

A wakeful hypometabolic physiologic state

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WALLACE, ROBERT KEITH, HERBERT BENSON, AND ARCHIE F. WILSON. *A wakeful hypometabolic physiologic state.* Am. J. Physiol. 221(3): 795-799. 1971.—Mental states can markedly alter physiologic function. Hypermetabolic physiologic states, with increased oxygen consumption, accompany anticipated stressful situations. Hypometabolic physiologic changes, other than those occurring during sleep and hibernation, are more difficult to produce. The present investigation describes hypometabolic and other physiologic correlates of a specific technique of meditation known as “transcendental meditation.” Thirty-six subjects were studied, each serving as his own control. During meditation, the respiratory changes consisted of decreased O_2 consumption, CO_2 elimination, respiratory rate and minute ventilation with no change in respiratory quotient. Arterial blood pH and base excess decreased slightly; interestingly, blood lactate also decreased. Skin resistance markedly increased, while systolic, diastolic, and mean arterial blood pressure, arterial PO_2 and PCO_2 , and rectal temperature remained unchanged. The electroencephalogram showed an increase in intensity of slow alpha waves and occasional theta-wave activity. The physiologic changes during meditation differ from those during sleep, hypnosis, autosuggestion, and characterize a wakeful hypometabolic physiologic state.

behavior; hypometabolism; O_2 consumption; CO_2 elimination; minute ventilation; respiratory quotient; blood pressure; pH; PO_2 ; PCO_2 ; base excess; blood lactate; heart rate; rectal temperature; skin resistance; electroencephalogram; meditation; respiratory rate

MENTAL STATES can markedly alter physiologic function. Hypermetabolic physiologic states, with associated increased oxygen consumption, accompany anticipated stressful situations (34, 61). Hypometabolic physiologic changes, other than those occurring during sleep and hibernation, are more difficult to produce, but may accompany meditative states.

Physiologic changes during meditation have been investigated, (1-4, 6, 11, 14, 15, 23, 29, 30, 38, 42-44, 46, 53, 55, 56, 58, 59), but interpretation of the results has been problematic because of difficulties of subject selection. It was difficult to evaluate which subjects were expert in the investigated technique and therefore could be expected to produce physiologic changes (4, 53); many so-called experts were located in geographic areas where adequate research facilities were not available; the magnitude of physiologic changes was sometimes dependent upon the length of time the subject had been practicing a particular technique and his personal aptitude for the specific discipline (30, 53). However, consistent physiologic changes have been ob-

served during the practice of certain mental techniques of meditation (1-3, 30, 46, 53, 56). Oxygen consumption and respiratory rate have decreased markedly, while the electroencephalogram has shown increased alpha- and occasional theta-wave activity. The present study confirms and extends earlier physiologic observations during the practice of one of these techniques, taught by Maharishi Mahesh Yogi, known as “transcendental meditation” (56).

Transcendental meditation was investigated because: 1) consistent, significant physiologic changes, characteristic of a rapidly produced wakeful hypometabolic state, were noted during its practice (2, 46, 56); 2) the subjects found little difficulty in meditating during the experimental measurements; 3) a large number of subjects were readily available who had received uniform instruction through an organization specializing in teaching this technique (Student's International Meditation Society, National Headquarters located at 1015 Gayley Avenue, Los Angeles, Calif. 90024). The technique comes from the Vedic tradition of India made practical for Western life (36). Instruction is given individually and the technique is allegedly easily learned, enjoyable, and requires no physical or mental control. The individual is taught a systematic method of perceiving a “suitable” sound or thought without attempting to concentrate or contemplate specifically on the sound or thought. The subjects report the mind is allowed to experience a thought at a “finer or more creative level of thinking in an easy and natural manner.” There is no belief, faith, or any type of autosuggestion involved in the practice (37). It involves no disciplines or changes in life style, other than the meditation period of 15 or 20 min twice a day when the practitioner sits in a comfortable position with eyes closed.

