

Yoga Breathing Techniques: Implications for Stress Management, Health, and Psychophysiological Research

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1990

Published on the internet in pdf and HTML at
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<http://jeksite.org/yoga/resp.htm>

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Abstract

Understanding and application of various respiratory practices are impeded by the many interacting physiological and psychological variables. Yoga techniques may offer insights into useful breathing practices and control of important variables. This review integrates relevant data from (a) the psychophysiological/psychological literature, (b) the physiological/medical literature, and (c) studies of yoga. The available data indicate that yogic slow breathing practices promote dominance of the parasympathetic system, can help control stress, and can contribute to treatment programs for some chronic diseases. Basic research is needed on yogic rapid breathing and alternate nostril breathing techniques. Yogic claims about nasal airflow laterality and cognitive laterality have partial support. Psychological factors such as anxiety and distraction, as well as the physical details of breathing techniques, are important variables in psychophysiological research on respiratory practices.

NOTE OF MAY, 1994: Several lines of research have progressed since this unpublished manuscript was prepared four years ago. These include: (a) several new studies of yoga breathing techniques have been reported, but they do not significantly alter the conclusion in this manuscript, and (b) the effects of deep breathing on the autonomic system and the effects of hyperventilation appear to be more complicated and/or variable than was recognized when the manuscript was prepared.

Various respiratory patterns and maneuvers can provide striking influences on the autonomic nervous system and may exacerbate or reduce adverse responses to stressors. For example, increased breathing rate is a typical response to stressful situations (Grossman, 1983; Magarin, 1982). This tendency can lead to breathing in excess of metabolic needs (hyperventilation), which causes reduced blood carbon dioxide concentrations. The reduced carbon dioxide causes psychophysiological and psychological effects that include (a) enhanced arousal and anxiety, and (b) decreased cerebral and coronary blood flow, which can lead to a variety of clinical symptoms including dizziness, poor performance, headache, chest pain, cardiac abnormalities, and sleep disturbance (Brown, 1953; Fried, 1987; Grossman, 1983; Lum, 1976; Magarin, 1982). Certain other respiratory patterns that modestly elevate blood carbon dioxide concentration appear to promote the opposite effects, including reduced anxiety and increased or well-maintained cerebral and coronary blood flow (Grossman, 1983).

However, practical applications of breathing techniques are hindered by the lack of understanding and control of the many interacting variables. A recent review of physiological mechanisms for respiratory influences on the cardiovascular system described a maze of interwoven and dramatically interacting control mechanisms (Daly, 1986). As indicated above, psychological factors can strongly interact with these physiological mechanisms. With the present state of knowledge, the psychophysiological effects of novel respiratory practices cannot be reliably predicted and replications of basic experiments are often inconsistent due to uncontrolled variables (several examples are given in following sections).

Yoga breathing practices may provide insights into valuable respiratory techniques and control of important variables. These practices are intended to maintain optimum health—with particular emphasis on stress reduction—but have received little scientific attention. According to yoga tradition, the practices were developed by extensive personal experimentation and keen introspection of the results. The breathing practices, or pranayama, are one component of hatha yoga, which is intended to give one a healthy body and mind.

Reduction of hypertension (Irvine, Johnston, Jenner, & Marie, 1986; Patel, Marmot & Terry, 1981; Patel & North, 1975) and dramatic improvement of heart disease (Ornish et al., 1979; 1983; 1990) have resulted from integrated treatment programs that included yoga breathing practices. However, the roles of individual treatment components have not been delineated in these studies. A review of the scientific information related to yoga breathing practices may be useful for evaluating the role of breathing practices in these programs and for improving the practices or adapting them to special cases.

According to yoga tradition, certain breathing practices induce relaxation and calmness, whereas others are invigorating and arousing. In addition, certain practices are claimed to influence cognitive functioning of the brain hemispheres.

This article is intended to (a) describe basic yoga breathing practices, (b) summarize the available scientific information relevant to the effects of these practices, and (c) identify topics needing further research. Health threats from potential misuse of certain powerful respiratory

techniques are also noted. The techniques are discussed individually in the sequence they are commonly practiced. Studies that combined several practices without isolating the effects of individual breathing techniques are included in the final discussion and conclusions section. The review focuses on the common basic breathing techniques, with emphasis on beginning to intermediate levels. Less common practices and extremely advanced practices are beyond the scope of this review.

Diaphragmatic Breathing

Yoga Practice

The basic mode of respiration used in many yoga practices and recommended for normal daily activities is slow, smooth breathing using the diaphragm rather than the respiratory muscles of the chest (Christensen, 1987, p. 136; Samskrti & Veda, 1985, p. 10). This breathing pattern is sometimes referred to as abdominal breathing, although, as noted below, the abdominal muscles may play a minor role. Breathing is through the nose rather than the mouth.

Scientific Information

The diaphragm is the dominant respiratory muscle for quiet breathing in awake healthy adults, but increased use of chest muscles and increased breathing rate are common results of stress and may become habitual. Slow diaphragmatic breathing appears to reduce adverse effects of stress and promote parasympathetic cardiovascular dominance. The opposite effects are induced by more rapid breathing using the chest muscles. Before discussing the available data, a brief review of the respiratory process may clarify the nature of these modes of breathing and the methodological issues in their investigation.

The Respiratory Process

Three muscle groups can be used in breathing: (a) the diaphragm, (b) the muscles of the rib cage, and (c) the abdominal muscles. This summary of the roles of these muscles is based on Collett, Roussos, and Macklem (1988); Grassio & Goldman (1986); Guyton (1986); and Troyer and Loring (1986).

The diaphragm is the most important muscle for inhalation. It is a thin sheet of muscle separating the chest and abdominal cavities. When relaxed the diaphragm forms an open-bottomed cylinder that extends up into the lower part of the rib cage along the sides of the rib cage, and forms a dome on top. Diaphragm contraction shortens the cylindrical portion and pulls the dome down. This movement expands the lungs by pulling them down, which creates a partial vacuum that causes inhalation if the airway is open. When the diaphragm relaxes, the elastic recoil of the lungs pulls it upward, causing exhalation. The downward pressure on the abdominal viscera from contraction of the diaphragm forces the abdominal wall to extend forward and/or the lower rib cage

to expand to the sides. The term abdominal breathing derives from this easily observed movement of the abdominal wall, but can also refer to the use of abdominal muscles described below.

Although upper chest movement is relatively inconspicuous in quiet breathing for a relaxed person, some thoracic muscles play a role. The external and parasternal intercostals (joining adjacent ribs) and the scaleni (connecting the shoulder area and spine) are activated during inspiration to hold the ribs in an expanded position that compliments the force of the diaphragm. However, the exact roles of each of the muscles are not yet resolved. The minimal chest movement combined with the fact that some chest displacement could be a result of diaphragmatic action have contributed to the difficulty in resolving this question. The internal intercostals may sometimes play a role in exhalation.

The abdominal muscles are the most powerful and important muscles for forced exhalation, but are normally not used in quiet breathing. Contraction puts inward pressure on the abdominal viscera, which then push the diaphragm up and reduce lung volume. In addition, these muscles may assist expiration by pulling down and deflating the lower rib cage. The important abdominal muscles for respiration are the rectus abdominus, the transverse abdominus, and the external and internal obloquies.

Abdominal muscles can contribute significantly to inhalation by pushing the relaxed diaphragm farther into the rib cage. This action (a) places the diaphragmatic muscle fibers on a more favorable part of their length-tension curve, and (b) converts some of the respiratory system expiratory elasticity to inspiratory forces.

Only about 10 percent of total respiratory capacity is used on each breath in quiet breathing. The volume of each exhalation or *tidal volume* is about 500 ml for a quiet adult male. Most of this tidal volume goes to lung areas that exchange oxygen and carbon dioxide with blood, but about 150 ml is *dead space* from passages that cannot contribute to gas exchange. Dead space volume is relatively constant whereas tidal volume varies greatly with physical exercise, breathing pattern, and other factors. Thus, larger tidal volumes have a smaller proportion of dead space. Dead space can increase significantly with lung disorders.

During normal quiet breathing, exhalation is driven by the elastic forces of the lung. Muscles used for inhalation contract to slow and control the rate of exhalation. The position of the relaxed diaphragm and corresponding lung volume after exhalation depend on a balance between the elastic forces collapsing the lungs inward and the elastic forces expanding the chest outward. This lung volume at the end of relaxed expiration is called the *functional residual capacity* (FRC).

About one fourth of the respiratory capacity not used with quiet breathing can be accessed with additional exhalation and three fourths with additional inhalation. If abdominal muscles force maximum reduction of lung volume, the *expiratory reserve volume* of about 1100 ml of air below FRC for an average male is expired. This combines with the tidal volume (500 ml) and the *inspiratory reserve volume* of about 3000 ml to give a *vital capacity* of 4600 ml. In addition, a *residual capacity* of about 1200 ml of air remains in the lung after maximum exhalation. These

values are typical for a young adult male. The volumes are about 25 percent less for an average female, and vary with body size, posture, and physical condition.

Adequate air flow or *ventilation* of the lungs can be achieved with slow breathing rate and large tidal volume or fast rate and small tidal volume. The ventilation rate is normally set to provide oxygen and remove carbon dioxide in accordance with metabolic needs.

The abdominal and chest muscles also have important functions for posture, locomotion, and verbalization that must be integrated with and may modify respiratory functions.

Thoracic Breathing

In a wide-ranging, extensive review of the literature related to respiration and stress, Grossman (1983) concluded:

A breathing pattern characterized as rapid, low-tidal volume, predominantly thoracic ventilation with relatively low alveolar and blood concentrations of carbon dioxide . . . is associated with psychological characteristics of anxiety, neurosis, depression, phobic behavior, and high levels of perceived and objective stressors. Voluntary performance of this breathing pattern seems to intensify subjective and physiological indicators of anxiety when exposed to stress. Cardiovascularly, voluntary production of this ventilatory pattern appears to bring about significant reduced parasympathetic tone and increased sympathetic dominance, which are expressed in augmented heart rate and cardiac output, muscle vasodilation, decreased blood flow and oxygen supply to the heart and brain, reduced [respiratory sinus arrhythmia] and baroreceptor responsiveness, and increased likelihood of major ECG abnormalities. (p. 293)

Stress causes a tendency for enhanced ventilation with upper chest breathing patterns that can become habitual in some people. This conclusion is supported by a variety of studies of stress reviewed by Grossman, by more recent studies of stress (Freeman, Conway & Nixon, 1986) and by studies of hyperventilation (Lum, 1976; Magarin, 1982).

