

# Noise and Stress: A Comprehensive Approach

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The fundamental purposes of hearing are to alert and to warn. As a result sound directly evokes emotions and actions. The processing of sound by the brain is outlined to provide a biological and psychological basis for understanding the way in which sound can become a human stressor. The auditory orienting response, startle reflex and defensive response translate sound stimuli into action and sometimes into stress induced bodily changes through "fight or flight" neural mechanisms. The literature on the health and mental health effects of noise then is reviewed in the context of an integrated model that offers a holistic approach to noise research and public policy formulation. The thesis of this paper is that research upon, and efforts to prevent or minimize the harmful effects of noise have suffered from the lack of a full appreciation of the ways in which humans process and react to sound.

## Introduction

The damaging effects of noise usually are regarded as limited to the structures of the ear through impairing one's ability to hear sounds such as speech and music. Often unappreciated is the fact that noise has more pervasive physiological effects (1, 2).

In the course of evolution, certain fishes developed organs of hearing to orient themselves in space. In amphibians, vision provided the ability to locate prey but was not sufficient in terrestrial environments to warn of other predators. Hearing accordingly developed as an organ for perceiving and responding to danger (3). Hearing also has played a role in sexual mating behaviors in mammals and even insects. These primitive functions exist in humans as well.

From the outset sound has evoked emotions and actions through the inner ear's direct connections to "fight or flight" neural mechanisms via the autonomic nervous system. Because of this defensive

purpose, hearing also cannot be turned off, and sound registers in the brain even during sleep. Only later in primate evolution did the auditory system include higher cerebral centers permitting the appearance of spoken language.

The current usage of the terms "nonauditory" or "extraauditory" is unfortunate. This distinction designates as nonauditory the auditory system's original, primitive influence upon wakefulness and body activity. The auditory system and physiological responses to sound are inseparably connected. Therefore, all of the effects of noise on the body mediated by the ears are "auditory" effects. More precisely, the effects of sound on the body through vibration of structures other than those of the auditory system are "non-auditory" or "extra-auditory."

Another basic consideration in understanding the functioning of the auditory system merits emphasis. The human auditory system was designed to process the frequencies and intensities relevant to survival in the sound environments of nature. The evolutionary process has not allowed humans enough time to adapt hearing to sounds generated by loud modern noise sources. This means that the auditory apparatus is not prepared to cope with commonly encountered urban and industrial noise. Consequently, we find ourselves exposed to sound envi-

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ronments that overload the auditory system. An analogous situation would occur in the visual system if we were forced to look at the sun and thereby damage the retina.

The fundamental relationships of hearing to emotion and action and the auditory system's vulnerability to modern sounds are not appreciated sufficiently by the public. Research also has suffered from a lack of breadth and depth in conception resulting in contradictory findings. For example, laboratory studies of healthy young people have concluded that noise has no harmful psychophysiological effects on humans. At the other extreme are reports that jet aircraft noise increases psychiatric hospital admissions.

We lack a comprehensive model to ensure that research on sound includes the critical variables that make it a significant source of human stress. Much of the research cited in this paper suffers from methodological inadequacies because noise is but one of a number of variables affecting complex human beings. Before delineating the system levels involved in bodily responses to sound, we first will outline the neuroanatomy and physiology of the central processing mechanism of sound.

## Neuroanatomy of the Auditory System

An appreciation of the structural basis for physiological and behavioral responses to sound can be gained from knowledge of the neuroanatomy of the auditory system (Fig. 1). The auditory pathways of the central nervous system consist of direct pathways from the inner ear to the auditory cortex and indirect pathways to the reticular activating system which connect to the limbic system and other parts of the brain, the autonomic nervous system and the neuroendocrine system (4).

The direct auditory connections consist of ascending pathways which carry impulses excited by sounds from the receptor cells in the organ of Corti to the auditory centers in the cerebral cortex. These pathways end in the temporal lobe where the sum of incoming impulses are consciously perceived and interpreted. The ascending auditory pathways travel along the auditory nerve via the cochlear nucleus, superior olivary complex, inferior colliculus, nuclei of the lateral lemniscus and geniculate body to a number of areas in the auditory cortex which in turn are connected to other cortical areas that

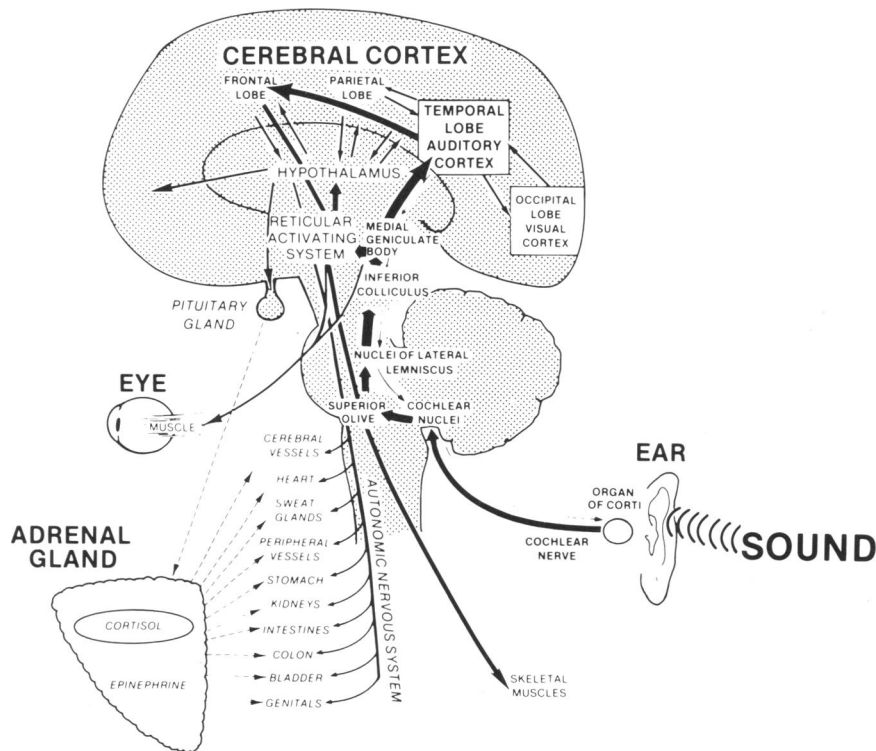


FIGURE 1. Processing of sound by the brain.

receive inputs from the other sensory organs as well.