METHODS

Thirty-six subjects were studied with each serving as his own control. Informed consent was obtained from each. The subjects sat quietly in a chair with eyes open for 10-30 min prior to the precontrol measurements. During the precontrol period, all subjects continued to sit quietly with eyes open or closed for 10-30 min. The subjects were then instructed to start meditating. After 20-30 min of meditation, they were asked to stop. During the postcontrol period, they continued to sit quietly with eyes closed for 10 min and then with eyes open for another 10 min. Blood pressure, heart rate, rectal temperature, and skin resistance and electroencephalographic changes were measured continuously. Other measurements were made and samples taken every

10 min throughout the precontrol, meditation, and post-control periods. Mean values were calculated for each subject in each period. The data from the precontrol period were then compared to those during meditation by use of a paired *t* test (52).

Oxygen consumption was measured in five subjects by the closed- (7) and in 15 subjects by the open-circuit methods (13). In the open-circuit method, expired gas was collected in a Warren E. Collins, Inc. 120 l Tisot spirometer for 6- to 10-min periods. The expired gas was analyzed in triplicate for P_{O_2} and P_{CO_2} with a Beckman Instruments, Inc. physiological gas analyzer model 160. Oxygen consumption, CO_2 elimination, and respiratory quotient were calculated according to standard formulas (13). In all subjects tested by the closed-circuit method and in four subjects tested by the open-circuit method, a standard mouthpiece and nose clip were used. A tight-fitting face mask was made for use in 16 subjects. The face mask contained two one-way low-resistance inspiration valves (id 1.5 cm) in its sides and a one-way expiration valve (id 2.3 cm) in its front. The Tisot spirometer was weighted to ensure adequate collection, regardless of tidal volume or rate of respiration. Total ventilation was measured in the four subjects with the unweighted Tisot spirometer. Respiration rate was recorded during the closed-circuit method measurements.

Systemic arterial blood pressure was measured and arterial blood samples were obtained from a polyethylene or Teflon catheter inserted percutaneously via a no. 18 Courmand or a Becton, Dickinson & Co. Longwell 20-g 2-in catheter needle, respectively, after local anesthesia with 5–10 ml of 1% procaine HCl (novocaine; Winthrop Laboratories, Inc.) or 2% lidocaine HCl (Xylocaine, Astra Pharmaceutical Products, Inc.). The catheters were filled with a dilute heparin saline solution (5,000 USP units Na heparin per 1 0.9% NaCl) and connected to a Statham P23Db strain-gauge pressure transducer. Systolic and diastolic or mean arterial blood pressure were recorded on either a Hewlett-Packard Co. Sanborn recorder, model 964, or a Brush Instruments Division, Clevite Corp. Mark 240 polygraph. Mean pressures were obtained by low-pass filtering in the driver amplifier. Average values for mean and systolic and diastolic blood pressure were calculated using horizontal lines of best fit drawn through records every 100 sec. Arterial blood samples were taken in heparinized syringes for determination of pH, P_{CO_2} , and P_{O_2} with a Sanz pH glass microelectrode and Radiometer (Copenhagen), model pH M4; a Severinghaus P_{CO_2} electrode system (49); and a Clark P_{O_2} Instrumentation Laboratory, Inc. ultramicro system, model 113-S1, respectively. Base excess was calculated for each of the arterial blood samples (51). Blood lactate concentration was determined by enzymatic assay from unheparinized arterial blood samples (48). Lactate determinations for each sample were performed in duplicate and the results averaged.

Electrocardiograms were recorded with a Grass Instruments Co. polygraph, model 5, or the Hewlett-Packard Sanborn recorder, model 964. Heart rate was calculated by counting the number of QRS electrocardiogram spikes occurring during two out of every five consecutive minutes. Rectal temperature was continuously measured with a

Yellow Springs Instruments, Inc. telethermometer, model 44TA, utilizing a flexible probe inserted 2.5–3.0 cm into the rectum. The values for rectal temperature were recorded every min. Skin resistance was measured with Beckman Instrument, Inc. silver-silver chloride electrodes placed 0.5 cm apart on the left palm (40) and recorded continuously on the Grass Instrument Co. polygraph, model 5 at a current of 50 μ a. Values for skin resistance were recorded every min.