The increased ventilation in response to stress presumably is in anticipation of physical activity such as a fight or flight reaction (Grossman, 1983). However, when little physical activity follows, a tendency to breathe in excess of metabolic needs results. In this context, the tendency to hyperventilate in response to stress in a civilized society is not surprising. The degree of hyperventilation and associated symptoms vary from mild to severe depending on dispositional and situational factors (Bass & Gardner, 1985; Clark & Hemsley, 1982; Freeman, Conway, & Nixon, 1986; Wientjes, Grossman & Defares, 1984).

As noted in the introduction, over breathing causes a variety of effects, including increased heart rate, arousal and anxiety, and various clinical symptoms due to decreased blood flow to the brain and heart. Note that voluntary hyperventilation usually induces increased arousal and anxiety in

normal subjects¹ (Clark & Hemsley, 1982; Grossman, 1983; Thyer, Papsdorf, & Wright, 1984). The reduced carbon dioxide concentration in the blood is a key physiological factor underlying these effects. The decreased blood flow to the heart and the heart rhythm abnormalities can pose a significant risk for those with cardiovascular problems.

Thoracic breathing is symptomatic of habitual or chronic hyperventilation and may be a potentiating factor (Freeman, Conway & Nixon, 1986; Lum, 1976). Lum (1976) reported that over 99 percent of the 640 patients he had seen for chronic hyperventilation were thoracic rather than diaphragmatic breathers. He suggested that some people with a tendency to respond to stress with thoracic breathing become habitual over breathers. The result is that:

The chronic hyperventilator lives much nearer the frontier of hypocapnic [low carbon dioxide] symptoms and any small additional stress, whether psychological or physical, may push him over into symptoms which add to the stress while leaving him mentally and physically less able to cope. Thus the vicious cycle may be triggered. (Lum, 1976, p. 214)

Based on clinical experience and very limited published data, Fried (1987, p. 8) estimated that incidence of habitual hyperventilation in the general population may be 10 to 15 percent and perhaps over 20 percent.

Autonomic Effects

Diaphragmatic breathing appears to lead to advantageous physiological and psychological effects through autonomic nervous system activity. Grossman (1983) concluded:

A slow, large-tidal-volume, predominantly abdominal pattern of ventilation . . . is associated at the psychological level with emotional stability, sense of control over the environment, calmness, a high level of physical and mental activity, and relative absence of perceived or objective stressors. Short-term modification of breathing pattern toward this type seems to cause a reduction of subjective and physiological indices of anxiety under conditions of stress; long-term modification seems to produce—with certain clinical populations—a diminution of psychological difficulties, e.g. neurotic tendencies, chronic anxiety responses, and psychosomatic symptoms. Cardiovascularly, this breathing pattern appears independently to produce relatively high [parasympathetic] tone and low sympathetic activation, which manifest as low heart rate, increased supply of blood and oxygen to the heart and the brain, and enhanced [respiratory sinus arrhythmia] and baroreceptor responsiveness. (p. 292)

¹ Intentional hyperventilation in supportive settings has been used to induce and release strong emotions and tension as a form of therapy or self improvement (Grof, 1988, pp. 170-184; Orr & Ray, 1983, p. 80-81). The experience with these methods (which have been applied to many thousands of people) and the results of research on hyperventilation are generally consistent with the concept that the net response to hyperventilation depends on dynamic interactions between psychological and physiological factors. Note for example that Saltzman, Heyman, and Sieker (1963) found no reports of increased anxiety in normal persons during one hour of hyperventilation; however, the experimenters intentionally minimized the possibility of anxiety by carefully explaining the experiment to the subjects and by reducing circulatory effects by having the subjects hyperventilate in a horizontal position.

Of particular relevance, Grossman noted that the four studies investigating the effect of paced slow respiration in stressful situations "uniformly indicate that mere voluntary changes of respiration rate by subjects under stressful circumstances serve to modify the subjective perception of anxiety" (p. 292). A more recent study by Cappo and Holmes (1984) also supports this conclusion. Several studies have also found paced slow respiration reduces autonomic reactivity as measured by skin resistance (but not heart rate) (Cappo & Holmes, 1984; Harris, Katkin, Lick, & Habberfield, 1976; McCaul, Solomon, & Holmes, 1979).

Similarly, slow diaphragmatic breathing has consistently proven successful therapy for persons with hyperventilation stress responses that reached clinical severity (Bonn, Readhead, & Timmons, 1984; Clark, Salkovskis & Chalkley, 1985; Grossman, de Swart, & Defares, 1985; Hegel, Abel, Etscheidt, Cohen-Cole, & Wilmer, 1989; Hibbert & Chan, 1989; Kraft & Hoogduin, 1984; Lum, 1976). Grossman (1983) cites various studies suggesting that slow breathing causes blood carbon dioxide concentrations to be in the upper normal range, which promotes psychophysiological effects generally opposite to those of hyperventilation.

Grossman (1983) notes that respiratory sinus arrhythmia (increased heart rate during inspiration) is a useful index of parasympathetic tone and is largest during slow deep breathing. He also cites evidence suggesting that normal parasympathetic tone promotes good health and may serve a protective function for the heart, whereas decreased parasympathetic tone may be related to heart disorders. He further suggests that the relative balance between the parasympathetic and sympathetic nervous systems may be important in determining responses to stress. More recent studies support the hypothesis that parasympathetic dominance has protective value for the cardiovascular system (Beere, Glagov, & Zarins, 1984; Jennings & Follansbee, 1985; Muranaka, et al., 1988).

Physical Effects

Diaphragmatic breathing has traditionally been considered the most efficient mode of quiet breathing (e.g., Miller, 1954; Sharp et al., 1974). Because tidal volume is typically larger in diaphragmatic breathing, the proportion of ventilation wasted as dead space is minimized. In addition, enhanced ventilation to the lower lungs increases efficiency of gas exchange because gravitational forces cause much higher blood flow in the lower lungs (West, 1988). Diaphragmatic-abdominal breathing can cause higher air flow to the lower lungs than thoracic breathing (Fixley, Roussos, Murphy, Martin, & Engel, 1978; Roussos et al., 1977; Sampson & Smaldone, 1984); however, this effect was not found in other studies (Bake, Fugl-Meyer, & Grimby, 1972; Grassio, Bake, Martin & Anthonisen, 1975; Grimby, Oxhoj, & Bake, 1975; Sackner, Silva, Banks, Watson, & Smoak, 1974) and apparently depends on details of respiratory muscle action and perhaps experimental methodology (see, Roussos et al., 1977).

Pressure on the abdominal viscera from diaphragmatic motion also contributes to venous blood return to the heart (Grossman, 1983; Permutt & Wise, 1986), which is an important determinant of cardiac output and efficiency (Guyton, 1986).

Diaphragmatic breathing has historically been recommended for persons with chronic obstructive lung disease (Barach, 1955; Frownfelter, 1987; Miller, 1954). However, efforts to quantify the

benefits have given mixed results (Jones, 1974; Rochester & Goldberg, 1980). A detailed review of the literature is needed, but is outside the scope of the present paper. Potential psychophysiological and psychological benefits should be considered in addition to the usual measures of lung function.

Nasal Breathing

Nasal breathing is the best means of warming and humidifying inhaled air in preparation for the lungs. Available information on the function and evolution of the human nose is consistent with a primal purpose of conserving moisture and heat (Cole, 1988; Franciscus & Trinkaus, 1988). In a temperate climate, the estimated energy expenditure to condition inhaled air can be equivalent to about one sixth of a person's daily energy output; however, about 30 to 40 percent of this energy is recovered by exhaling through the nose (Cole, 1982, 1988). Higher efficiencies of heat and moisture recovery occur in cold and/or dry environments.

The nose also filters incoming air (Guyton, 1986, p. 477), has irritant receptors that trigger protective reflexes (Widdicombe, 1986), and, of course, provides the sense of smell. The resistance to air flow in nasal breathing may be an efficient passive means of slowing air flow to provide adequate gas exchange at low ventilation rates (Hairfield, Warren, Hinton, & Seaton, 1987; Jackson, 1976; McCaffrey and Kern, 1979a). Nasal breathing is the normal and preferred mode of quiet respiration.

The intriguing hypothesis that nasal respiration plays an important role in controlling brain temperature may have important implications for brain functioning and psychological states (Dean, 1988; Zajonc, Murphy, & Inglehart, 1989). However, the basic mechanisms and effects of brain cooling have not yet been resolved (Wheeler, 1990).

Further Research

Role of abdominal muscles. Both the yoga and scientific literatures have focused on comparing diaphragmatic-abdominal breathing with thoracic breathing, but have little discussion of the specific role of the abdominal muscles. The abdominal muscles may shift the expiratory end volume, alter the rib cage shape, or play no role. Differing use of the abdominal muscles may be a factor in the inconsistent replications of certain respiratory findings. One yoga master recommends that abdominal muscles not be used once diaphragmatic breathing is established (Samskrti & Veda, 1985 p. 10). Research may be of particular value on the following topics:

1. Abdominal breathing may help stretch and relax the diaphragm in persons who manifest stress by excessive tonic diaphragm contraction. Some individuals have increasing contraction and immobilization of the diaphragm as stressful topics are discussed (Faulkner, 1941; Holmes, Goodell, Wolf, & Wolff, 1950, p. 49; Wolf, 1947). The prevalence of excessive tonic diaphragm tension, both acute and chronic, and the effects of abdominal pressure on the diaphragm in these cases may merit further investigation.