There also are descending pathways from the temporal cerebral cortex to the dorsal cochlear nucleus via the inferior colliculus and to the organ of Corti via the medial geniculate body, inferior colliculus and lateral lemniscus through the olivocochlear bundle. These descending pathways have inhibitory and, to a minor degree, excitatory influences.

In addition to these direct pathways to and from cerebral cortex, there are a variety of indirect connections from the inner ear to the brain centers that control basic physiological, emotional and behavioral responses of the body. Nerve fibers branch out from the various synaptic junctions along the direct auditory pathways to motor cell nuclei subserving reflexes within the brainstem and to the reticular activating system in the midbrain.

Impulses reaching the reticular activating system excite still other impulses that spread to higher cerebral centers that control alertness, cognition and motor performance. At the same time the reticular activating system conveys impulses to hypothalamic autonomic nervous system centers which are linked to the sympathetic-adrenal neuroendocrine system and thereby regulate the secretion of the catecholamines, adrenaline (epinephrine) and noradrenaline (norepinephrine). Impulses conveyed by the reticular activating system also are transmitted to the pituitary-adrenal neuroendocrine system which secretes corticosteroids (cortisol). The catecholamines play an important role in mobilizing immediate adaptive resources of the body, and the corticosteroids provide for more enduring adaptation to prolonged stress (5). Thus, the auditory apparatus is connected to the entire central nervous system and the neuroendocrine system as well.

## Physiology of Sound

In conjunction with the other special senses, the auditory system serves to maintain the arousal of the brain projections to the temporal cortex and the reticular activating system via the limbic system and the hypothalamus. In this way cognitive processes and emotions interplay with sound stimuli in influencing the state of consciousness.

The cerebral cortex requires a certain level of arousal to make optimum use of incoming sensory information upon which efficient behavior and physiological functioning depend (6). Neither underarousal nor overarousal is conducive to effective performance of physiological functioning (7). Sound can

improve performance on tasks which are inherently underarousing, repetitive, and monotonous. Conversely, sound can impair performance on tasks demanding concentration and complicated responses (8). Sound contributes to the homeostasis of the central nervous system and consequently influences the physiological homeostasis of the body through the autonomic and neuroendocrine centers of the hypothalamus.

The arousal level of the central nervous system depends upon the intensity, complexity, variability, predictability and meaning of sound stimuli. The auditory system responds most to changes in the timing of sound stimuli. Therefore, a transient increase in the firing of auditory neurons may be produced by the termination of a sound as well as by its inception. Some neurons in the auditory system respond to stimulus onset with a high rate of impulse discharge, quickly cease firing, remain silent while the stimulus is continued, and discharge a second burst of impulses when the stimulus stops. However, in a much larger number of neurons, the rate of firing declines to a lower level of activity shortly after the initial high frequency discharge and then is tonically maintained during long periods of continued stimulation. These sound stimulus-induced alterations persist after the stimulation ceases (9).

The direct effects of certain sounds on emotions and attitudes is illustrated by the fact that chalk scraping on a blackboard can cause chill sensations in a listener. Musical rhythm, tempo and melody can evoke moods ranging from calmness to excitation or elation. Music also can promote positive attitudes toward work. The further influence of higher cerebral cortical centers on the emotional reaction to sound stimuli is illustrated by a study of sound in hospitals in which one source of annoyance was staff conversations in the halls, not because of undue loudness but because of the discussion of patients (10).

Sound stimuli also influence the other sensory systems. For example, sound input overload can induce visual changes in color perception, cause nystagmus and vertigo and even act as an analgesic (11).

In summary, sound stimuli play a vital role in maintaining arousal of the brain and thereby influence the basic physiological functioning of the body. Sound may influence the body after cessation of the stimulus through reverberating neural circuits within lower and higher brain centers. In this way sound can produce physiological reactions that develop a momentum of their own independent of the original stimulus.

## Fundamental Auditory Responses

### Orienting Response (Novelty Reflex)

The basic behavioral response to all sound stimuli is the orientation reflex, which involves ascending and descending auditory cortical pathways and is reflected by an arousal pattern in the electroencephalogram. The response orients the head and eyes toward the source of a sound in order to ready the organism to receive and respond to the sound stimulus situation. There is an associated decrease in auditory threshold and increased attention to the sound stimulus.

The orienting response occurs to sounds of low or moderate intensity and significance. The person's cognitive appraisal of the sound stimulus determines the intensity and duration of the orienting response. It extinguishes, or habituates, after varying repetitions so that the individual can accommodate to familiar and insignificant sounds with relative ease and concentrate on a preferred activity. If an appreciable amount of time passes between repetitions of a specific sound, habituation disappears and repetition of the same sound again evokes an orientation response. Habituation usually does not occur if attention to a sound is voluntarily sustained or if a sound has special significance, either positive or negative. Sounds of close to hearing threshold intensity do not easily habituate, probably because of the auditory system's difficulty in assessing their significance.

