). In a longitudinal study, Wallace et al. (95) found significantly faster recovery of paired H reflex in comparison with controls. Finally, Clements and Millstein have reported significant improvement of absolute hearing threshold in association with TM (24). Wallace has hypothesized (95,96) that the sensory and motor changes and their correlation with EEG coherence and performance measures is due to an increased degree of alertness associated with meditation.

CLINICAL AND AGING STUDIES

While it is beyond the scope of this report to review indepth the various clinical studies on the TM and TM-Sidhi program, a brief summary of these findings may provide a context in which to understand the significance of some of the physiological effects. A number of studies have specifically examined effects of regular TM elicitation on major cardiovascular risk factors such as hypertension, high cholesterol levels, and smoking. Four prospective longitudinal studies on hypertensive or borderline hypertensive patients have reported significant reduction of systolic and diastolic blood pressure in patients beginning the transcendental meditation program (15,17,21,25). Another study reported significant declines after 3 months but not after 6 months (73). Markedly lower blood pressure levels in comparison with normative values have been reported in older age groups regularly practicing TM (97). A very carefully controlled prospective longitudinal study by Cooper et al. (26) on the second cardiovascular risk factor, high cholesterol levels, showed significant improvement in hypercholesteranemia patients who began the TM program as compared to matched non-meditative controls. Finally, in a large retrospective study and in a smaller prospective study, significant decrease of cigarette smoking in TM subjects as compared to controls has been reported (18,28,78).

Other clinical studies have reported improvement in a variety of conditions in association with meditation, including asthma (105), insomnia, and abuse of several categories of nonprescribed drugs (84,85). One recent study reported a marked reduction in health care cost in subjects practicing the TM program as compared to a comparison group (75). In studies of TM and aging (95), long-term meditators have been reported to have significantly lower biological age in comparison with nonmeditator and general population norms. Significant correlation between length of meditation practice and younger biological age was also reported.

To the extent that many affective and organic disorders are related causally or, by association, to stress, decrease of adrenocortical activity and other indications of decreased stress may be related to health benefits reported for meditation. Certain specific effectors of better health in connection with meditation may already have been identified in such physiologic changes as decreased vascular resistance, increased cerebral perfusion and muscle relaxation.

STATE EFFECTS OF MEDITATION

While there are conflicting findings in individual areas of measurement, taken as a whole, data at several different levels of biological organization now support the probable existence of a distinct and reproducible pattern of physiological change corresponding to meditation (state effects), although, despite an explosion of physiological research, we still have little indepth understanding of this behavior. However, some conclusions can be drawn, and an initial picture of the acute physiology of meditation can be formed.

This description requires formulation of a few basic hypothesis. While these will not be accepted by everyone, and may well prove incorrect, it is hoped they will be heuristically useful. As noted in the beginning of the review, since most of the physiological research on meditation has been carried out on TM, it is not known whether other stylized practices may create the same physiology. Similarity of physiological changes reported during TM with many of those reported in earlier research on meditation supports a degree of congruence at least between the end state goals of various practices known as "meditation."

Summary

The subjective experience of what is described as "restful alertness" or "pure consciousness" by the long-term regular practitioner of TM, appears to be a patterned physiological response of overall decreased peripheral metabolism and activation in many of its features, including decreased whole body, muscle, and red cell metabolism, as well as decreased plasma thyroid and adrenocortical hormone secretion. Electrophysiologically, increased galvanic skin resistance and/or decreased phasic skin resistance response, and decrease or disappearance of the EMG, frequently reported accompaniments of meditation, are also qualities consistent with rest. Other changes that may be described as extraordinary include alteration of the nature of intermediary metabolism by muscle and red cell; and phasic five-fold elevation of AVP. Finally, while the meditation response may be very rapid, many careful studies seem to have found most clear cut effects after minimum TM periods of 15–30 minutes.

Repeated practice apparently increases magnitudes of such acute concomitants of meditation as periods of breath stoppage, decreased oxygen consumption, redistributed circulation to brain, decreased adrenocortical activity, and increased coherence across a wider range of frequencies in the electroencephalogram. Although little is yet known about long-term effects of meditation, reported endocrine and blood pressure changes in longitudinal studies are also consistent with decreased activation in normal individuals practicing meditation.