2. Diaphragmatic and abdominal breathing cause rhythmic pressure on and movement of the abdominal organs, which could affect the functioning of those organs. In fact, a yoga breathing exercise of pulling in the abdominal muscles during exhalation is claimed to create perfect digestion (Rama, 1988, pp. 191-192). Digestion and slow diaphragmatic breathing are both associated with parasympathetic activity and therefore may be both autonomically and mechanically coupled. Similarly, the stress response of thoracic breathing with a relatively inactive diaphragm may provide minimal mechanical stimulation of the abdominal organs and appears consistent with reduced gastrointestinal activity during sympathetic arousal and anticipated physical activity. The potential interaction between the gastrointestinal system and the respiratory system deserves investigation, particularly with regard to the effects of psychological factors such as stress.

3. The use of abdominal muscles to drive end expiration below relaxed expiratory position (FRC) may lead to less efficient gas exchange and to lower cardiac efficiency, particularly in older persons and persons with lung impairment. The small airways in the lower lung tend to close with exhalation below FRC (Collet, Roussos, & Macklem, 1988). These airways reopen only when pressure is sufficient to overcome surface tension. Until inspiration exceeds the needed pressure, air is distributed to the upper lung, resulting in inefficient gas exchange. For normal young people some airways are closed at residual capacity (maximum possible exhalation), but most are open. With age, lower airway closure increases and may occur with normal exhalation (i.e., at FRC). In addition, respiratory actions that increase plural pressure (pressure in the thoracic cavity surrounding the heart and lungs) tend to decrease venous return to the heart (Permutt & Wise, 1986) and thus reduce cardiac efficiency. Exhalation below FRC increases plural pressure (Collett, Roussos, & Macklem, 1988) and, therefore, may reduce cardiac efficiency.

Improved experimental controls. Studies on the effects of breathing mode have rarely considered (a) the subjects' responses to the experimental procedure, and (b) individual differences in pattern of breathing and chronic stress level. Troyer and Loring (1986, p. 473) note that normal subjects are well known to adopt a more thoracic breathing mode during respiration experiments. This result is not surprising in light of the evidence that anxiety leads to a tendency for thoracic breathing. Likewise, the variation in the tendency to hyperventilate suggests that individual differences are very important factors. Studies that find thoracic breathing prevalent in a quiet breathing condition (e.g., Sharp, Goldberg, Druz, & Danon, 1975) raise questions about the effects of the experimental procedure and subject pool. Careful attention should be given to subject pool and the subjects' reactions to experimental procedures and personnel.

Complete Breath

Yoga Practice

The *complete breath* technique, also called three part breathing, slowly fills and empties the entire lung capacity (Christensen, 1987, p. 137; Samskrti & Veda, 1985, p. 173; Satchidananda, 1970, p. 142). A

smooth maximum inhalation is accomplished by first expanding the abdomen and lower rib cage, then expanding the middle rib cage, and finally expanding the upper rib cage. The abdomen naturally withdraws as the chest is fully expanded. The arms are sometimes slowly raised overhead to help expand the chest. A slow maximum exhalation follows in the reverse order—sinking the upper chest, then the middle chest, and finally pulling in the abdomen. The complete breath may be done in either a sitting or a standing position. The mind is focused on the breath and the release of tension during breathing.

This technique is often done three to five times at the beginning of hatha yoga sessions or at the beginning of the yoga breathing practices. Yoga texts recommend this technique at other times to counter stress and refresh the mind and body.

Scientific Information and Further Research

The summary of scientific information and suggestions for further research are combined because very little relevant scientific work has been done on this technique. (As discussed below, the technique has been used in studies that combined various breathing and physical relaxation practices.)

Autonomic Effects

Because the complete breath is the extreme case of slow deep breathing, the psychophysiological effects discussed for diaphragmatic breathing may possibly be extrapolated to this technique. However, such an extrapolation would go beyond the range of available data as no studies were found that used this specific sequence for full breathing capacity. For example, Hirsch and Bishop (1981) found that respiratory sinus arrhythmia (a good index of parasympathetic tone) consistently increased as tidal volume increased, but, the maximum tidal volume studied was only half vital capacity and the sequence of breathing was not specified.

The complete breath passes through a range of changing autonomic reflexes so the net effects are difficult to predict. Lung volume or stretch reflexes, for example, decrease parasympathetic activity at moderate lung inflations, which in turn causes increased heart rate due to increased sympathetic dominance. At large lung volumes, however, autonomic reflexes cause decreased heart rate (Daly, 1986). Basic research on the psychophysiological effects of the complete breath remains to be carried out.

Physical Effects

The complete breath gently contracts and stretches all respiratory muscles. This presumably is beneficial, particularly for sedentary persons who may not otherwise exercise some respiratory muscles. Research on release of muscle tension accumulated during stressful activities might be fruitful.

The full inhalation of the complete breath should provide maximum opening of the collapsed lower airways, which may be of particular value to older persons and those with lung impairment. However, the full exhalation will also provide maximum collapsing of airways. For maximum airway opening, the complete breath practice should end after an inhalation, rather than after a full exhalation.

Rapid Breathing

Yoga Practice

Two rapid breathing techniques are used in basic yogic practices (Samskrti & Franks, 1978, p. 158; Satchidananda, 1970, pp.145-146). One technique is a quick short forced exhalation using the abdominal muscles, followed by a slower automatic diaphragmatic inhalation as the abdominal muscles are relaxed. The volume of air is smaller than normal tidal volume. The other technique has the same short forced exhalation, but the inhalation is also short and forced using the diaphragm and extending the abdomen. These two techniques will be referred to here as *automatic inhalation* and *forced inhalation*, respectively. The automatic inhalation technique is more common. Both techniques use nasal breathing and are done in a sitting position. The mind is focused on breathing, particularly the abdominal contractions.

For both techniques, beginners repeat about ten to twenty of the inhalation-exhalation cycles at a rate of about one cycle per second. One complete breath technique is usually done very slowly after the series of rapid cycles. After a short rest, the series of cycles and complete breath may be repeated once or twice. Over a period of several weeks or months the practitioner may work up to two to three cycles per second for a series of one hundred or even several hundred cycles. In the advanced stages, breathing may be very vigorous and the breath is held after a series of rapid cycles (see section on breath holding below).

Most yoga manuals and instructors state that a person should stop and rest if any sensations of dizziness or light headedness occur during rapid breathing. Also, rapid breathing should not be done within about two hours after a meal. In more advanced, vigorous practice, the stomach, bladder and bowels should be empty.

The common yoga terms for the basic rapid breathing techniques are kapalabhati and bhastrika; however, some authors use kapalabhati for an automatic inhalation technique whereas others use it for forced inhalation. The term bhastrika has similar variations in use, but usually indicates a more advanced practice that includes breath holding.

Scientific Information

Yoga practitioners describe rapid breathing as invigorating. As discussed below, mild arousal may be caused by gentle, controlled hyperventilation and/or significant exercise of the respiratory

muscles. The information presented in this section is based on data for rapid breathing without breath holding. Breath holding is discussed in a separate section below.

Rapid Breathing and Hyperventilation

Rapid breathing such as one breath per second normally causes hyperventilation and can be used for hyperventilation provocation tests (e.g., Freeman, Conway, & Nixon, 1986). As discussed above, hyperventilation causes arousal and sympathetic dominance.

However, the yoga rapid breathing techniques cause only slight or no excess ventilation. Several lines of evidence support this conclusion. (a) As noted in the description of the practice, dizziness and other symptoms of significant hyperventilation are specifically avoided. (b) Wenger and Bagchi (1961) reported that the pattern of heart rate, finger temperature and pulse volume was different during automatic inhalation rapid breathing ("kapalabhati") than during hyperventilation. However, the observed pattern could be consistent with slight excess ventilation. (c) Mean carbon dioxide concentrations of alveolar air (where gas exchange with blood occurs in the lungs) after automatic inhalation rapid breathing were similar to resting levels, not lower as occurs with hyperventilation (Kavalayananda & Karambelkar, 1957a; 1957b; 1957c). The eight experienced practitioners breathed at about 2 cycles per second. (d) The average arterial carbon dioxide partial pressure was slightly (14 percent) reduced but within the normal range during a predominantly thoracic variation of (apparently) forced inhalation rapid breathing at nearly four cycles per second (Frostell, Pande, & Hedenstierna, 1983).

The small volume of each breath makes very inefficient respiration that prevents excess ventilation. Available data indicate average tidal volumes during automatic inhalation rapid breathing of about 35 to 55 percent of the average resting tidal volume (Frostell, Pande & Hedenstierna, 1983; Gore & Gharote, 1987; Karambelkar & Bhole, 1988; Karambelkar, Deshpande, & Bhole, 1982; Miles, 1964). The net effect can be seen from a hypothetical example consistent with these data. Typical respiration of 15 breaths per minute at 500 ml tidal volume gives 7,500 ml per minute total ventilation, of which 5,250 ml (70%) goes to lung areas with gas exchange, assuming 150 ml dead space. For comparison, 120 breaths per minute at 215 ml tidal volume gives 25,800 ml per minute total ventilation, of which 7,800 ml (30%) goes to gas exchange areas.² (As discussed below, oxygen consumption may increase by a factor of 1.5 during rapid breathing due to the extra work of respiration.) Because total ventilation increases more than carbon dioxide production, carbon dioxide concentration in expired air is lower during yogic rapid breathing than during normal breathing (Karambelkar, Deshpande & Bhole, 1982, 1984a).

² Artificial respiration using mechanical high frequency ventilation has established that adequate ventilation can occur even with tidal volumes near or less than respiratory dead space—although the exact mechanisms of air flow are still not understood (reviewed in Drazen, Kamm & Slutsky, 1984).