Even after behavioral habituation has occurred, sound stimuli continue to activate both cortical and subcortical areas of the brain (9). This is in part because excitation transmitted by the reticular activating system continues to arrive in the cerebral cortex after that transmission directly ceases. When the decision is made not to orient to a sound, descending cortical excitation actively restrains, but does not eliminate, the reticular activating system's excitation from spreading to higher areas of the brain. After the orienting response to sound habituates, there may be no change or an increase in the amplitude of the electrical responses evoked in the cerebral cortex and the medial geniculate body. The reticular activating system and the structures that it influences continue to be affected by sound even after behavioral habituation has occurred. This is not surprising because the organism's survival would be threatened by decreased alertness to danger if unattended stimuli were excluded from cognitive appraisal.

### Startle Reflex

The second basic auditory response is the startle reflex which is evoked by sounds of sudden, intense, or frightening significance. The reflex has a series of components. First, the middle ear muscle reflexes via the superior olive to the tensor tympani through the fifth cranial nerve and to the stapedius muscle through the seventh cranial nerve provide a small degree of protection against sounds of extremely high intensity. The auropalpebral reflex via the superior olive and the sixth cranial nerve produces eye blinking. There also is opening of the mouth and flexion of the neck via the seventh and eleventh cranial nerves. More generally, there is flexion of most muscle groups in a "freezing" posture with raising of the shoulders, abduction of the arms, flexion of the fingers, contraction of the abdomen, and bending of the knees mediated by the ascending auditory and descending cerebral cortical motor pathways. The typical reflex is completed in less than one second.

Those components of the startle reflex that reflect cerebral cortex activity are subject to habituation or enhancement, however, those involving lower centers in the brainstem are not. The startle reflex accordingly can be decreased by anticipation, increased by background sound levels and exaggerated by emotional states such as fear.

### The Defensive Response ("N" Response)

Although usually an extension of the orienting or startle responses, the defensive response merits separate consideration because it can occur independently of them and does not require sounds of high intensity. This response is produced by sounds of sufficient intensity, significance or duration to be perceived as threatening and to mobilize a "fight or flight" reaction. The response includes alerting of the cerebral cortex, emotional arousal, and preparation of the body for action (12).

Sounds in the range of 70 to 120 dB can produce the defensive response which appears first in the form of skeletal muscle tension that quickly reaches its peak and decays within a few seconds. Next there is a decrease in skin electrogalvanic resistance which changes more gradually than the skeletal muscle tension. Pupillary dilation occurs as well. A variety of circulatory responses are next in order: first an acceleration of pulse rate and decrease in pulse pressure, then a constriction of the finger and dilation of the chin blood vessels, followed by a slowing of pulse rate and an increase in pulse pressure. Finally in the series comes a shift to slower,

deeper breathing. The defensive response also includes a reduction in salivary and gastric secretions and slowing of digestive processes (4).

The defensive response largely involves the sympathetic nervous system but has some parasympathetic aspects. This response is not limited to a single organ system or structural division of the nervous system. It occurs independent of emotional response on the part of the subject. It is altered by sound intensity and band width in a dose-dependent fashion. It does not completely habituate (13), although under laboratory experimental conditions, substantial apparent physiological habituation has been reported (14). It also may be elicited by low levels of sound with special significance (15).

Under actual working conditions, the physiological effects of the defensive response were found in sawyers exposed to bandsaw noise (16). Another laboratory study noted a decrease in blood eosinophile level reflecting a stress response after 25 min exposure to 85 dB level noise (17).

The defensive response can become the stress that leads to the General Adaptation Syndrome that will be described more fully later with its alarm, resistance, and exhaustion stages if the sound stressor is of sufficient duration, quantity, and quality (18). When this takes place the hypothalamic-pituitary-adrenal axis is mobilized with resulting increase in adrenal cortisol and epinephrine output. During prolonged exposure to intense sounds, these endocrine effects may produce gastroduodenal ulcers and renal changes in laboratory animals (1).

Next we will enumerate the critical variables that determine whether or not sound stimuli become stressors that produce human stress.

## Sound as a Stressor

Modern urbanization, crowding, the mass media, information technology, conditions of work and noise are overloading the human sensory environment (19). Of these stimuli our interest is in sound, particularly noise, although sound with meaning, such as speech, also can contribute to overloading an individual's processing capabilities. The progressive increase in noise from industrial, traffic and home sources, both machine and human generated, has reached offensive proportions in the United States (20, 21).

Noise essentially is unwanted sound. As such, subjectively experienced noise is any sound that produces annoyance or communication or task performance interference. The same sound stimulus may be perceived subjectively as noise by some and not by others. For this reason it is useful to define objectively experienced noise as sound that pro-

duces harmful bodily effects, which may or may not be subjectively perceived. This point is important because noise can be subjectively or objectively stressful, or both.

In information processing terms, noise is sound that overloads the central nervous system's prothis state can be detected by changes in the electroencephalogram (27). The reception of a stimulus is influenced by two kinds of cognitive state characteristics, current transient influences and enduring qualities of the individual.

The first characteristics are transient influences that are more evident and easily measured than the second type. They include level of mental arousal, from sleep through alertness to anxiety; the context of sensory stimuli arriving through the other special senses; the motor context which includes ongoing task performance, the activities of the individual; the meaning of the stimulus evoked by associations from cerebral cortical memory areas; the degree of perceived control of the stimulus, whether one is able to control the situation is helpless or expects failures (25) and social values and attitudes toward the stimulus sources.

The level of mental arousal is influenced whether or not a sound stimulus is consciously perceived as a stressor. During the stage of early sleep, for example, sound can produce orienting and defensive responses and alter the quality of sleep without causing awakening. At the other extreme, an anxious individual can experience heightened sensitivity to a sound stimulus. For example, a study of college age males rated on an anxiety scale disclosed that for subjects rated high on anxiety, household noise levels were stressors as manifested by impaired task performance and subjective frustration (28).