Electroencephalograms (EEG) were recorded with a Grass Instrument Co. electroencephalograph model 6. The EEG traces were recorded with an Ampex Corp. tape recorder, model FR-1300. The skin electrodes were placed, according to the International 10–20 system, at Fpl, Cz, T3, P3, O1, O2, and A2 (26). Grass Instruments Co. gold-plated cup electrodes and EEG electrode cream were employed. Recordings were monopolar with A2 acting as the reference electrode, and the ground electrode was placed over the right mastoid bone. The EEG tracings were recorded as analog data on tape and then were converted to digital data by a Systems Data, Inc. SDS 930 computer with a nominal accuracy of one part in 2048, operating at 256 samples/sec on each channel. These digital data were subsequently processed by an IBM 360-91 computer with spectral analysis computed by the BMD X92 program (19), sampling 2 of every 15 sec of data with a resolution of 1 c/sec for 32 frequencies. Every 10 samples were averaged and displayed as a time history of intensity (mean square amplitude) for each frequency and as a contour map of time vs. frequency with a representation of intensity (57). The sampling of short periods of data was used to increase the likelihood of including temporary frequency changes which might have occurred during the meditation period. Eye movements (electro-oculograms), were recorded in five subjects with the electrodes placed at E1 and A1, and E2 and A1 (45).

RESULTS

The age of the subjects ranged from 17 to 41 years with a mean of 24.1 years. There were 28 males and eight females. The length of time practicing transcendental meditation ranged from 0.25 to 108.0 months, with a mean of 29.4 months. Oxygen consumption averaged 251.2 ml/min prior to meditation, with small variation between the two mean precontrol measurements (5.3 ml/min) (Table 1). During meditation, O_2 consumption decreased 17% to 211.4 ml/min, and gradually increased after meditation to 242.1 ml/min. Carbon dioxide elimination decreased from 218.7 ml/min during the precontrol period to 186.8 ml/min during meditation. Respiratory quotient prior to meditation was in the normal basal range (0.85) and did not change significantly thereafter. Minute ventilation decreased about 1 liter/min and respiratory rate decreased about three breaths per min during meditation.

Systolic, diastolic, and mean arterial blood pressure changed little during meditation (Table 1). Average systolic blood pressure before meditation was 106 mm Hg; average diastolic blood pressure 57 mm Hg; average mean blood pressure 75 mm Hg. The arterial pH decreased slightly in almost all subjects during meditation, while

TABLE 1. *Physiologic changes before, during, and after meditation*

Measurement	No. of Subjects	Precontrol Period, mean \pm SD	Meditation Period, mean \pm SD	Postcontrol Period, mean \pm SD
Oxygen consumption, ml/min	20	251.2 ± 48.6	211.4 $\pm 43.2^*$	242.1 ± 45.4
CO ₂ elimination, ml/min	15	218.7 ± 41.5	186.8 $\pm 35.7^*$	217.9 ± 36.1
Respiratory quotient	15	0.85 ± 0.03	0.87 ± 0.04	0.86 ± 0.05
Respiratory rate, breaths/min	5	13 ± 3	11 $\pm 3^\dagger$	11 ± 3
Minute ventilation, l/min	4	6.08 ± 1.11	5.14 $\pm 1.05^\dagger$	5.94 ± 1.50
Blood pressure, mm Hg				
Systolic	6	106 ± 12	108 ± 12	111 ± 10
Diastolic	6	57 ± 6	59 ± 5	60 ± 5
Mean	9	75 ± 7	75 ± 7	78 ± 7
pH	10	7.421 ± 0.022	7.413 $\pm 0.024^\dagger$	7.429 ± 0.025
Pco ₂ , mm Hg	10	35.7 ± 3.7	35.3 ± 3.7	34.0 ± 2.9
Po ₂ , mm Hg	10	103.9 ± 6.4	102.8 ± 6.2	105.3 ± 6.3
Base excess	10	-0.5 ± 1.5	-1.3 $\pm 1.5^*$	-1.0 ± 1.8
Blood lactate, mg/100 ml	8	11.4 ± 4.1	8.0 $\pm 2.6^*$	7.3 ± 2.0
Heart rate, beats/min	13	70 ± 8	67 $\pm 7^\dagger$	70 ± 7
Rectal temperature, °C	5	37.5 ± 0.4	37.4 ± 0.3	37.3 ± 0.2
Skin resistance, kilohms	15	90.9 ± 46.1	234.6 $\pm 58.5^*$	120.5 ± 92.0

P is the probability of the mean value of the precontrol period being identical to the mean value of the meditation period. **P* < 0.005. †*P* < 0.05.