Heart Rate

Heart rate increases during yogic rapid breathing. Average heart rate increased from a baseline of 77 beats per minute to 86 beats per minute for 12 subjects performing automatic inhalation rapid breathing at about 120 breaths per minute (Bhole, 1982). Likewise, Wenger and Bagchi (1961) found that average heart rate for five yogis increased from about 77 to about 90 beats per minute while performing automatic inhalation rapid breathing ("kapalabhati"). Average respiration rate was not reported, but the example record showed about two breaths per second. Average heart rate of 64 beats per minute at rest increased to 94 beats per minute during thoracic forced inhalation breathing at about 4 cycles per second for three highly trained subjects (Frostell, Pande, & Hedenstierna, 1983).

The degree of heart rate increase varies with the intensity and perhaps type of rapid breathing. Heart rates of 120, 120 and 157 beats per minute were found in three males during "vigorous" forced inhalation rapid breathing (Hoffman & Clarke, 1982). The subject with the rate of 157 had regularly practiced yogic breathing for over four years, whereas the other two subjects had less experience. Corresponding heart rates during "gentle" forced inhalation rapid breathing were 100, 100, and 121 beats per minute and during resting conditions were 78, 74 and 70. For all subjects, heart rate accelerated during the first 20 to 40 seconds of rapid breathing and then leveled off at the faster rate. Specific respiration rates were not reported, but comments indicate rates of 1.5 to 2 breaths per second.

Physical Effects

Yogic rapid breathing provides significant exercise for the respiratory muscles with only a mild to moderate overall body work output. Overall physical work is measured by comparing oxygen consumption during exercise with consumption while sitting quietly. Oxygen consumption increases by a factor of two for walking at two miles per hour and factors of eight or more for intense exercise such as running (deVries, 1986, p. 349). (For comparison, practices such as certain types of meditation are called *hypometabolic* because oxygen consumption is lower than while normally sitting quietly [Wallace, Benson, & Wilson, 1971].)

The average oxygen consumption rates during automatic inhalation rapid breathing have been 1.1 to 1.8 times higher than while sitting quietly (Gore & Gharote, 1987; Karambelkar & Bhole 1988; Karambelkar, Deshapande & Bhole, 1982; Miles, 1964). These figures are for the overall average in each study. Karambelkar and Bhole (1988) reported that average oxygen consumption increased as duration of rapid breathing increased from one to five minutes.

Other rapid breathing techniques that use more respiratory effort have higher oxygen consumption. Frostell, Pande, and Hedenstierna (1983) estimated that the forced inhalation thoracic breathing at about 4 breaths per second (that was maintained continuously for 30 to 60 minute periods) increased oxygen uptake compared to sitting quietly by a factor of three, which was about 23 percent of maximal aerobic capacity and an over 200-fold increase in respiratory work.

Likewise, the high heart rates observed by Hoffman and Clarke (1982) during forced inhalation breathing are consistent with moderate rather than mild work loads.³

Persons subject to adverse reactions to exercise should use caution with rapid breathing. For example, elevated serum muscle enzyme activity from vigorous breathing exercises during an asthmatic episode may have exacerbated and prolonged the attack in one susceptible patient (Tamarin, Conetta, Brandstetter & Chadow, 1988).

Further Research

Autonomic and psychological effects. Other than heart rate, autonomic effects of yogic rapid breathing have received very little study. Wenger and Bagchi (1961) reported decreased average finger temperature and increased skin conductance during rapid breathing, which is consistent with the expected increased sympathetic activity. Further study is needed, particularly on effects on the cardiovascular system. Likewise, investigations of possible effects of rapid breathing on arousal, performance, anxiety, stress response, etc. are needed.

Air flow responses. Potential psychophysiological responses to air flow during rapid breathing deserve investigation. Stimulation of air flow receptors in the nose may activate reflexes that reduce the drive to breath (Widdicombe, 1986). Other studies suggest that nasal air flow receptors may stimulate electrical activity in the brain (Kristof, Servit & Manas, 1981; Servit, Kristof, & Kolinova, 1977; Servit & Strejckova, 1976; Ueki & Domino, 1959).

Cardiac arrhythmias. The potential for rapid breathing to stabilize and stimulate heart beat merits study for clinical applications. When heart rate and breathing were synchronized, which occurred at about 110 to 115 cycles per minute, heart rate showed reduced variability in three healthy subjects (Hoffman & Clarke, 1982). In two case reports, nodal premature beat cardiac arrhythmias disappeared after automatic inhalation rapid breathing (Monjo, Gharote, Bhagwat, 1984). One patient used about 120 breaths per minute and stimulated heart rate to 105 beats per minute. The other patient had severe ischemic heart disease and used only 60 breaths per minute.

Regional distribution of air. Preferential distribution of air to the upper lungs could contribute to the inefficient ventilation and the absence of excessive ventilation during yogic rapid breathing; however, air distribution has not been studied for small tidal volume, diaphragmatic rapid breathing.

³ Respiratory muscle exercise can increase the ability to maintain high ventilation (Belman & Gaesser, 1988; Kim, 1984; Morgan, Kohrt, Bates, & Skinner, 1987); however, practical benefits of increased respiratory muscle endurance are not yet established. The available evidence indicates that respiratory muscles are not a limiting factor for physical performance by normal persons, except possibly under the most extreme conditions of intense or prolonged exercise (Belman & Gaesser, 1988; Morgan, Kohrt, Bates, & Skinner, 1987). The case for benefits is stronger for persons with chronic obstructive lung disease because their activities can be limited by respiratory muscle endurance; but, the training procedures, practical benefits, and types of patients that may benefit have not yet been well documented (Cox, van Herwaarden, Folgering & Binkhorst, 1988; Kim, 1984; Levine, Weiser, & Gillen, 1986). The usual clinical respiratory endurance training uses high ventilation breathing with equipment that increases inspired carbon dioxide to prevent the adverse effects of hyperventilation. This training is limited because of the lack of equipment suitable for home use.

The rapid thoracic breathing studied by Frostell, Pande and Hedenstierna (1983) strongly shifted air flow to lung regions with low gas exchange rates.

Alternate Nostril Breathing

Yoga Practice

Alternate nostril breathing consists of slow deep quiet breaths using one nostril at a time (Sanskriti & Franks, 1978, pp. 159-161; Satchidananda, 1970, pp. 143 & 149). The thumb or ring finger are used to close off the other nostril. Three variations exist, depending on when the nostrils are switched. In one variation, the active nostril is switched after each inhalation. In the second variation, exhalation is through one nostril and inhalation through the other. After a few cycles, the inhalation and exhalation nostrils are reversed. The third variation switches nostrils after several breaths. For all three techniques, each breath is as slow as comfortable using full lung capacity as in the complete breath. A sitting position is used.

Beginners attempt to make the duration of inhalation and exhalation equal and do only about six single nostril breaths between rests. With practice, the duration of exhalation is slowly extended to twice the duration of inhalation and the practice is continued for several minutes. The mind is focused on the slow deep breathing in a manner similar to meditation. The advanced practice continues for 10 to 20 minutes or longer with the breath held after inhalation and/or exhalation. Yoga writings use a variety of terms for alternate nostril breathing, including nadi shodhanam, nadi suddhi and sukha purvaka.

Scientific Information

Existing research efforts have focused on understanding the psychophysiology of nasal functioning. This work is important background for understanding the potential effects and significance of the alternate nostril breathing technique, but basic direct research on the technique remains to be done. As discussed below, research has verified the yoga claims that nasal air flow is usually greater in one side of the nose than the other, and that the open side switches every few hours. The available data relevant to the yogic claim that this asymmetric nasal air flow is related to lateral brain functioning are inconsistent and difficult to interpret.

Autonomic Effects

Average heart rate increased from 71 to 78 beats per minute and blood oxygen, carbon dioxide, and pH did not change significantly after ten minutes of alternate nostril breathing (Pratap, Berrettini, & Smith, 1978). The ten subjects had two to five years experience with the technique. Average respiration rate was 2.7 breaths per minute during the last minute of alternate nostril breathing. The breath was not held except very briefly to move the hands while switching closed nostrils. (Data

from an investigation of advanced alternate nostril breathing is presented in the later section on breath holding.)

Background on Nasal Dominance

According to yoga tradition, alternate nostril breathing improves the functioning, coordination and balance for two modes of cognitive activity that are reasonably similar to current concepts of right and left hemispheric brain functioning (Rama, Ballentine & Ajaya, 1976). Ancient yoga writings claim that the modes of mental activity are related to which nostril is dominant or most open to air flow. Mental capabilities corresponding the left hemisphere dominate when the right nostril is more open. Likewise, right hemispheric mental capabilities dominate when the left nostril dominates. Equal air flow through both nostrils represents a balance of the two mental modes.

Yoga tradition also claims that nostril dominance and corresponding cognitive mode alternate approximately every one (Bhole & Karambelkar, 1968) or two hours (Rama 1986, p.89). According to these writings, the cycle becomes erratic with emotional disturbance, irregular eating or sleeping habits, and various other life style factors.

Nasal Airway Resistance

The airways of the nose are lined with erectile tissue that swells when engorged with blood. The swelling increases congestion and resistance to air flow, which enhances humidifying and warming of inhaled air (Cole, 1982, 1988) and may be an efficient passive mechanism for braking the respiratory system elasticity during periods of low ventilation (Hairfield, Warren, Hinton, & Seaton, 1987; Jackson, 1976; McCaffrey and Kern, 1979a; 1979b).

Nasal airway resistance changes in response to changing air flow or air conditioning needs. Nasal congestion (a) decreases (vasoconstriction) with exercise or with elevated carbon dioxide levels from breathing carbon dioxide, rebreathing with a bag, or holding the breath, and (b) increases (vasodilation) with hyperventilation or breathing cold air (Cole, Forsyth, & Haight, 1983; Cole, Haight, Love, & Oprysk, 1985; Dallimore & Eccles, 1977; Forsyth, Cole, & Shephard, 1983; Hasegawa & Kern, 1978; McCaffrey & Kern, 1979b; Richerson & Seebohm, 1968; Takagi, Proctor, Salman, & Evering, 1969; Tatum, 1923). Nasal resistance can vary greatly among subjects and over time (Holmes, Goodell, Wolf, & Wolff, 1950; Takagi et al., 1969).