The interaction of sound stimuli with other sensory stimuli may be significant. For example, related visual stimuli enhance the effect of sound. Clinically, sound can have an analgesic effect when certain intensities and frequencies occur in the presence of pain as is known in the practice of dentistry.

The ongoing motor activity of an individual influences cognitive state with higher levels of arousal by sound stimuli occurring while complex tasks are being performed and lower levels of arousal occurring when routine, monotonous activities are taking place.

For obvious reasons related to survival at a primitive level the meaning of sound is one of the most important factors that determines an organism's response. Threatening sounds of any kind portend potential danger, however, certain sounds acquire particular significance because of their symbolic meaning to the individual. Conversely, familiar,

repetitive sounds of moderate intensity cease to attract attention. Meaning connoting potential danger, then is related to unfamiliarity, rapid changes in intensity, or learned associations. For example, a study of evoked auditory potentials in the brain demonstrated that quickly changing acoustical events produce prominent cerebral excitation. The study also showed that sounds with symbolic meaning were perceived as more annoying than meaningless sounds of the same intensity and also produced larger evoked cerebral potentials (29).

Of particular importance is the fact that habituation does not occur to repeated novel laboratory stimuli that imply conflict or are coupled with an instruction to pay attention to that stimulus. Even covert associations with sound stimuli, such as a subject's attitude toward the experimenter, may decrease habituation (8). In addition, the symbolic meaning of a sound stimulus can evoke irrational responses, adding unconscious determinants of meaning (30, 31).

In addition to the meaning of the sound stimulus, a sound's predictability is an important determinant of response. In one study, unpredictable noise resulted in lower tolerance for frustration and greater impairment of performance efficiency than predictable noise (32). Furthermore, those investigators found that an individual's ability to control the noise source, and even the belief that one could, reduced the adverse impact of unpredictable noise (8). They postulated that the deleterious effects of noise were a function of unpredictability and the belief that one ceasing capacity because it is too great in quantity, appears too rapidly or is dissonant in meaning or pattern. Noise is a commonly used standardized stressor in laboratory testing designed to evaluate human responses to stress (5, 22). In laboratory

animals, for example, it is used as a stressor to produce lesions in the renal, reproductive and cardiovascular systems (23).

Another illustration of the use of sound is in stress studies such as the one by Cantrell, who exposed healthy young male volunteers to intermittent noise for several weeks (24). He found significant increases in plasma cortisol and blood cholesterol levels in addition to associated annoyance and sleep disturbance effects during prolonged exposure to bursts of 85 to 90 decibel noise.

We can use current approaches in stress research to facilitate our understanding of sound as a stressor (22, 25). In stress research the environmental conditions and the intervening bodily structures and processes that determine when and in what forms stress reactions occur are taken into account (26).

The work of Rahe, although encompassing life change in addition to sensory stressors, is particularly useful in identifying specific variables that should be taken into account in research on the human effects of noise. Rahe developed a life stress and illness model which identifies the key steps along a pathway extending from a person's exposure to a stressor to the eventual reporting of an illness (25). Rahe's model (Fig. 2) utilizes the analogy of a series of optical lenses and filters in which stressors are depicted by a series of "light rays" of different stimulus characteristics.

The influence of a person's perceptual state in altering the experience of a stressor is represented by a "polarizing filter" shown in step 1. Possible sensitization, or desensitization, of a person to a stressor is indicated by changes in the "light rays" as they pass through the filter. The psychological defense mechanisms which appear to be capable of "diffracting away" a stressor's impact are depicted

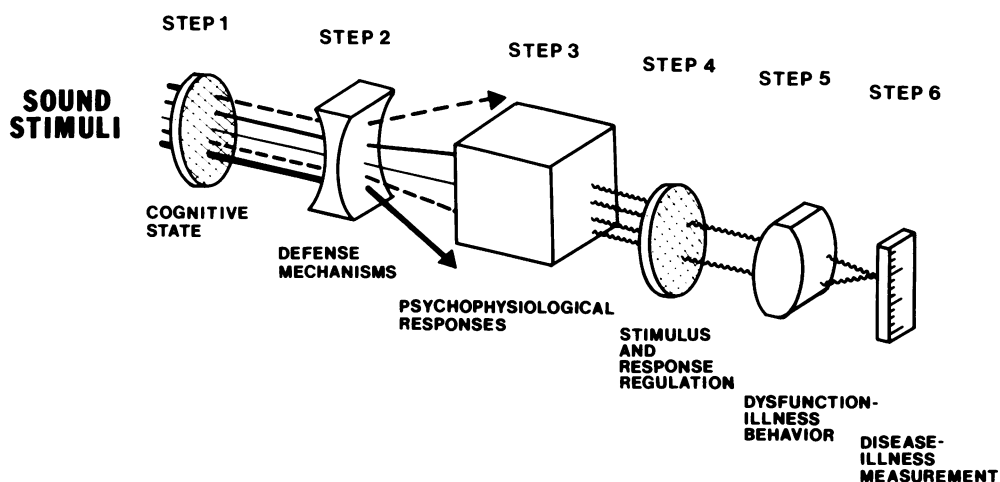


FIGURE 2. Rahe model of life stress and illness (25).

by the negative lens in step 2. Stimuli not so diffracted pass on to produce a variety of physiological reactions represented by the "black box" in Step 3. The wavy lines emerging from the black box cease to represent specific stressors and begin to indicate various psychophysiological responses to perceived and "undefended" stressors. Next a "color filter" shown in step 4 depicts how a person may cope with or absorb certain of these physiological reactions. Prolonged psychophysiological activations, if unabsorbed, lead to organ dysfunction and eventually to psychological and bodily symptoms. Symptomatic individuals may then seek medical care. A person's "focusing" of attention on symptoms is indicated by the illness behavior "positive lens" in step 5. If these symptoms are reported to health personnel, the person receives a medical diagnosis which then can be used as a measure of illness as represented in Step 6.