It is particularly with respect to decreased activation that there is some agreement between studies of diverse meditation practices, although properly controlled investigation of adequate numbers of subjects are few in most of the earliest research. For example, we have noted several reports of decreased respiration and increased galvanic skin response in Zen and Yoga meditators.

However, while decreased activation is apparently a necessary characteristic of meditation, it is not a sufficient one and therefore meditation is not "relaxation." Ordinary rest is also accompanied by declines of oxygen consumption and respiratory rate, according to several reports. However, effects on muscle metabolism, circulation, renin and AVP secretion, adrenocortical activity, interhemispheric EEG coherence, and subjective experience differ quantitatively and qualitatively between the two behaviors, with the proviso again that this conclusion is most clearly demonstrated in the long-term TM subject. Also, sleep is hypometabolic, but during meditation the effects on secretion of cortisol, prolactin, and AVP, as well as EEG activity, differ from those of sleep. As we shall speculate, these distinctions may be related to the defining subjective characteristics of the meditative state as described in the introduction: While it is tranquil, it is also described as an alert condition.

Meditation as an Integrated Response

It is at this juncture that it may be appropriate to attempt to unify some of these data. Presently, many attempts to understand and to compare meditation with other behavior utilize a undimensional hypothesis or paradigm: Meditation either is or is not "relaxation," and it is either greater or less in its relaxation effects than unstylized, ordinary rest of other behavior such as sleep. It now seems unlikely that the wide variety of basic physiological data on meditation that exists can be usefully comprehended in this way. Particularly to be mentioned in this regard are such findings as increased cardiac output, probable increased cerebral blood flow, increased plasma renin and prolactin, and findings reminiscent of the "extraordinary" character of classical reports: apparent cessation of CO_2 generation by muscle, decreased meditator sensitivity to end tidal CO_2 and five-fold elevation of plasma AVP. Finally, EEG, evoked sensory and motor response, and red cell metabolic data are not satisfactorily explained in terms of global "decreased activation."

We propose that many of these data can be understood in a hypothesis of *increased* central nervous activity during meditation with several of the wide variety of peripheral circulatory and metabolic changes subserving this increase. Increased cerebral blood flow, due to shunting of blood away from renal and hepatic circuits, supports such a hypothesis directly. That a coordinated circulatory response may be a significant aspect of meditation is supported by other data as well: the combination of decreased peripheral vascular resistance (indicated by increased cardiac output despite constant blood pressure) and increased levels of AVP and renin, perhaps serving to help maintain blood pressure under conditions of markedly reduced sympathetic activity. By sparing glucose, red cell and muscle metabolic changes can also be integrated within the putative response by postulating that they provide extra glucose for increased central nervous tissue utilization. This speculation is attractive, because red cell and nervous tissue have in common almost obligatory metabolic dependence upon glucose and together, in normal individuals, account for most of blood glucose consumption. With respect to muscle, a shift for beta oxidation of fatty acids would spare glucose and cease to generate CO_2. The hypothesized meditation response has a physiology analogous in several respects with other well described entities, especially REM and the diving reflex. In both of these peripheral activity is reduced to subserve either increase or maintenance of central activity in what have been described as "heart-brain preparations." This hypothesis of integrated regulation of metabolism during meditation to supply increased cerebral metabolism is described in detail by Jevning (43,54).

With respect to the EEG of meditation, there is also evidence of an "activated" aspect, corresponding to what subjects describe as "deepest" states of meditation. In studies we have reviewed by Hebert and Lehman and by Banquet of TM, such states are accompanied by high amplitude theta and/or fast frequency beta bursts consistent with activation. In agreement with the classical literature, beta bursts during "samadhi" were described by Das and Gastaut (27) as characterizing a state activated in its nature. Finally, as has already been remarked, decreased reaction time and other improvements in sensory and motor performance can be associated with a more alert state of the central nervous system.