Psychological factors such as stress, fear, and frustration can apparently affect nasal resistance. Eccles (1982) noted that adrenaline, which is released during stress, causes decreased nasal resistance. Clinical observations of patients with chronic or recurrent nasal congestion found that congestion increased during periods of anxiety or conflict with frustration, resentment and guilt (Holmes et al., 1950; O'Neill & Malcomson, 1954; Wolff, 1950), but decreased during fear and panic (Holmes et al., 1950, pp. 58 & 114). Holmes et al. (1950, p. 140) suggested that increased nasal congestion was associated with a passive, withdrawing response to stressors, whereas decreased congestion occurred in preparation for heightened respiration of an active fight or flight response.

Sympathetic nerves control nasal congestion whereas parasympathetic nerves control nasal secretion with some associated influence on blood flow and congestion (reviewed in Eccles, 1982). Reduced nasal sympathetic vasoconstrictor tone causes congestion, whereas increased sympathetic activity causes decongestion. Reduced parasympathetic tone causes reduced nasal secretion and reduced congestion, whereas increased parasympathetic tone causes increased nasal secretion and increased congestion. These conclusions are supported directly by experiments with animals and are consistent with the effects of surgical and chemical nerve blockade in humans (e.g., Chandra, 1969; Golding-Wood, 1973; Haight & Cole, 1986; Millonig, Harris, & Gardner, 1950; Richerson & Seeborn, 1968).

Nasal Dominance

Numerous studies consistently show that one side of the nose usually has higher airway resistance in most people and that the asymmetric resistance switches sides after a few hours (e.g., Clarke, 1980; Eccles, 1978; Gilbert & Rosenwasser, 1987; Hasegawa & Kern, 1977; Heetderks, 1927; Keuning, 1968; Stoksted, 1952, 1953).

However, the widely used term *nasal cycle* may not be technically correct because there is little evidence that the changes in nasal resistance have reasonably constant periods. As noted by Gilbert and Rosenwasser (1987), most nasal cycle studies have observed subjects for only a few hours on one day whereas much longer or repeated study periods are needed for relevant time series statistical analysis. Changes of nasal dominance during these short periods cannot be assumed to be a continuing cyclic (i.e., fixed period) process. In one of the few studies to attempt replicate testing, Hasegawa and Kern (1977) noted "of the five subjects who had second studies, none had reproducible findings" (p. 33). Likewise, failure to observe nasal resistance alternations in these short study periods does not mean they do not routinely occur in a subject.

Longer studies have given mixed evidence for regular cycles. Obvious regular shifts about every three hours were found for one subject examined for 18 hours (Principato & Ozenberger, 1970). Regular shifts about every one to two and half hours were found for two subjects examined for seven days (Eccles, 1978). However, for eight subjects studied for one month, the alternations in nostril dominance did not have regular periodicities, except for some very weak daily patterns found by averaging over the month (Clarke, 1980; Funk & Clarke, 1980). Most subjects in these latter studies also had one side dominant more often than the other.

Factors Affecting Nasal Dominance

Asymmetric or unilateral pressure on the chest, shoulders, trunk or buttocks can shift nasal dominance. The pressure triggers vasomotor reflexes that increase nasal resistance on the side of the pressure and decrease it on the other side (Bhole & Karambelkar, 1968; Cole & Haight, 1984, 1986; Davies & Eccles, 1985; Haight & Cole, 1984, 1986; Rao & Potdar, 1970; Singh, 1987; Takagi & Kobayasi, 1955). These reflexes cause (a) the readily observed congestion in the lower nostril and decongestion in the upper nostril when people lie on their sides, (b) the ancient yoga observation that placing a crutch or yoga-danda under one arm while upright leads to ipsilateral nasal congestion and contralateral

decongestion, and (c) in at least some persons, nasal dominance shifts due to asymmetrical weight distribution while seated (Haight & Cole, 1986). The widely varying time periods between nasal dominance shifts are not surprising if asymmetrical weight distribution can cause the shifts. Haight and Cole (1989) report that 37 of 42 subjects showed a nasal response to unilateral pressure.

Increased ventilation demands can also alter nasal dominance. Nasal resistance can become low and nearly symmetric during exercise, rebreathing with a bag, and probably breath holding (Dallimore & Eccles, 1977; also supported by the example in Ohki, Hasegawa, Kurita, & Watanabe, 1987). The amplitude of nasal resistance fluctuations is less while standing compared to sitting (Cole & Haight, 1986).

The hypothesis that anxiety and other life style factors cause shifts in nasal dominance is conceptually consistent with the evidence noted above that psychological factors affect nasal resistance, but specific studies of psychological factors and nasal dominance have not been reported. Eccles (1978) suggested that uncontrolled environmental factors may normally obscure the regular nasal cycles observed in his seven day laboratory study.

The neural mechanisms controlling nasal resistance are primarily ipsilateral, but some evidence suggests possible contralateral effects in some people. Unilateral sympathetic efferent severance or blockade in humans caused pronounced ipsilateral nasal congestion, and no apparent effect on contralateral nasal resistance and responses in several studies (Fowler, 1943; Haight & Cole, 1986; Holmes, et al., 1950, pp. 113-119). However, during unilateral sympathetic blockade, slight increases in contralateral resistance that may have been related to the blockade occurred in one study (Stoksted & Thomsen, 1953) and reduced contralateral nasal responses to exercise occurred in another study (Richardson & Seebom, 1968). Unilateral parasympathetic severance has resulted in less secretion and less congestion on the side of severance in several hundred patients surgically treated for excessive nasal secretion (Golding-Wood, 1973; Jarvis, Marais, & Milner, 1970; Millonig, Harris, & Gardner, 1950). The immediate unilateral effects were followed by contralateral effects about two weeks after surgery in about one third of the cases. The factors causing the unpredictable contralateral effects in a minority of the patients are not known.

Ultradian Rhythms

Shannahoff-Khalsa with various others have suggested that the nasal dominance alternations reflect an underlying endogenous cycle of shifting right-left dominance in the brain and autonomic system. They report lateral changes in brain wave activity (Werntz, Bickford, Bloom & Shannahoff-Khalsa, 1983) and peripheral catecholamines (Kennedy, Ziegler, & Shannahoff-Khalsa, 1986) tightly coupled with nasal dominance. In addition, they cite a variety of studies suggesting ultradian (less than a day) cycles in psychophysiology and performance with periods of about 80 to 150 minutes. In particular, the report by Klein and Armitage (1979) of 90 to 100 minute cycles in verbal and spatial performance that were 180 degrees out of phase supports the hypothesis of alternating lateral processing. These cycles are proposed to be an extension of alternating lateral dominance in rapid eye movement and nonrapid eye movement sleep stages.

Unfortunately, there are few noncontroversial findings in ultradian-laterality rhythm research. Replication of the Klein and Armitage (1979) study failed to find cycles of lateral cognitive processing (Kripke, Fleck, Mullaney & Levy, 1983). Some recent writers have strong arguments for doubting the basic hypothesis that rapid eye movement/nonrapid eye movement sleep cycles reflect reciprocal shifts in lateral brain activity (e.g., Antrobus, 1987; Armitage, Hoffman, Loewy, & Moffit, 1989). The integrated total EEG measure used by Werntz et al. (1983) and in several previous studies of lateral brain activity primarily reflects alpha activity, whereas lower amplitude higher frequency activity may be more important indicators of lateral cognitive processing (Armitage, 1989; Ray & Cole, 1985). The situation is compounded because Werntz et al. used the opposite interpretation than is traditional for this measure (i.e., they hypothesized that higher amplitude EEG [i.e., alpha activity] indicated more mental activity instead of less).

Convincing conclusions about rhythms of lateral physiological functioning will probably require extensive further research. This is a very difficult research area—the number of potentially important variables and methodological details are vast, as are the speculations about inconsistent findings.

Single Nostril Breathing and Brain Laterality

A recent experiment found evidence that performance on left hemispheric (verbal) and right hemispheric (spatial) tasks were affected by single nostril breathing, but the results provided little support for the specific predictions from yoga (Block, Arnott, Quigley, & Lynch, 1989). The results were contrary to the yoga predictions for males, and in the predicted direction for females on only the spatial task. For the spatial task, males performed significantly better during right nostril breathing than during left nostril breathing, whereas females had the opposite result. For the verbal task, males performed significantly better during left nostril breathing than during right nostril breathing, whereas females showed no difference in performance. Nasal air flow was not measured in this study. Single nostril breathing began five minutes before the tasks.

Two earlier experiments found that breathing through one nostril did not significantly affect performance on verbal and spatial tasks, but males and females were not analyzed separately (Klein, Pilon, Posser & Shannahoff-Khalsa, 1986). In one study, performance was measured before, during, and after 15 minutes of single nostril breathing. In the other study, performance was measured before and after 30 minutes of single nostril breathing.

The Klein et al. (1986) experiments also included measurement of asymmetric nasal air flow and reported equivocal results correlating air flow with performance on the tasks. Post hoc analyses combining both experiments correlated the difference between task scores with the degree of asymmetric nasal air flow. The correlation for the data collected before the single nostril breathing period gave a suggestive result ($p < .05$, uncorrected for multiple post hoc analyses) in the direction of yoga predictions, but explained less than four percent of the variance for 114 subjects. A similar result was obtained for the data collected after single nostril breathing. These results were due primarily to performance on the spatial task. Unfortunately, males and females were not analyzed

separately. The initial subject pool was 56 percent female, but some subjects of unspecified sex were excluded. The effect of single nostril breathing on lateral nasal airflow was not reported.