PCO₂ and PO₂ showed no consistent or significant changes during meditation. The average base excess decreased about 1 unit during meditation.

Mean blood lactate concentration decreased from the precontrol value of 11.4 to 8.0 mg/100 ml (Table 1). In the 10 min following meditation, lactate continued to decrease to 6.85 mg/100 ml, while in the next and final 10 min it increased to 8.16 mg/100 ml. During the 30-min precontrol period, there was a slow decrease in lactate concentration of 2.61 mg/100 ml per hr. At the onset of meditation, the rate of decrease markedly increased to 10.26 mg/100 ml per hr.

During meditation, the average heart rate decreased by 3 beats/min (Table 1). Rectal temperature remained essentially constant throughout the meditation period (Table 1). Skin resistance increased markedly at the onset of meditation, with a mean increase of about 140 kilohms (Table 1). After meditation skin resistance decreased, but remained higher than before meditation.

The EEG pattern during transcendental meditation showed increased intensity (mean square amplitude) of 8-9 cycles/sec activity (slow alpha waves) in the central and frontal regions (Fig. 1). The change in intensity of 10-11 cycles/sec alpha waves during meditation was

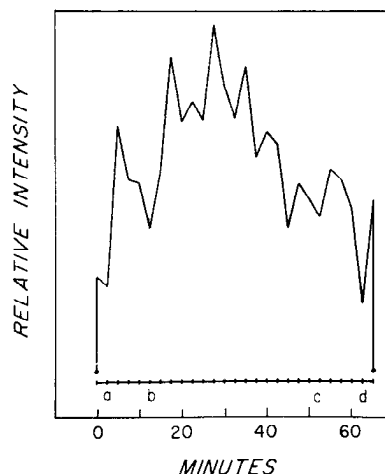


FIG. 1. Relative intensity of 9 cycles/sec activity (alpha-wave activity) in lead FP1 (see text) in a representative subject. *a-b*: pre-meditation control period with eyes closed. *b-c*: meditation period. *c-d*: postmeditation period with eyes closed. During meditation period, relative intensity of alpha-wave activity increased.

variable. In five subjects, the increased intensity of 8-9 cycles/sec activity was accompanied by occasional trains of 5-7 cycles/sec waves (theta waves) in the frontal channel (Fig. 2). Intensity of 12-14 cycles/sec waves and 2-4 cycles/sec waves either decreased or remained constant during meditation. In three subjects, who reported feeling tired and drowsy at the beginning of meditation, flattening of the alpha activity and low voltage mixed frequency waves with a prominence of 2-7 cycles/sec activity was noted. As meditation in these three subjects continued, the pattern was replaced by regular alpha activity. In the five subjects in whom electro-oculograms were recorded, no changes were observed.

DISCUSSION

Consistent and pronounced physiologic changes occurred during the practice of a mental technique called transcendental meditation (Table 1). The respiratory changes consisted of decreased O₂ consumption, CO₂ elimination, respiratory rate, and minute ventilation, with no change in respiratory quotient. Arterial blood pH and base excess decreased slightly; interestingly, blood lactate also decreased. Skin resistance markedly increased and the EEG showed an increase in the intensity of slow alpha waves with occasional theta-wave activity.

The physiologic changes during transcendental meditation differed from those reported during sleep. The EEG patterns which characterize sleep (high-voltage slow-wave activity, 12-14 cycles/sec sleep spindles and low-voltage mixed-frequency activity with or without rapid eye movements) (45), were not seen during transcendental meditation. After 6-7 hr of sleep, and during high-voltage slow-wave activity, O₂ consumption usually decreases about 15% (8, 10, 20, 33, 47). After only 5-10 min of meditation, alpha-wave activity predominated and O₂ consumption decreased about 17%. During sleep, arterial pH slightly decreases while PCO₂ increases significantly, indicating a respiratory acidosis (47). During meditation, arterial pH also decreased slightly. However, arterial PCO₂ remained