The value of Rahe's model is that it incorporates pertinent system levels in conceptualizing human responses to stressors, ranging from organ system to societal levels. It permits inclusion of both subjective and objective data as well. Furthermore, the model reflects clinical realities by recognizing the social factors that influence whether or not experienced dysfunctions become labeled as manifestations of illness. For these reasons, we will use Rahe's model to elucidate key variables in the human experience of sound as a stressor.

## Cognitive State

Bearing in mind the preceding discussion of the characteristics of sound experienced as noise, the first step in processing a sound stimulus is the cognitive state of the individual. Some variations in this state can be detected by changes in the electroencephalogram (27). The reception of a stimulus is influenced by two kinds of cognitive state characteristics, current transient influences and enduring qualities of the individual.

The first characteristics are transient influences that are more evident and easily measured than the second type. They include level of mental arousal, from sleep through alertness to anxiety; the context of sensory stimuli arriving through the other special senses; the motor context which includes ongoing task performance, the activities of the individual; the meaning of the stimulus evoked by associations from cerebral cortical memory areas; the degree of perceived control of the stimulus, whether one is able to control the situation is helpless or expects failures (25) and social values and attitudes toward the stimulus sources.

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The importance of attitude toward the noise source is illustrated by another study in which a positive or negative attitude toward all aspects of one's community consistently influenced the reporting of perceived annoyance by noise positively or negatively (35). In the same vein, a Swedish study disclosed that propaganda promoting the importance of the air force diminished the reported annoyance levels in a community exposed to military aircraft noise (36).

The second kind of variables that influence the cognitive state of an individual are enduring background characteristics in the form of individual differences in temperament and cognitive styles, organic disease processes and mental illness.

Individual variations have been demonstrated in the ways that sensory stimuli are processed. Some individuals reduce and some augment the intensity of stimuli, leading to low or high sensitivity to a particular stimulus (19). Sensitivity to noise also is correlated with empathic, creative, intellectually oriented personality traits, confirming Schopenhauer's comment that "noise is a torture to people of great intellect" (37). Extraverted children may have a higher level of noise tolerance than introverted children (38). Moreover, individuals who express criticism tend to report annoyance by noise (35). Further evidence of individual differences in sensitivity to noise is reflected by the finding that some people thrive on noise which tends to synchronize their electroencephalograms while most people show electroencephalographic desynchronization (39, 40). At the other extreme, it is likely that 4 to 6 % of the normal population is "noise sensitive," in the sense that they do not adapt to noise at all (8). For all of these types of individuals, noise has implications detrimental to their mental health.

As an illustration of other background illness characteristics, one study showed that cardiac in-

farction and schizophrenic patients showed greater stress responses to noise as measured by cortisol and urinary catecholamine levels than did normal subjects (41). Similarly, persons with cerebral vascular disease were found to be more susceptible to the detrimental effects of noise than normal subjects (42). Another unique group of patients harmed by sound are those susceptible to audiogenic seizures. Some are affected by sounds that produce the startle response and others by sounds such as music (43).

The role of psychiatric status in sensitivity to sound was suggested in a study in which normal subjects and patients with specific phobias showed habituation of physiological responses to noise while hysterical patients did not. Moreover, patients with diffuse phobias, anxiety neuroses and agitated depressions all habituated more slowly than normals (44). In a general sense, another survey found that psychiatric patients were more annoyed by noise than normal subjects (45).

## Defense Mechanisms

The next cluster of variables that influence an individual's response to sound stressors are internal defense mechanisms noted in step 2 of Rahe's model. In contrast with coping techniques which are directed toward changing the stimulus environment, the defense mechanisms are devoted to maintaining homeostasis or internal equilibria, within the person.

The defense mechanisms operate automatically and unconsciously. The most primitive is the acoustic reflex which offers a small degree of protection from high intensity sounds. Another example of a physiological defense is cerebral cortical inhibition such as was demonstrated in a study of laboratory animals exposed to extreme sound which ultimately produced convulsive seizures and lethal cerebral hemorrhages. This study found that a seizure producing epileptogenic focus of excitation arising in the medulla was actively inhibited by the cerebral cortex. When this inhibitory process was exhausted, seizures occurred (46).

In addition to these physiological defenses, psychological defenses shield the individual from physiological arousal and also play a significant role in reducing sensitivity to sound. For example, the psychological defenses of repression and denial can minimize physiological responses as was found in a study of patients in a coronary intensive care unit (25).



## Psychophysiological Responses

The next level, step 3 in the model, comprises psychophysiological responses to sound stressors. The psychophysiological responses can be divided into two categories. First are responses within the awareness of the individual, such as sweating, change in heart rate and muscle tension. Second are those responses which occur outside of one's direct awareness, such as changes in serum lipids, cortisol, blood pressure and blood sugar levels.

The psychophysiological responses are manifestations of the defensive response to sound, can be immediate or delayed, and occur in interactional patterns. Thus, studies of single physiological responses oversimplify the mixture of responses. An example of an immediate psychophysiological response to noise is the finding of elevated diastolic and systolic blood pressures and urinary excretion of norepinephrine metabolites in brewery workers on days in which they deliberately did not wear hearing protective devices (48).

Genetic and constitutional individual differences may increase the likelihood that a particular organ system will respond to stressors more than others and over time lead to disease. There also may be a critical period during infancy in which visceral learning takes place, adding conditioning of an individual's disposition to the physiological responsiveness through a specific "target" organ system (49). For example, in certain predisposed individuals, the target organ is the cardiovascular system, and sound stimuli produce intermittent increases in blood pressure which may eventually cause structural changes in blood vessels leading to permanent hypertension (50).