Another study reported single nostril breathing caused relatively larger total integrated EEG activity contralateral to the open nostril (Werntz, Bickford, & Shannahoff-Khalsa, 1987). The results for the one male and four female subjects were all in the same direction. As noted above, the traditional interpretation for this finding would be relatively more mental activity on the same side as the open nostril, which is counter to the predictions from yoga. After citing a study (Ray & Cole, 1985) suggesting that alpha activity, and by implication total integrated EEG, does not reflect lateral cognitive processing, the authors considered the results ambiguous.⁴

Several physiological studies on animals and humans indicate that nasal air flow receptors stimulate electrical discharges predominantly to the same side of the brain as the receptor (Kristof, Servit & Manas, 1981; Servit, Kristof, & Kolinova, 1977; Servit & Strejckova, 1976; Ueki & Domino, 1959). Although the studies show that unilateral nasal hyperventilation can trigger ipsilateral, and to a lesser extent contralateral, epileptic EEG activity in susceptible subjects, the overall implications are not clear. Of course, the very slow air flow rates of the alternate nostril breathing technique should minimize stimulation of the nasal airflow receptors indicated by these and other studies (Widdicombe, 1986).

Taken together, these studies provide little evidence for the specific cognitive effects of single nostril breathing that have been hypothesized based on yoga tradition. However, the specific yogic alternate nostril breathing techniques apparently were not used in any of these studies. In addition, any conclusions appear premature until basic questions about methodology and interpretation are resolved, and until further replications and explorations are carried out.

Further Research

Autonomic and psychological effects. Basic research on the effects of alternate nostril breathing techniques remains to be done. These techniques are widely held by practitioners to calm and sooth the mind, and appear ripe for research. Breathing rates near the subjects' limit of slow breathing may be particularly interesting due to enhanced carbon dioxide concentrations and minimum stimulation of air flow and olfactory receptors.

⁴ In another extension of the hypothesis of Werntz et al. (1983) that nasal dominance indicates activation of the contralateral brain hemisphere, Backon (1988) proposed that right hemispheric activation is associated with overall parasympathetic dominance in the body and left hemispheric activation is associated with overall sympathetic dominance. In studies with one subject, he reported that blood glucose levels were higher (Backon, 1988) and eye blink rates were lower (Backon & Kullok, 1989) during forced unilateral right nostril breathing than during left nostril breathing. In an abstract, Matamoros, Backon and Ticho (1988) reported lower intraocular pressure in 68 subjects after 20 minutes of unilateral right nostril breathing. Although various questions can be raised about generalization of the single-subject studies and about the methodology in the intraocular pressure study (which will presumably be answered with full publication), the ultimate evaluation of these studies must await not only replication, but also further research on the underlying assumption that single nostril breathing stimulates the contralateral side of the brain.

Autonomic reflex receptors on the face and in the nose that could possibly be stimulated by holding one side of the nose closed during alternate nostril breathing also offer research potential. As discussed in the next section, such receptors are an important component of the dive response. The receptors respond to water and some other mechanical stimulation (Daly, 1986; Daly & Angell-James, 1979; Elsner & Gooden, 1983). Medical procedures such as packing one side of the nose to halt a nose bleed can apparently activate this reflex (Daly & Angell-James, 1979; Fairbanks, 1986; Jackson, 1976). The related oculocardiac reflex has similar effects—gentle pressure on the closed eyes causes heart rate slowing and reduced respiratory drive characteristic of the dive response (Daly, 1986).

Prolonged exhalation. Research is needed on the hypothesis that the prolonged exhalation of alternate nostril breathing and other yogic slow breathing techniques promotes calmness and parasympathetic dominance. Heart rate slowing during exhalation (respiratory sinus arrhythmia) is the result of greater parasympathetic activity during exhalation (Daly, 1986; Grossman, 1983). Likewise, increased alpha EEG activity (Lehmann & Knauss, 1976) and theta activity (Lorig, Schwartz, & Herman, 1989) have been reported during exhalation. Muscle sympathetic activity has been found to vary with phase of respiration, but inconsistent findings suggest that variables such as breathing pattern are also important (Eckberg, Nerhed, & Wallin, 1985). In an initial investigation of prolonged exhalation, Cappo and Holmes (1984) found that slow breathing with prolonged exhalation resulted in less arousal from threats than breathing with equal durations of inhalation and exhalation (as used in previous studies), or with prolonged inhalation. The effect of the prolonged exhalation treatment was significantly different than for a control group without paced respiration, but the differences among breathing treatments did not reach statistical significance.

Nasal dominance. The hypotheses that lateral nasal dominance is related to lateral brain processing and that unilateral nasal breathing effects lateral brain activity both need further investigation. If nasal dominance is confirmed to have significant psychological or psychophysiological effects, then investigation of the factors controlling nasal dominance becomes important. Because any natural endogenous nasal cycle in humans is apparently normally overshadowed by exogenous factors, the most efficient course may be to first focus on the exogenous factors. The pressure points, postures, and weight distribution that shift nasal dominance due to asymmetric body pressure is an important and easily researched area. The finding that weight distribution while sitting can affect nasal dominance may have significant implications for daily life, but is based primarily on only two subjects (Haight & Cole, 1986). The hypothesis that stress, depression, fear, etc. alter nasal dominance and resistance also needs further research.

Theory. Research on nasal dominance is hindered by the lack of a coherent rationale for the phenomena. The speculation (e.g., Eccles, 1978) that the alternations of nasal airflow allow one side of the nose to rest from its air conditioning function offers a testable hypothesis, but provides no obvious explanation for the important and perhaps dominating effects of asymmetric body pressure, or for the possible effects on cognitive processing. The hypothesis that nasal respiration affects brain temperature and brain functioning (Zajonc, Murphy, & Inglehart, 1989) also offers research potential.

Therapy. Friedel (1948) discussed eleven case reports in which chest pain of angina pectoris and related stress were greatly relieved by alternate nostril breathing. Alternate nostril breathing was described as an effective means to obtain the benefits of slow deep diaphragmatic breathing, including parasympathetic stimulation and elevated blood carbon dioxide concentrations. Prakasamma (1984) reported that patients with restricted expansion of the lungs due to pleural effusion had significantly quicker re-expansion after 20 days of alternate nostril breathing treatment than a control group that followed routine physiotherapy. The patients reported that they enjoyed alternate nostril breathing.

Breath Holding

Yoga Practice

During intermediate and advanced practice of rapid breathing and alternate nostril breathing techniques, the breath is held after full inhalation (Rama, 1986; Satchidananda, 1970). With rapid breathing, the breath is held between groups of rapid breaths for just a few seconds initially and, after more practice, for as long as comfortable. With alternate nostril breathing, each completed inhalation is held for a few seconds initially and gradually extended to a period four times as long as the inhalation time—the time ratios for inhalation, breath hold, and exhalation being 1:4:2 in the final stage. In more advanced practices, the breath may also be suspended after exhalation. The mind is focused inward during breath holding and may concentrate on a particular area of the body such as the heart or forehead regions.

During breath suspension, the head is bent forward with the chin pressing against the hollow of the throat, and the anal sphincter muscles are usually contracted. These techniques are called the chin lock (Jalandhra Bandha) and root lock (Moola Bandha) respectively.

The abdominal lock (Uddiyana Bandha) is applied in more advanced breath holding, but is performed as an independent practice first. In the initial practice, the person stands, bending forward slightly with the arms resting on slightly bent knees. As air is exhaled, the abdominal muscles are drawn back and up toward the spine, creating a hollow in the abdomen. After maximum exhalation, the chin lock is applied and the chest is expanded, creating inhalation pressure against the closed air way, which further draws the abdominal region upward. When used with other breathing practices, the abdominal lock is initially used with exhalation. Later, chest expansion and abdominal muscle contraction are applied with breath holding after full inhalation, although inhalation pressure, of course, reduces as lung inflation increases.

Most yoga instructions give stern warning that prolonged breath suspension (kumbhaka) should be done only by experienced practitioners under the guidance of a knowledgeable teacher (e.g., Rama, Ballentine & Hymes, pp. 117-118, 122; Satchidananda, 1970, p. 144). Breath holding is commonly introduced gradually and without strain in yoga training.

Scientific Information

As discussed below, breath holding can initiate powerful parasympathetic and sympathetic reflexes. The net psychophysiological effects depend greatly on various physical and apparently psychological parameters during the breath hold. The limited available data suggests that the yoga locks during breath hold minimize stimulation of these potentially strong reflexes in beginning and intermediate students. Large oscillations of heart rate and blood pressure have been reported during yoga breathing techniques after several years of advanced practice.

Cardiovascular Effects of Breath Holding

Increased blood carbon dioxide concentrations from breath holding cause opening of the nasal airways as noted under alternate nostril breathing. Other effects of breath holding depend strongly on interactions among concomitant autonomic reflexes.

Heart rate for an inactive person (a) commonly decreases by roughly ten percent if the breath is held after maximum inhalation (summary in Lin, 1982, p. 274), (b) has little change if breath suspension is after normal exhalation (i.e., at FRC), and (c) increases or has little change if suspension is after maximum exhalation (Angelone & Coulter, 1965; Kawakami, Natelson, & DuBois, 1967; Openshaw & Woodroof, 1978; Song, Lee, Chung, & Hong, 1969). This research is characterized by significant variability of results among subjects and among studies. These and other studies also verify that the breath can be held much longer after inhalation than after exhalation (Lin, 1982, p. 286).

Exhalation pressure against the closed airway during breath holding increases heart rate whereas inhalation pressure can reduce heart rate (Craig, 1963; Paulev, 1968; Paulev et al., 1988; Sharpey-Schafer, 1965; Song, Lee, Chung, & Hong, 1969). Strong exhalation pressure (positive intrapulmonary pressure) can increase heart rate by over 30 percent above the baseline rate. Heart rate effects from negative intrapulmonary pressure are usually of smaller magnitude and lower consistency than the effects of positive pressure. Lack of control of lung inflation and intrapulmonary pressure in many studies of heart rate during breath holding probably contributes to the variability of experimental results.

Control of pressure in the lungs requires deliberate effort because respiratory system elasticity leads to exhalation pressure if the respiratory muscles are relaxed after inhalation. Thus, heart rate slowing from breath holding can be canceled unless tension is maintained in the respiratory muscles.