For completeness, we note briefly here on other models that have been proposed in attempts to integrate some of the reported physiological data on meditation. In discussing possible neural mechanisms that might operate during yoga, Zen and TM meditation, Gellhorn and Kiely (37) formulated a model in terms of their own theories of balance of parasympathetic or trophotropic and sympathetic or ergotrophic states. They suggested that during meditation there is a predominant trophotropic state with weaker ergotrophic discharges which serve to maintain full awareness. Gellhorn hypothesized that ". . . reduction of the proprioceptive activation of the hypothalamus and the reticular formation in the relaxed state creates favorable conditions for cortical thought processes to go on without interference, while an adequate state of awareness is maintained by corticifugal impulses impinging on the reticular formation" (7). They also noted analogous aspects in the phenomenologies of REM and meditation.

Anand (2), in explaining the increased alpha wave activity in several yoga meditators, also speculates about the neurophysiology of meditation. He postulates that the brain activity of yogis during meditation is dependent upon the mutual influences between the ascending reticular activating system and the cortex, and is independent of activation of the reticular activating system through external and internal afferents. Wallace has also proposed a role for the reticular activating system, emphasizing the function of specific thalamic nuclei in generating alpha activity in the frontal cortex, and the hypothalamus in generating the integrated hypometabolic response seen during TM (35,37,82,87,88).

Banquet and Sailhan (10), based on their extensive EEG research, attempted to expand upon these early hypotheses in terms of specific patterns of neural activity. They suggest that since the EEG during the TM resembles a kind of diffuse recruiting response, meditation activates nonspecific thalamic nuclei while simultaneously blocking external synaptic inputs. This mode of closed-circuity functioning permits vigilance through cortical activation of the nonspecific thalamus.

Finally, Dillbeck and Orme-Johnson (32) note that in developing a neural model it is important to be familiar with the traditional theoretical framework of the TM technique. In particular the three most important concepts are: (a) there is a state of transcendental consciousness that is predicted to have unique physiological correlates, including global physiological integration characteristic of a restfully alert state rather than just reduced somatic arousal; (b) the TM technique is best viewed as a dynamical process with alternating substages of transcendental consciousness and physiological normalization; and (c) the regular practice of the TM technique is predicted to develop better health and adaptive efficiency.

CONCLUSION

Many problems exist in this field of research; and several primary questions, such as have been neatly summarized by Davidson (28) almost a decade ago, still remain unanswered, despite an avalanche of data. Among these are considerations of motivation, control, and selection. The meditator represents an individual who has repeatedly elicited a rest state—in the case of the long-term subject—for 4–10 years now. A question therefore arises: Is the pattern of physiologic response associated with meditation unique to meditation, or might any relaxation condition repeated for several years yield the same response? The answer to this question is unknown. However, this question is different from one with which it is often confused and which we believe can be answered affirmatively: the question of whether a physiology different from that of other behavior, such as sleep and ordinary or unstylized rest, can be reproducibly elicited by meditation and studied in the laboratory.

Although facts therefore support the relevance of physiology to meditation (and, indeed, the relevance of meditation to physiology), the precise relationship of physiology to the unique subjectivity of meditation remains a primary research question. However, progress has been made in identifying probable objective markers of clear experience of samadhi or pure consciousness, viz., respiratory suspension, increased GSR, and EEG coherence; and of more favorable circumstances for the study of samadhi, such as meditation periods of at least 15–30 minutes and investigation of the long-term TM subject. Utilization of these findings, coupled with the increasing availability of more experienced meditators and focus on more in depth measurements, should allow more precise physiological understanding of samadhi, the subjectively identifiable goal of meditation.