## Stimulus and Response Regulation

The next cluster of variables are stimulus and response reduction mechanisms. These coping techniques may deal with the stressor itself or with the physiological and emotional responses to it (51, 52). Using ear protective devices is an example of dealing with the stressor itself by reducing the reception of the sound stimulus.

If one becomes aware of the psychophysiological responses, particularly if they are seen as threats to health, deliberate response management techniques can be employed. For example, muscle relaxation may "absorb" the muscle tension that contributes to elevation in blood pressure.

In a broader social sense, stimulus regulation can be achieved through an individual's participation in community, industrial and consumer efforts to acous-

tically condition home and working environments and manufactured products.

## Dysfunction: Illness Behavior

In step 5 in the model, the lack or failure of defense mechanisms and regulation techniques play important roles in producing dysfunction. The concept of sensory and information input overload is useful in understanding how the central nervous system responds when defense mechanisms and regulation techniques fail to adequately screen incoming stimuli. In this conception sensory inputs are the sound stimuli and information inputs are sounds with symbolic, message containing meaning. Overload results from an excess of the number or rate of sensory or symbolic stimuli or both.

Human experiments have shown the disorganizing and psychotogenic effects of sensory overload. Experimental exposure to intense visual and auditory sensory overload produces dramatic effects in the form of heightened and sustained arousal, mood changes, illusions, hallucinations, and body image distortions (19).

Sensory and informational sound overload also are commonplace in modern, urban living (53). Jets, air compressors, sirens, rock and roll music and road traffic are generally unpredictable and often uncontrollable sources of stimulation that contribute to making the sound of our environment inimical to mental well being. Low frequency noises have effects similar to the more familiar piercing high frequency sounds (54, 55).

A typical household vignette illustrates the unrecognized importance of sound sensory and informational overload in our lives. The washing machine provides a steady hum, the clothes dryer suddenly begins to vibrate; then the telephone jangles while the delivery boy rings the doorbell; a jet aircraft rumbles overhead and automobile horns are heard, a television set blares in the background; and amidst this confusion, children begin to fight, cry and scream. The overall noise level is not high by hearing damage risk criteria, but a homemaker can attest to the resulting frustration, irritability and even anger. Over time, one manages to adapt to this noise routine. However, one makes errors in balancing the checkbooks, screams at the children for minor transgressions, is irritable with one's spouse, and generally shows symptoms of stress by the end of the day. Furthermore, when one becomes resigned to a lack of control over one's environment, the resulting "learned helplessness" itself may become a stressor and contribute to additional symptoms of depression (10, 56).

Selye's classic work on stress provides a framework for understanding the body's responses to sensory and information input overload (18). His terms stressor and stress are comparable to stress and strain in physics. In his view stressors produce two types of changes in the body. The first is a primary nonspecific change in an organ system called the "Local Adaptation Syndrome." This local adaptation occurs repeatedly in normal living. For example, running produces stress in the musculoskeletal and cardiovascular systems. The resulting exhaustion is reversible through rest.

The second change is the "General Adaptation Syndrome" which is activated by intense and persistent stressors that produce a specific effect on the adrenal glands, thymus and stomach. The fully developed general adaptation syndrome consists of three stages: an alarm reaction, a stage of resistance and an ultimate stage of exhaustion. Extremely severe stress can lead rapidly to exhaustion and death.

Stressors, then, set in motion adaptive responses which maintain biological and psychological homeostasis. In addition to specific organ system responses, a relatively stereotyped set of neuroendocrine reactions contribute to the development of the general adaptation syndrome. Most prominent are increased secretion of the adrenal cortical hormone, cortisol, and increased activity of the sympathetic nervous system, including increased secretion of epinephrine by the adrenal medulla. The increase in sympathetic nervous system activity prepares the individual for "fight or flight." The net effect of these responses is to mobilize nutrients, such as glucose from the liver and fatty acids from fat tissue, to "arouse" the central nervous system, to provide more oxygen and nutrients to skeletal muscles, to increase contractibility of skeletal muscles and to increase coagulability of the blood. When these responses are persistent, the sustained effects of cortisol may appear in the form of gastric ulceration, inhibition of immune responses, hypertension, atherosclerosis, sterility and personality changes (57). Most stressors act for a limited time and produce changes corresponding to the first and second stages of Selye's syndrome. The complete general adaptation syndrome results in a specific set of physical changes: enlargement of the adrenals, shrinkage of the thymus and lymph nodes and ulceration of the stomach.

Selye's conception helps to explain that subjective experience and physiological responses to stressors can appear to have returned to normal or pre-stressor levels during the second stage of resistance. This point is essential in understanding the phenomenon of habituation which has been repeat-

edly observed in experimental studies of human responses to sound as a stressor (8, 14). Habituation may reflect the completion of a local adaptation syndrome cycle with restoration of normal bodily functioning. On the other hand, it may reflect a stage of resistance during which the body is moving into the full general adaptation syndrome which gains a momentum of its own and exacts a physiological cost through the development of dysfunction of the various organ systems.

A stimulus appraised as threatening gradually loses its capacity to arouse an emotional response if it is reappraised on repetition as less harmful and results in adaptation (26). This surface adaptation may be deceptive, however, and continued exposure to the stressor may produce cumulative effects that appear after stimulation is terminated. This may be in the form of strain induced by the adaptive responses themselves. In spite of adaptation, then, stressors may cause biological and behavioral aftereffects following cessation of the stimulus (8).

Laboratory studies of the physiological and behavioral reactions to noise indicate that adaptation (habituation) generally takes place in healthy subjects. There is laboratory evidence, however, which suggests that some components of physiological responses to noise do not habituate completely (58), although this work has been questioned (14). It is important to distinguish between the tension response of an organism to stressors and stress which is a dangerous condition resulting from failure to manage tension effectively (59).