Breath holding also causes vasoconstriction and decreased blood flow to the limbs, presumably with well maintained flow to the brain and heart (Brick, 1966; Elsner, Franklin, Van Citters & Kenny, 1966; Heistad, Abboud, & Eckstein, 1968). The reduced peripheral blood flow is accentuated by exhalation pressure during breath holding (Paulev, 1969, pp. 83-99).

Breath holding combined with stimulation of receptors on the face or in the nose initiates the *dive response*. This response greatly enhances (a) heart rate slowing, and (b) blood flow to the brain and heart muscle at the expense of the periphery (reviewed in Daly, 1986; Elsner & Gooden, 1983). The response also reduces the drive to breath and often increases blood pressure. Heart rate reductions

of 20 to 35 percent are common for an inactive person (Lin, 1982, p. 274). The dive response may override the normal cardiovascular response to exercise and may even be intensified by exercise (Elsner & Gooden, 1983, p. 50).

The nature of facial stimulation appears to be important, but is not well understood. Water or some types of mechanical stimulation on the face, eyes, or nasal lining can initiate the dive response (Daly & Angell-James, 1979; Elsner & Gooden, 1983, pp. 92-96; Jackson, 1976; Widdicombe, 1986). One uniform finding is that cold water on the face enhances the response. Stimulation of the receptors without concurrent breath holding appears to cause the same types of cardiovascular responses, but to a lesser degree (Brick, 1966; Heistad & Wheeler, 1970; Whayne, & Killip, 1967). However, better understanding of these receptors and possible interactions with lung volume and intrapulmonary pressure is needed before these effects can be discussed with confidence.

Breath holding and the dive response can initiate both parasympathetic and sympathetic cardiovascular responses. Heart rate slowing is apparently mediated by the parasympathetic system whereas the reduced peripheral blood flow presumably results from increased peripheral sympathetic activity (Elsner & Gooden, 1983, p. 101; Paulev, 1969, p. 94). For comparison, meditation and related relaxation procedures often tend to increase peripheral blood flow (Levander, Benson, Wheeler, & Wallace, 1972; Luthé, 1963; Rieckert, 1967), as does mental stress (Bennett, Hosking, & Hampton, 1976). Various mechanisms may mediate the cardiovascular responses. For example, the altered heart rate during positive or negative intrapulmonary pressure may be, in part, a response to altered venous return to the heart due to intrapleural pressure changes (Craig, 1963; Paulev, 1969, p. 71).

Psychological factors can override or possibly enhance the autonomic responses to breath holding. Mental distraction or preoccupation during breath holding or the dive response can attenuate or eliminate the cardiovascular responses (Ross & Steptoe, 1980; Wolf, 1978; Wolf, Schneider, & Groover, 1965). Wolf et al. (1965) also reported that subjects who were rushed or harassed with a multitude of instructions failed to show a dive response, but the response normally occurred in quiet test conditions. They also reported that with repeated testing, the dive response became more pronounced and became a conditioned response—the cardiovascular responses began at the signal for facial immersion prior to immersion. Fear appeared to enhance the dive response (Wolf, 1978; Wolf et al. 1965). In a few subjects, the stress of arterial puncture for the experiment induced striking heart rate slowing and peripheral vasoconstriction prior to the breath holding procedure.

These psychological factors may contribute to the wide variability in the results of experiments on breath holding.

Chin and Abdominal Locks

Given the importance of factors such as intrapulmonary pressure, the chin and abdominal locks may have decisive influence on the cardiovascular response to yogic breath holding.

The available data indicate that heart rate for relatively inexperienced subjects increases slightly or shows no change during breath holding with chin and abdominal locks. Average heart rate increased about 8 percent during full inhalation breath holding with the chin lock (but no abdominal

lock) compared to the average baseline rate (Bhole, 1979). The six subjects had only about seven weeks experience with the lock. Average heart rate showed no change from the baseline rate during abdominal locks in a study with 39 subjects with apparently less than eight months training (Oak & Bhole, 1984). Average heart rate increased by about 10 percent in another study with 28 subjects (Gopal, Anantharaman, Balachander & Nishith, 1973). This study included the root lock and found similar heart rate responses in subjects with no previous experience and in subjects with at least six months training. Likewise, heart rate responses were similar for breath holding after full inhalation or exhalation.

However, certain individuals may show a striking heart rate decrease during yogic breath holding. The heart rate of a healthy 21 year old male slowed to 34 beats per minute while doing the abdominal lock after three weeks practice (Monjo, Gharote, & Bhagwat, 1984). Heart rate was normal before and after the maneuver.

Radiological and direct observation indicated that the expanded chest of the combined chin, abdominal, and root locks avoided physical pressure on the heart and blood vessels, and maintained blood flow to and from the head (Gopal & Lakshmanan, 1972). The authors also reported that the shape of the heart indicated good venous return. This latter result is not surprising because contraction of the abdominal muscles greatly increases venous return and cardiac output (Guyton, 1986, p. 277). Similarly, Lamb et al. (1958) noted that pilots discovered early in aviation that "undesirable effects of G forces could be alleviated in part by tightening of the stomach muscles and taking a deep breath, thus enhancing venous return to the heart" (p. 570). Yogic writers have also noted that the chin lock can help maintain a closed air way during breath holding (e.g., Rama Ballentine, & Hymes, 1979, p. 124).

Advanced Breath Holding

Schmidt (1983) observed large rhythmic swings in heart rate and blood pressure during advanced yoga breathing practices by a subject with over five years experience. Heart rate during alternate nostril breathing increased to about 120 beats per minute during breath holding and quickly decreased to about 60 bpm during the slow exhalation. Blood pressure in the left brachial artery decreased to about 55/30 mm hg (systolic/diastolic) during breath holding and quickly increased to about 150/65 mm hg during the slow exhalation. The subject's baseline resting heart rate was about 70 bpm and blood pressure about 105/50 mm hg. The time ratios for inhalation, breath hold, and exhalation were 1:4:2, with about one breath per minute. Similar large swings were observed for two other slow full volume yoga breathing techniques and for two other advanced practitioners.

The subjects reported that the experience of enhanced energy, mental and physical balance, calmness, and mental clarity associated with the breathing practices increased greatly after several years of practice. The author noted (with out providing data) that beginners following the same techniques did not show such strong physiological changes. According to the advanced subjects, more successful practice and prolonged breath holding depend on increased concentration and relaxation during practice.

Schmidt noted that these cardiovascular responses presumably cause large oscillations in blood flow to various organs, which could possibly be related to the mental effects. However, he also noted that further research is needed to determine the mechanisms and details of these striking cardiovascular effects. Positive intrapulmonary pressure may contribute to these effects. The valsalva maneuver (sharp exhalation pressure against a closed airway) produces increased heart rate and reduced blood pressure, which is followed by reduced heart rate and increased blood pressure after cessation of the maneuver (Daly, 1986, p. 569).

Cardiac Arrhythmias

Breath holding and the dive response can induce a variety of cardiac arrhythmias (Lamb, Dermksian, & Sarnoff, 1958; Olsen, Fanestil, & Scholander, 1962; Wayne & Killip, 1967), but these appear to be a health threat only for people with significant pre-existing heart abnormalities (Paulev, 1969, p. 72). The strong parasympathetic cardiac stimulation from the dive response has been successfully and safely used as a means of halting paroxysmal atrial tachycardia, but requires extreme caution in patients susceptible to ventricular abnormalities because dangerous arrhythmias can be induced (Mathew, 1978; Wildenthal & Atkins, 1979; Wildenthal, Leshin, Atkins, & Skelton, 1975). Efforts to minimize fear and distractions that could possibly enhance or neutralize the dive response are recommended with this treatment (Wildenthal, Leshin, Atkins, & Skelton, 1975).

In case studies of two patients reporting heart rhythm abnormalities at rest, the abdominal lock exacerbated a nodal cardiac arrhythmia in one case and induced premature ventricular beats in the other (Monjo, Gharote, & Bhagwat, 1984).

Thus, the yogic cautions that breath holding techniques should be introduced gradually and only with proper guidance and experience appear to be reasonable, particularly in the absence of a thorough heart examination. The techniques appear to pose no threat when done properly and introduced gradually for normal subjects. The implications of the reported large swings in heart rate and blood pressure during advanced breath holding practices need further study.

Physical Effects

The very limited data on oxygen consumption during rapid breathing with breath suspension are within the range discussed above for rapid breathing without breath holding (Karambelkar, Deshpande, & Bhole, 1983; 1984b; Miles, 1964). This limited data provides no evidence that yogic breath holding causes either an extreme increase or an extreme decrease in oxygen consumption.

Further Research

Psychophysiological effects. The elevated carbon dioxide levels from breath holding may have psychophysiological effects similar to those discussed for diaphragmatic breathing. Substantial blood carbon dioxide concentrations appear to contribute to the beneficial effects of slow deep breathing. Further research on the psychophysiological effects of the yogic breath holding

techniques is needed, particularly when combined with rapid breathing and alternate nostril breathing. The evidence that advanced practices produce effects that are different from the beginning practices must be considered in planning research.

Psychological factors. Mutual interactions between autonomic responses to breath holding and psychological factors such as distraction, stress, fear, etc. may provide important information on the relation between the autonomic and central nervous systems as well as on useful breathing techniques.

Carotid sinus stimulation. Some yogic writers suggest that after extensive practice, the chin lock stimulates the parasympathetic carotid sinus pressure receptors in the neck and alters the practitioner's state of consciousness (e.g., Kavalayananda, 1966, p. 28; Rama, Ballentine, & Hymes, 1979, p. 124). Although the available data show little evidence of strong parasympathetic stimulation (heart rate slowing) during the chin lock for most subjects, the topic needs further study as minor modifications of the technique could easily have major effects. Stimulation of the carotid sinuses while holding the breath may pose significant cardiac threats (Daly, 1986, p. 577).

Variations and Other Techniques

In addition to the basic yoga breathing techniques described above, several variations and other techniques are described in yoga manuals. For example, rapid breathing may be done through one nostril at a time (Samskrti & Franks, 1978, p. 158). Because yoga practice focuses on the basic techniques described in earlier sections and virtually no research has been carried out on these other techniques, they will not be discussed here.