REFERENCES

1. Akishige, Y. A historical survey of the psychological studies in Zen. Kyushu Psychological Studies, V. Bull. Faculty Lit. Kyushu Univ. 11:1–56; 1968.
2. Anand, B. K.; China, G. S.; Singh, B. Some aspects of electroencephalographic studies on yogis. Electroencephalogr. Clin. Neurophysiol. 13:452–456; 1961.
3. Appelle, S.; Oswald, L. E. Simple reaction time as a function of alertness and prior mental activity. Percept. Mot. Skills 38(3, pt. 2):1263–1268; 1974.
4. Badawi, K.; Wallace, R. K.; Rouzere, A. M.; Orme-Johnson, D. Electrophysiological changes during periods of respiratory suspension in the transcendental meditation technique. Psychosom. Med. 46:267–276; 1984.
5. Bagchi, B. K.; Wenger, M. A. Electrophysiological correlates of some yogi exercises. Electroencephalogr. Clin. Neurophysiol. (Suppl)7:132–149; 1957.
6. Banquet, J. P. EEG and meditation. Electroencephalogr. Clin. Neurophysiol. 33:454; 1972.
7. Banquet, J. P. Spectral analysis of the EG in meditation. Electroencephalogr. Clin. Neurophysiol. 35:143–151; 1973.
8. Banquet, J. P.; Bourzeix, J. C.; Leseure, N. Potentiels evoques et etats de vigilance induits au cours d'epreuves de temps de reaction de choix. Rev. Electroencephalogr. Neurophysiol. Clin. 19:221–227; 1979.
9. Banquet, J. P.; Sailhan, M. EEG analysis of spontaneous and induced states of consciousness. Rev. Electroencephalogr. Neurophysiol. Clin. 4:445–453; 1974.
10. Banquet, J. P.; Sailhan, M. Quantified EEG spectral analysis of sleep and transcendental meditation. In: Orme-Johnson, D. W.; Farrow, J. T., eds., Scientific research on the transcendental meditation program: Collected papers (vol. 1), Livingston Manor, NY: MIU Press; 1977.
11. Barwood, T. J.; Empson, J. A. C.; Lister, S. G.; Tilley, A. J. Auditory evoked potentials and transcendental meditation. Electroencephalogr. Clin. Neurophysiol. 15:671–673; 1978.
12. Becker, D. E.; Shapiro, D. Physiological responses to clicks during Zen, yoga, and TM meditation. Psychophysiology 18: 694–699; 1981.
13. Behanam, K. T. Yoga, a scientific evaluation. New York: MacMillan; 1937.
14. Bennett, J. E.; Trinder, J. Hemispheric laterality and cognitive style associated with transcendental meditation. Psychophysiology 14:293–296; 1976.
15. Benson, H.; Rosner, B. A.; Marzetta, B. R.; Klemchuk, H. P. Decreased blood pressure in borderline hypertensive subjects who practiced meditation. J. Chron. Dis. 27:163–171; 1974.
16. Benson, H.; Stewart, R. F.; Greenwood, M. M.; Klemchuk, H.; Peterson, N. Continuous measurement of O_2 consumption and CO_2 elimination during a wakeful hypometabolic state. J. Hum. Stress 1:37–44; 1975.
17. Benson, H.; Wallace, R. K. Decreased blood pressure in hypertensive subjects who practiced meditation. Circulation 45–46(Suppl.): 516(a); 1972.
18. Benson, H.; Wallace, R. K. Decreased drug abuse with transcendental meditation: A study of 1,862 subjects. In: C. J. D. Zarafonetis ed. Drug abuse: Proceedings of the international conference, Philadelphia, PA: Lea and Febiger; 1972:369–376(b).
19. Bevan, A. J. W. Endocrine changes in Transcendental Meditation. Clin. Exp. Pharmacol. Physiol. 7(1):75–76; 1980.
20. Bevan, A. J. W.; Young, P. M.; Wellby, M. L.; Nenadovic, P.; Dickins, J. A. Endocrine changes in relaxation procedures. Paper presented at the meeting of the endocrine Society for Australia, August; 1976.
21. Blackwell, B.; Hanenson, I. B.; Bloomfield, S. S.; Magenheim, H. G.; Nidich, S. I.; Gartside, P. Effects of transcendental meditation on blood pressure: A controlled pilot experiment. Psychosom. Med. 37:86; 1975.
22. Brose, T. A psychophysiological study. Main Curr. Mod. Thought 4:77–84; 1946.
23. Bujatti, M.; Riederer, P. Serotonin, noradrenaline, and dopamine metabolites in the transcendental meditation technique. J. Neural Transm. 39:257–267; 1976.
24. Clements, G.; Milstein, S. L. Auditory thresholds in advanced participants in the transcendental meditation program. In: Orme-Johnson, D. W.; Farrow, J. T., eds. Scientific research on the transcendental meditation program: Collected papers (vol. 1), Livingston Manor, NY: MIU Press; 1977.