Another factor should be taken into account. More than lower animals, human reactions to stressors not only depend upon the direct impact of stimuli themselves but also on associated cues that signify the meaning and consequences of the stimuli. Human stress, therefore, must be defined in terms of transactions between a stimulus and an individual's reaction to the situation.

The fact that sound stimuli are processed cognitively, therefore, introduces the important conception that psychological stressors, such as the anticipation of harm, can strongly influence human responses to sound stressors (52). Activation of the neuroendocrine system usually depends upon the individual's recognition of a stressor as a threat. The auditory system, however, like heat or cold stressors, automatically activate the reticular activating system and thence can evoke autonomic-neuroendocrine responses.

Dysfunction resulting from sound stressors, then, may be the direct result of the sound stressor situation or may indirectly result from the activation and progress of the general adaptation syndrome. Dysfunction may be subjectively experienced

as symptoms, for example, annoyance and tinnitus, or be objectively demonstrable as physical signs, for example, elevated blood pressure and hearing loss. At the same time subjective reports of interference with task performance and speech communication also can be accompanied by objective changes in cerebral responses on the electroencephalogram (27).

Human dysfunction can be categorized according to the influence of noise on five basic, interrelated functions that influence the well being, or mental health, of an individual: (1) hearing, (2) sleep, (3) task performance, (4) speech communication and (5) emotional state.

**Hearing.** The effects of noise on hearing in the form of temporary and permanent threshold shifts and progressive deafness are well documented (60-62). There are three levels of hearing at which loss of acuity can occur: the primitive, warning, and symbolic (63).

The primitive level includes the familiar background sounds of one's every day environment. Loss at this level constitutes a form of sensory deprivation and may lead to a sense of isolation. Loss of hearing at the warning level contributes to a sense of insecurity and physical vulnerability in the environment. Loss at the symbolic level interferes with interpersonal communication and may result in social isolation, withdrawal and depression. Overlap between levels of hearing loss magnifies the psychological impact on the affected individual.

In addition the need to wear a hearing aid in itself may cause self-consciousness and undermine self-esteem. The emotional and psychological reactions to hearing loss accordingly are threats to an individual's mental health (13, 64, 65).

In a more general vein, the loss of hearing with aging (prebycusis) has been related in part to noise exposure in urbanized societies (66, 67).

**Sleep.** Chronic sleep disorders detrimentally affect health and well-being. A major portion of complaints about noise arise from disturbance of rest and sleep (31). The Environmental Protection Agency Urban Noise survey found that 28% of the sampled population experienced sleep disturbance which also was rated as the most annoying effect of noise (20). Similar findings have been reported by other surveys (68-71).

The electrophysiological response to noise tends to decrease during exposure to noise during sleep, however, autonomic responses do not (31, 72). This has been shown in a study in which cardiovascular responses did not habituate to traffic noise experienced by sleeping subjects (73). In sleep, noise evokes the same orienting response in the form of EEG arousal and changes in heart rate, GSR and

finger vasoconstriction as during waking without its voluntary motor component (31).

The evidence also is clear that noise exposure during sleep lightens the level of sleep, especially for subjects of an anxiety-introversion personality type (27, 70, 74). Sleep disturbances have been reported in response to low frequency noise in the 20-1000 Hz range (55). Intermittant noise above the mean background level has a greater effect than louder, more continuous noise on vegetative functions (75). Age and sex in addition to sleep stage are critical factors in determining the physiological responses of noise sensitive individuals. Older subjects and women are more sensitive than younger subjects and men. Moreover, sounds with meaning tend to awaken subjects at lower intensities than those without meaning (76).

A study devoted to the next day effects of noise-exposed interrupted sleep showed impaired performance of tasks affected by the lack of sleep. There also is suggestive evidence that noise experienced during the waking hours may reduce the duration of sleep of susceptible persons (77).

All of these findings suggest that susceptible persons may be affected by noise occurring during sleep as well as during the waking state. For night workers, mothers with babies and elderly persons, day and nighttime noise can be a significant problem (31).

**Task Performance.** There is little evidence that significant performance impairment on simple tasks occurs under continuous noise below 80 to 90 dB (77). Unpredictable or intermittent noise, however, does affect performance at even lower levels (78). It is well established that noise has a negative effect on work tasks that involve listening or conversing (79). Adverse effects occur with complex, multi-component tasks that require prolonged vigilance or continuous performance and those in which information content is high. Under these circumstances, impairment of task performance persisting after exposure to noisy environments has been reported (80, 81).

Evidence has accumulated regarding noise interference in the school performance of children. When children are involved in complex activities requiring precise movements and intense concentration, noise produces inattention and impaired task performance (82, 83).

A study of the effects of noise generated by expressway traffic in homes showed higher reading achievement for children exposed to lower ambient noise levels (84). Another study suggests poorer task performance by young children from noisy than quiet homes (85).

A study compared children from schools and

homes with noise levels of 87-99 dBA with those of 48-65 dBA levels. The children in the noisy environments showed increased distractibility and impaired achievement in school. Over a period of four years they became more distractible, indicating increased sensitivity to noise with the passage of time (86, 87). Children exposed to high noise levels in schools also attain lower reading achievement than those with low noise levels (88-90).

One study of preschool children found that reflex motor reactions to sound and light stimuli were delayed in those exposed to moderate background levels. The children with the higher noise level required more time in task performance as well (91).

All of these performance effects influence an individual's attitude toward work and may constitute additional stressors in themselves, contributing to frustration and stress reactions.

**Speech Communication.** Interference with communication through speech not only creates personal frustration but has consequences in social interaction. Individuals react to noise levels that do not completely interfere with intelligibility. Noise accordingly may reduce efforts to converse, lead to repeated speech, and ultimately to withdrawal (92). The hearing impaired are particularly susceptible to these reactions (93). Interference with communication between teachers and children in air traffic exposed schools also has been found (94).