However, the Ujjayi technique should be mentioned as it is considered a fundamental technique in some yoga schools, though not as widely practiced in the United States as in some other countries. This technique has also been the topic of research. Ujjayi consists of very slow smooth maximum inhalation, followed by slow smooth maximum exhalation. Air flow is restricted by keeping the glottis in the throat partially closed, which results in a soft uniform low hissing sound. During inhalation, the abdominal muscles are kept slightly contracted, resulting in increased emphasis on maximum chest expansion. The technique is continued for a few minutes initially. In more advanced practice the breath is held after inhalation and sometimes after exhalation. The ratio of inhalation, breath holding, and exhalation in the advanced practice is 1:4:2. The mind is focused on breathing, particularly the low hissing sound.

Ujjayi was one of the techniques that induced the large oscillations of heart rate and blood pressure reported by Schmidt (1983). The pattern of cardiovascular fluctuations was similar to that described above for alternate nostril breathing. Studies investigating oxygen consumption during Ujjayi have found varying results. Rao (1968) reported that oxygen consumption for one inexperienced subject during Ujjayi increased above resting rates by about 8 percent at low altitude and about 10 percent at high altitude. Miles (1964) reported oxygen consumption for one experienced subject (who smoked cigarettes regularly) increased by an average of 19 percent during Ujjayi. Karambelkar, Deshapande, and Bhole (1984b) reported that average oxygen consumption during

Ujjayi was slightly below the average resting rate for three subjects with over one year experience. Breath holding was done in all studies.

Discussion and Conclusions

Physical Effects

Slow simple diaphragmatic breathing provides efficient respiration in terms of muscular activity, cardiac output, and, at least under some conditions, optimal distribution of air for gas exchange. At the other extreme, the yogic rapid breathing techniques give extremely inefficient respiration that can provide significant exercise for the respiratory muscles. This inefficient respiration prevents significant hyperventilation during rapid breathing and results from tidal volume being relatively close to the respiratory dead space volume. Relative efficiency or energy expenditure (oxygen consumption) has not been established for the very slow, full volume respiration techniques such as alternate nostril breathing.

Autonomic Effects

Yogic breathing techniques can influence sympathetic/parasympathetic balance. Slow diaphragmatic breathing promotes parasympathetic dominance, whereas the rapid breathing techniques may promote arousal and sympathetic dominance, particularly if slight hyperventilation is induced. The very slow full volume respiration of the complete breath and alternate nostril breathing techniques probably promote parasympathetic dominance, but need further research.

The psychophysiological effects of yogic breath holding practices may vary greatly with degree of experience. Breath holding can cause parasympathetic and/or sympathetic cardiovascular effects depending on concomitant factors such as intrapulmonary pressure and degree of inhalation. The limited available evidence suggests that beginning to intermediate practitioners have little change or slight increases in heart rate during yogic breath holding techniques. However, a group of advanced practitioners had very large oscillations of heart rate and blood pressure during slow full volume breathing techniques with breath holding. These large effects apparently occurred only after several years experience. The effects of these cardiovascular oscillations on blood flow to the various organs and their possible role in the reported pleasant, beneficial subjective experiences from the practices are not known.

Practice of hatha yoga (breathing techniques and stretching postures) appears to shift overall basal autonomic balance to the parasympathetic direction. This hypothesis is supported by a two month experiment with random assignment to experimental and control groups (Gharote, 1971), a three month prospective study without a control group (Joseph, et al., 1981), and a cross sectional

comparison between a group of advanced yoga practitioners and a less experienced group (Wenger & Bagchi, 1961).

The ancient yoga claims that nasal airflow resistance is usually greater in one nostril than the other and alternates between nostrils every few hours have been consistently verified in numerous studies. The claimed relationship between nasal dominance and lateral cognitive functioning has yet to be adequately explored. However, the few initial studies suggest that complicating factors such as sex and handedness must be considered, as is consistent with other research on brain laterality.

The psychophysiological effects of respiratory maneuvers depend greatly on physiological and psychological details. The effects of intrapulmonary pressure, lung inflation, and psychological factors on cardiovascular responses to breath holding clearly demonstrate this principle.

Stress Management

There is substantial evidence that slow diaphragmatic breathing reduces adverse psychophysiological and psychological effects of chronic stress and reduces reactivity in stressful situations. Although this evidence is primarily based on simple slow deep breathing, the benefits almost certainly also apply to very slow, full volume breathing techniques such as the complete breath and alternate nostril breathing. An experiment by Scopp (1974) supports this extension. Subjects randomly assigned to treatments had significantly lower state anxiety and trait anxiety after about two weeks practice of yogic breathing techniques than control subjects. The yoga breathing techniques consisted of the complete breath, alternate nostril breathing, and another less common slow full volume technique. The control subjects had comparable time periods devoted to lectures and discussions about the benefits and methods of relaxation, and were encouraged to relax as best they could after the lecture-discussion periods.

The available data indicate that practice of hatha yoga (postures and breathing) results in slower, deeper basal respiration. This hypothesis is supported by a six week randomized experiment (Dhanaraj, 1974—summarized in Funderburke, 1977); a ten week prospective study with a control group, but apparently not random assignment (Makwana, Khirwadkar, & Gupta, 1988); three prospective studies without control groups (Anantharaman & Kabir, 1984; Anantharaman & Subrahmanyam, 1983; Udupa, Singh, & Settiwar, 1971—also summarized in Udupa & Singh, 1972); and cross sectional studies comparing experienced yoga practitioners with controls chosen with some matching for age and body size (Gopal, Anantharaman, Balachander, & Nishith, 1973; Gopal, Bhatnagar, Subramanian, & Nishith, 1973; Stanescu, Nemery, Veriter, & Marachal, 1981).

The potential stress management value of yogic rapid breathing techniques needs further study. The common sequence of breathing practices is complete breath, rapid breathing and alternate nostril breathing. The possibility that performing rapid breathing before a slow technique may enhance tension reduction deserves investigation.

No evidence of basal respiration rate slowing was found for six subjects after six months practice of Ujjayi (a slow breathing technique) followed by rapid breathing, and without yoga stretching postures (Udupa, Singh, & Settiwar, 1975). This result hints that the relationships among the

postures and various breathing practices needs investigation; but, of course, conclusions are limited by the small sample size, the specific techniques selected, and the absence of relevant control groups.

Breathing Practices and Integrated Treatment Programs

Yoga based slow deep breathing practices combined with yoga postures and/or related physical and mental practices have produced significant, in some cases remarkable, improvements of chronic diseases in controlled experiments. Heart disease (Ornish et al., 1979; 1983; 1990) and hypertension (Irvine, Johnston, Jenner, & Marie, 1986; Patel, Marmot & Terry, 1981; Patel & North, 1975) have received the most attention. Experimenters have also reported significant results for chronic lung disease, although improvements in symptom reports have generally not been reflected in standard lung function measures (Kulpati, Kamath, & Chauhan, 1982; Tandon, 1978). Significant improvement of asthma has also been reported with hatha yoga practice, but these studies are less convincing as they lacked control groups (Bhagwat, Soman, & Bhole, 1981; Nagendra & Nagarathna, 1986), or had questions about initial differences between groups (Nagarathna & Nagendra, 1985; comments in Bradley, 1985).

The stress reduction benefits of slow deep diaphragmatic breathing suggest that breathing practices are a valuable component of these integrated treatment programs. This concept is also supported by Scopp's (1974) study, which found that a treatment with both yogic breathing practices and a physical relaxation procedure produced significantly lower state and trait anxiety than either the breathing or relaxation treatments alone. Anxiety reduction for the combined treatment was approximately equal to the sum of the reductions for the two individual treatments.

Breathing practices may have a mutually reinforcing relationship with other physical and mental control practices. The experience with hyperventilation demonstrates that stress and respiratory function mutually interact—stress can affect respiration and respiration can affect stress responses. This suggests that concomitant practices that reduce stress responses may enhance the beneficial effects of breathing practices. The evidence suggesting that psychological factors such as anxiety, distraction, and depression can affect respiratory factors such as nasal resistance and autonomic reflexes of the dive response is in line with this hypothesis.

Because the combined psychological, physiological, and environmental forces that lead to chronic disease are strong and well established, it can be expected that a battery of therapeutic effort is optimal for overcoming these forces. Breathing practices appear to be a useful component of that battery.

Precautions

Yogic breathing practices provide no known health threats to normal persons when carried out in accordance with the usual instructions and precautions. However, persons with cardiac abnormalities should have approval from a physician and be careful to avoid hyperventilation during rapid breathing and to avoid marked heart rate changes during breath holding.

To be on the safe side when yoga techniques are offered to the general public, the instructions should emphasize that rapid breathing should be stopped and performed less vigorously if dizziness or other signs of significant hyperventilation occur. Also, breath holding should be introduced gradually, without strain, and using proper techniques. Advanced practices with significant breath retention should be explored cautiously. These precautions are described in most yoga manuals and courses. It should also be noted that most yoga masters believe that abuse of advanced breathing practices pose significant health threats beyond the cardiac effects discussed here. These other potential threats have not yet been scientifically investigated; however, several anecdotal reports of psychological and physiological disturbances apparently related to unsupervised, excessive yoga practice have been described (Krishna, 1971; Sannella, 1987).

Further Research

Two areas stand out in particular as potentially important topics for further research:

1. The evidence that psychological factors (distraction, anxiety, frustration, fear, etc.) strongly affect cardiovascular-respiratory relationships brings into focus the need to investigate and control these factors in experiments and in therapeutic applications of breathing practices. The yoga practice of concentrating awareness inward on respiration during breathing practices deserves investigation. The importance of these psychological factors also implies that the degree of experience with a breathing practice deserves particular consideration. It cannot be assumed that a subject's initial encounter with a breathing technique accurately indicates the potential effects.

2. The alternate nostril breathing technique is widely held by practitioners to promote a calm, alert mind and body, yet basic research on the psychophysiological effects of the practice remains to be carried out.

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