25. Cooper, M. J.; Aygen, M. M. Effects of meditation on serum cholesterol and blood pressure. J. Isr. Med. Assoc. 95:1-2; 1978.
26. Cooper, M. J.; Aygen, M. M. A relaxation technique in the management of hypercholesterolemia. J. Hum. Stress 5(4):24-27; 1979.
27. Das, N. N.; Gastaut, H. Variations de L'Activite Electrique du Cerveau du Coeur et des Muscles quelletiques au Cours de la meditation et de l'extase yogique. Electroencepholog r. Clin. Neurophysiol. 6(Suppl.):211-219; 1957.
28. Davidson, J. M. The physiology of meditation and mystical states of consciousness. Perspect. Biol. Med. 19:345-380; 1976.
29. Davis, H.; Davis, P. A.; Loomis, A. L.; Harvey, F. N.; Gobarat, G. Changes in human brain potentials during the onset of sleep. Science 86:448-450; 1937.
30. Dhanaraj, V. H.; Singh, M. Reduction of metabolic rate during TM. Scientific Research on the transcendental meditation program: Collected papers (vol. 1) Pheinweiler, Germany: MERU Press; 1976.
31. Dillbeck, M. C.; Bronson, E. C. Short-term longitudinal effects of the Transcendental Meditation technique on EEG power and coherence. Int. J. Neurosci. 14:147-151; 1981.
32. Dillbeck, M. C.; Orme-Johnson, D. W. Psychological differences between transcendental meditation and rest. Am. Psychol. 42:879-881; 1987.
33. Farrow, J. T.; Hebert, R. Breath suspension during the transcendental meditation technique. Psychosom. Med. 44(2):133-153; 1982.
34. Fenwick, P. B. C.; Donaldson, S.; Gillis, L.; Bushman, J.; Fenton, G. W.; Perry, I.; Tilsley, C.; Serafinowicz, H. Metabolic and EEG changes during transcendental meditation. Biol. Psychol. 5:101-118; 1977.
35. Figar, S. Conditional circulation responses in men and animals. In: Hamilton, W. F., ed. Handbook of physiology: Circulation. Washington, DC: Am. Physiol. Soc., 1969, sect. 2, vol. III, p. 1991.
36. Garoutte, B.; Aird, R. B. Studies on the cortical pacemaker: Synchrony and a-synchrony of bi-laterally recorded alpha and beta activity. Electroencephalogr. Clin. Neurophysiol. 10:259-268; 1958.
37. Gellhorn, E.; Kiely, W. F. Mystical states of consciousness: Neurophysiological and clinical aspects. J. Nerv. Ment. Dis. 154(6):399-405; 1972.
38. Goleman, D.; Schwartz, G. Meditation as an intervention in stress-reactivity. J. Consult. Clin. Psychol. 44(3):456-466; 1976.
39. Haynes, C. T.; Hebert, J. R.; Reber, W.; Orme-Johnson, D. The psychophysiology of advanced participants in the TM program: Correlations of EEG coherence, creativity, H reflex and transcendental consciousness. Scientific research on the transcendental meditation program: Collected papers (vol. 1) Pheinweiler, Germany: MERU Press; 1976.
40. Hebert, R.; Lehmann, D. Theta bursts: An EEG pattern in normal subjects practicing the transcendental meditation technique. Electroencephalogr. Clin. Neurophysiol. 42:397-405; 1977.
41. Hoenig, J. Medical research on yoga. Confina Psychiatrica 11: 69-89; 1968.
42. Holmes, D. J.; Solomon, S.; Cioppro, B. M.; Greenberg, J. L. Effects of TM and resting on physiologic and subjective arousal. J. Pers. Soc. Psychol. 44:245-252; 1980.
43. Jevning, R. Interated metabolic regulation during acute rest states in man, similarity to fasting: A biochemical hypothesis. Physiol. Behav. 43:735-737; 1988.
44. Jevning, R.; Pirkle, H. C.; Wilson, A. F. Behavioral alteration of plasma phenylalanine concentration. Physiol. Behav. 19:611-614; 1977.
45. Jevning, R.; Wilson, A. F. Behavioral increase of cerebral blood flow. Physiologist 21(4):60(a); 1978.
46. Jevning, R.; Wilson, A. F.; Davidson, J. M. Adrenocortical activity during meditation. Horm. Behav. 10:54-60; 1978.