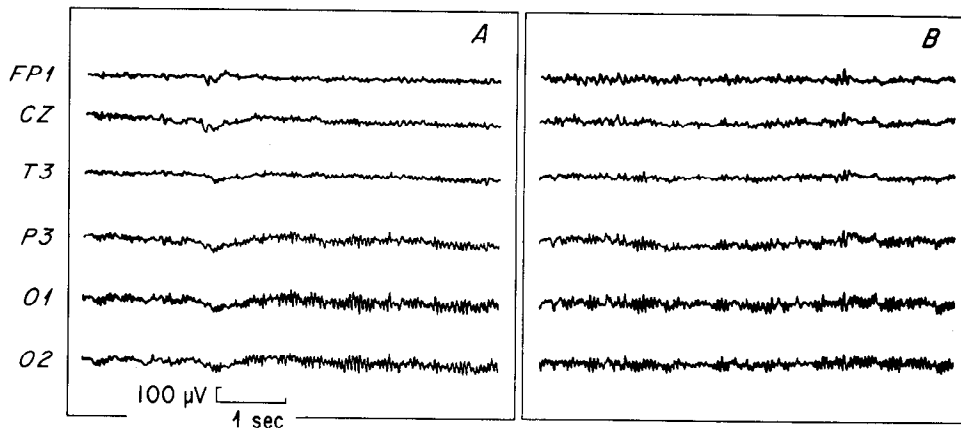


FIG. 2. EEG records of a subject with theta-wave activity during meditation. A: EEG record close to start of meditation period. B: EEG record during middle of meditation period. EEG leads are noted on vertical axis (see text). In A, alpha-wave activity is present as shown in leads P3, O1 and O2. In B, prominent theta-wave activity is present in lead FP1 simultaneous with alpha-wave activity in leads T3, P3, O1, and O2.

constant while base excess decreased slightly, indicating a mild condition of metabolic acidosis. The skin-resistance changes during meditation were also different from those observed during sleep (22, 54). In sleep, skin resistance most commonly increases continuously, but the magnitude and rate of increase are generally less than that which occurred during meditation.

The consistent physiologic changes noted during transcendental meditation also differed from those reported during hypnosis or autosuggestion. During hypnosis, heart rate, blood pressure, skin resistance, and respiration either increase, decrease, or remain unchanged, approximating changes which normally occur during the states which have been suggested (5, 25, 32). During so-called hypnotic sleep, in which complete relaxation has been suggested, no noticeable change in O_2 consumption occurs (5, 24, 60). EEG patterns occurring during hypnosis are usually similar to the suggested wakeful patterns and therefore differ greatly from those observed during meditation (32).

Operant conditioning procedures employing physiologic feedback can also alter autonomic nervous system functions and EEG patterns (9, 21, 28, 31, 39, 50). Animals can be trained to control autonomic functions, such as blood pressure, heart rate, and urine formation (9, 18, 39). Human subjects can alter their heart rate and blood pressure by use of operant conditioning techniques (31, 35, 50) and can be trained to increase alpha-wave activity through auditory and visual feedback (21, 28). However, the physiologic changes during transcendental meditation occurred simultaneously and without the use of specific feedback procedures.

The relative contribution of various tissues to lactate production has not been established, but muscle has been presumed to be a major source (16). The fall in blood lactate observed during meditation might be explained by increased skeletal muscle blood flow with consequent increased aerobic metabolism. Indeed, forearm blood flow

increases 300% during meditation while finger blood flow remains unchanged (46). Patients with anxiety neurosis develop an excessive rise in blood lactate concentration with "stress" (12, 27). The infusion of lactate ion can sometimes produce anxiety symptoms in normal subjects and can regularly produce anxiety attacks in patients with anxiety neurosis (41). The decrease in lactate concentration during and after transcendental meditation may be related to the subjective feelings of wakeful relaxation before and after meditation. Further, essential and renal hypertensive patients have higher resting serum lactate levels than normotensive patients (17). The subjects practicing meditation had rather low resting systolic, diastolic, and mean blood pressures.

A consistent wakeful hypometabolic state accompanies the practice of the mental technique called transcendental meditation. Transcendental meditation can serve, at the present time, as one method of eliciting these physiologic changes. However, the possibility exists that these changes represent an integrated response that may well be induced by other means.

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