47. Jevning, R.; Wilson, A. F.; Smith, W. R. The Transcendental Meditation technique, adrenocortical activity, and implications for stress. Experientia 34(5):618-619; 1978.
48. Jevning, R.; Wilson, A. F.; Smith, W. R.; Morton, M. E. Redistribution of blood flow in acute hypometabolic behavior. Am. J. Physiol. 235:R89-R92; 1978.
49. Jevning, R.; Wilson, A. F.; Vanderlaan, E. F. Plasma prolactin and growth hormone during meditation. Psychosom. Med. 40: 329-333; 1978.
50. Jevning, R.; Wilson, A. F.; O'Halloran, J. P.; Muscle and skin blood flow and metabolism during states of decreased activation. Physiol. Behav. 29:343-348; 1982.
51. Jevning, R.; Wilson, A. F.; O'Halloran, J. P.; Walsh, R. N. Forearm blood flow and metabolism during stylized and unstylized states of decreased activation. Am. J. Physiol. 245:R110-R116; 1983.
52. Jevning, R.; Wilson, A. F.; Pirkle, H.; O'Halloran, J. P.; Walsh, R. N. Metabolic control in a state of decreased activation: Modulation of red cell metabolism. Am. J. Physiol. 245: C457-461; 1983.
53. Jevning, R.; Wilson, A. F.; Pirkle, H.; Walsh, R. N. Modulation of red cell metabolism by states of decreased activation: Comparison between states. Physiol. Behav. 35:679-682; 1985.
54. Jouvet, M. Recherches sur les structures nerveuses et les mecanismes responsables des differents phases du sommeil physiologique. Arch. Ital. Biol. 100:125-206; 1962.
55. Kanellakos, D. P. Transcendental consciousness: Expanded awareness as a means of preventing and eliminating the effects of stress. In: Speilberger, C. D.; Sarason, I. G., eds. Stress and anxiety Vol. 5. Washington, DC: Hemisphere Publishing Co.; 1978.
56. Kanellakos, D. P.; Lukas, J. S. The psychobiology of transcendental meditation: A literature review. Menlo Park, CA: W. A. Benjamin; 1974.
57. Karambelkar, P. V.; Vinekar, S.; Bhole, M. Studies on human subjects staying in an airtight pit. Indian J. Med. Res. 56:1282-1288.
58. Kasamatsu, A.; Hirai, T. An electroencephalographic study on the Zen meditation (Zazen). Folia Psychiatr Neurol. Japon. 20: 315-336; 1966.
59. Kesterson, J.; Clinch, N. F. Metabolic rate, respiratory exchange ratio and apnea during meditation. Am. J. Physiol. R256:632-638; 1989.
60. Kobal, G. A.; Wandhoefer, A.; Plattig, K. H. EEG power spectra and auditory evoked potentials in transcendental meditation. Pflugers Arch. 359:191; 1975.
61. Lang, R.; Dehof, K.; Meurer, K. A.; Kaufman, W. Sympathetic activity and transcendental meditation. J. Neural Transm. 44: 117-135; 1979.
62. Legrand, P.; Toubol, M.; Barrabino, J.; Darcourt, G.; Fadeuilhe, A. Contingent negative variation in meditation. Electroencephalogr. Clin. Neurophysiol. 43:532-533; 1977.
63. Levine, P. H. The coherence spectral array (COSPAR) and its application to the studying of spatial ordering in the EEG. Proceedings of the San Diego Biomedical Symposium, 15:237-247; 1976.
64. Loomis, A. L.; Harvey, E. N.; Hobart, G. A. Potential rhythms of the cerebral cortex during sleep. Science 81:597-598; 1935.
65. Maharishi Mahesh Yogi. On the Bhagavad Gita. Baltimore, MD: Penguin; 1969.
66. Maharishi Mahesh Yogi. Transcendental meditation. New York: Signet Books; 1971.
67. Maharishi Mahesh Yogi. Enlightenment and invincibility. Rheinweiler, Germany: MERU Press; 1978.
68. McEvoy, T. M.; Frumkin, L. R.; Harkins, S. W. Effects of meditation on brainstem auditory evoked potentials. Int. J. Neurosci. 10:165-170; 1980.
69. Michaels, R. R.; Huber, M. J.; McCann, D. S. Evaluation of transcendental meditation as a method of reducing stress. Science 192:1242-1244; 1976.
70. Michaels, R. R.; Pano, J.; McCann, D. S.; Vander, A. J. Renin, cortisol and aldosterone during transcendental meditation. Psychosom. Med. 41:50-54; 1979.

71. Miles, W. Oxygen consumption during three yoga-type breathing pattern. J. Appl. Physiol. 19:75-82; 1964.
72. Morse, D. R.; Thorton, S.; Furst, M. L. A physiological and subjective evaluation of meditation, hypnosis and relaxation. Psychosom. Med. 39:304-324; 1977.
73. O'Halloran, J. P.; Jevning, R.; Wilson, A. F.; Skowsky, R.; Alexander, C.; Walsh, R. N. Major behaviorally induced potentiation of arginine vasopressin secretion. Physiol. Behav.; in press.
74. Orme-Johnson, D. W. Autonomic stability and transcendental meditation. Psychosom. Med. 35:341-349; 1973.
75. Orme-Johnson, D. W. Medical care utilization and the transcendental meditation program. Psychosom. Med. 49:493-507; 1987.
76. Orme-Johnson, D. W.; Haynes, C. T. EEG phase coherence, pure consciousness, creativity and TM-Sidhi experiences. Int. J. Neurosci. 13:211-217; 1981.
77. Pagano, R. R.; Rose, R. M.; Stivers, R.; Warrenberg, S. Sleep during transcendental meditation. Science 181:308-310; 1976.
78. Pollack, A. A.; Weber, M. A.; Case, D. B.; Laragh, J. H. Limitations of transcendental meditation in the treatment of essential hypertension. Lancet: 71-73; 1977.
79. Radhakrishnan, S. The principal Upanishads. New York: Humanities Press; 1974.
80. Rao, S. Metabolic cost of head-stand posture. J. Appl. Physiol. 17:117-118; 1962.
81. Rao, S. Oxygen consumption during yoga-type breathing at altitudes of 520m and 3900m. Indian J. Med. Res. 56:701-705; 1968.
82. Reddy, M. K. Acute effects of the transcendental meditation technique on selected psychophysiological parameters and performance. Oslo, Norway: Norwegian Coll. of Phys. Ed. and Sports; 1976. Dissertation.
83. Robin, E. D.; Whaley, R. D.; Crump, C. H.; Travis, D. M. Alveolar gas tensions, pulmonary ventilation and blood pH during physiologic sleep in normal subjects. J. Clin. Invest. 37:981-989; 1958.
84. Shafii, M.; Lavely, R. A.; Jaffe, R. D. Meditation and marijuana. Am. J. Psychiatry 131:60-63; 1974.
85. Shafi, M.; Lavely, R. A.; Jaffe, R. D. Meditation and the prevention of alcohol abuse. Am. J. Psychiatry 139:942-945; 1975.
86. Snyder, F.; Hobson, J. A.; Morrison, D. F.; Goldfrank, F. Changes in respiration, heart rate, and systolic blood pressure in human sleep. J. Appl. Physiol. 19:417-422; 1964.
87. Stigsby, F.; Rodenberg, J. C.; Moth, H. B. Electroencephalographic findings during mantra meditation (transcendental meditation)—a controlled, quantitative study of experienced meditators. Electroencephalogr. Clin. Neurophysiol. 51:434-442; 1981.
88. Subrahmanyam, S.; Potkodi, D. Neurohumoral correlates of transcendental meditation. J. Biomed. 1:73-88; 1980.
89. Sugi, Y.; Akutsu, K. Studies on respiration and energy-metabolism during sitting in Zazen. Res. J. Phys. Ed. 12:190-206; 1968.
90. Swami Prabhavananda. The Eternal companion. Hollywood, CA: Vedanta Press; 1970.
91. Vakil, R. Remarkable feat of endurance of a yogi priest. Lancet 2:871; 1950.
92. Wallace, R. K. Physiological effects of transcendental meditation. Science 167:1251-1254; 1970.
93. Wallace, R. K.; Benson, H.; Wilson, A. F. A wakeful hypometabolic physiologic state. Am. J. Physiol. 221(3):795-799; 1971.
94. Wallace, R. K.; Benson, H. The physiology of meditation. Sci. Amer. 262(2):84-90; 1972.
95. Wallace, R. K.; Dillbeck, M. C.; Jacobe, E.; Harrington, B. The effects of the transcendental meditation and TM-Sidhi program on the aging process. Int. J. Neurosci. 16(1):53-58; 1982.
96. Wallace, R. K.; Mills, P. J.; Orme-Johnson, D. W.; Dillbeck, M. C.; Jacobe, E. Non-pharmacologic modification of the paired H-reflex in normal subjects practicing meditation. Exp. Neurol.; in press.
97. Wallace, R. K.; Silver, J.; Mills, P. J.; Dillbeck, M. C.; Wagner, D. Effects of long-term practice of the transcendental meditation and TM-Sidhi program on systolic blood pressure. Psychosom. Med. 45(1):41-46; 1983.
98. Wallace, R. K.; Simon, B.; Guich, S.; Tomlinson, P. F.; Petrick, L.; Beth, S.; Walton, K. G. Rise in urinary 5-hydroxyindoleaceatic acid (5-HIAA) associated with practice of the transcendental meditation program. Soc. Neurosci. Abs. 6: 725; 1980.
99. Wandhoeffer, A.; Kobel, G.; Plattig, K. H. Decrease of latency of auditory evoked potentials in humans practicing transcendental meditation. EEG/EMG 7(2):99-103; 1976.
100. Warshal, V. Effect of TM on normal and Jendrassik reflex time. Percept. Mot. Skills 50:1103-1106; 1980.
101. Wenger, M. A.; Bagchi, B. K. Studies of autonomic functions in practitioners of yoga in India. Behav. Sci. 6:312-323; 1961.
102. Wenger, M. A.; Bagchi, B. K.; Anand, B. K. Experiments in India on "voluntary" control of the heart and pulse. Circulation 24:1319-1325; 1961.
103. Werner, O.; Wallace, R. K.; Charles, B.; Janssen, G.; Chalmers, R. Endocrine balance and the TM-Sidhi programme. Scientific research on the transcendental meditation program: Collected papers (vol. 2). Rheinweiler, Germany: MERU Press; in press.
104. Williams, P.; West, M. EEG responses to photic stimulation in persons experienced at meditation. Electroencephalogr. Clin. Neurophysiol. 39:519-522; 1975.
105. Wilson, A. F.; Honsberger, R.; Chiu, J. T.; Novey, H. S. Transcendental meditation and asthma. Respiration 32:74-80; 1975.
106. Wilson, A. F.; Jevning, R.; Guich, S. Marked reduction of forearm carbon dioxide production during states of decreased metabolism. Physiol. Behav. 41:347-352; 1987.
107. Wolkove, N.; Kreisman, H.; Darragh, D.; Cohen, C.; Frank, H. Effect of transcendental meditation on breathing and respiratory control. J. Appl. Physiol.: Respirat., Environ. Exercise Physiol. 56:607-612; 1984.
108. Yogananda, Paramahansa. Autobiography of a Yogi. Los Angeles, CA: SRF Publishers; 1972.
109. Zimmer, H. Philosophies of India. Princeton, NJ: Princeton University Press, 1951:455.