Children's speech acquisition and language development may be impaired since the repetition of speech needed to develop these skills is reduced as background noise level increases. Noise accordingly may interfere with the perception of speech by young children and affect the acquisition of language. More than adults, children depend upon the clear perception and repetition of speech sounds during early learning periods (61).

**Emotional State.** The most prominent subjective emotional response to noise is annoyance, a commonly reported but difficult to describe and quantify emotional state. Research on annoyance is hampered by the ambiguity of the term and the fact that one can be annoyed by noise itself or by its symptomatic and behavioral consequences. Arhlin relates annoyance to the direct effects, such as hearing loss, sleep, task performance and speech interference, and the indirect effects of noise, such as blood pressure elevation, headaches, fatigability, anxiety, depression and accident risk (95).

A standardized definition of annoyance is needed because each study tends to report annoyance in a different way. In its most specific sense annoyance is an emotion with a protective function. It motivates an individual to try to avoid or influence the

sound stressor. Like discomforts such as pain, chill and warmth, annoyance serves to warn an individual of unpleasant or harmful environmental conditions. Annoyance also can be produced by interference with task performance sleep and somatic symptoms. The direct experience of annoyance by noise itself differs from indirect annoyance because of a headache.

Annoyance directly related to noise, then, is an unpleasant emotion experienced as irritability and is a form of anger or hostility related to the state of the individual in a particular social and environmental context. For example, the sound of the barking of one's own dog may be less annoying than the barking of a neighbor's dog. In another vein, some experimental subjects refused to continue in a noise study because they perceived it as unpleasant (8). There also is a tendency to regard sound as noise at work more than at home (96). Because of this relationship to the peculiarities of the context, annoyance can be expected to vary in its occurrence and reporting.

Annoyance is heightened when noise is perceived as unnecessary; when those responsible for the noise are perceived as unconcerned about the exposed population's welfare; when other aspects of the environment are disliked; when noise is believed to be harmful to health, and when noise is associated with fear (10).

Although defined differently from study to study, annoyance is a commonly used concept in surveys of community responses to noise. The tendency is to define annoyance of the respondents in terms of physiological responses, although a scale has been developed that excludes somatic symptoms (45). It can be inferred then that the more annoyed a respondent the greater the physiological reactions the person is experiencing. Direct physiological measurements would be preferable to subjective reports, however, the stage of this research is not sufficiently advanced to permit the specific measurement of noise induced stress isolated from other environmental stressors.

The evaluation of annoyance is further complicated. Not only is it an ambiguous concept, but respondents are influenced by the questions they are asked. For example, more positive responses were obtained when people were asked if aircraft noise produced specific symptoms than if asked about symptoms without suggesting a connection to aircraft noise (97, 98). When annoyance was analyzed according to attitude, activity interference and symptoms, McKennel found that 65% of his sample reported feeling annoyed, 35% reported interference with activities and 5% reported symptoms (99).

Although methodological problems are important in assessing studies of reported annoyance due to noise, a number of surveys suggest that between 30% and 40% of urban dwellers are regularly annoyed by noise (20, 21, 31, 96, 100). In the flight pattern of Heathrow airport in London, 65% reported annoyance (99).

Noise in industrial situations also may induce what has been described as an "astheno-vegetative syndrome" in the form of increased fatigability, decreased capacity for focusing attention and slowing of motor reactions (101).

### **Disease: Illness Measurement**

In step 6 of the model, whether or not people define themselves as ill depends upon individual and cultural attitudes toward assuming the patient role. These personal and social factors influence whether or not an individual minimizes or exaggerates symptoms and adopts "sick" behaviors such as missing work and seeking health care. The critical step for defining illness, then, occurs when health care is sought and a diagnosis is established. This point is the entree for measuring illness resulting from sound induced stress.

There is an inevitable gap between laboratory studies of the immediate and delayed effects of noise on health. Still, some investigators regard noise pollution in densely populated areas as a social danger comparable to that of known ingested carcinogens and air pollutants (102). Imposing problems, however, stand in the way of proving this thesis as illustrated by methodological criticisms of a study which found that people residing near the Los Angeles International Airport had a higher death rate from stress related diseases than a control population (103).

More specifically, European research on industrial noise has identified a cluster of symptoms encountered by physicians and referred to as "noise sickness" (31, 104). This syndrome is manifested by tinnitus, increased sensitivity to noise, fatigability, lowering of general resistance to illness, headaches, irritability, sleep interference, "heart pains," weight loss, tremors, digestive disorders and ultimately hearing loss. These symptoms are based upon the stress responses of the auditory, autonomic, cardiovascular, endocrine, and gastrointestinal systems and precede the actual loss of hearing.

Although short-term studies show that work performance can be maintained under noisy conditions, the more important consideration is the long-range effect of noise on health. The European data appear to show that complete physiological and psychological adaptation to prolonged noise exposure does not

occur. The person reacts unfavorably to noise from the beginning, and adverse reactions progressively increase with the passage of time. This is most evident in work requiring complex task performance. Because of the cumulative negative effect on one's state of health, the adaptation of many individuals working in noisy environments exacts a health cost (101).

For convenience we will briefly summarize the relationship between noise exposure and (1) mental illness, (2) cardiovascular disorders, (3) gastrointestinal disorders, (4) neurological disorders and (5) fetal abnormalities.

**Noise and Mental Illness.** The role of noise in mental illness is most difficult to assess. Several studies of mental hospitals in the vicinity of Heathrow Airport in London disclosed a small but significantly higher admission rate than those in less noisy areas (105-107).

Another piece of evidence relating a form of mental illness to noise is through an indirect relationship between noise induced hearing loss and mental illness. Acquired deafness forces a change in life style toward greater social isolation and leads to an over-representation of mental illness in deaf people of all ages. One study found that 46% of a group of elderly deaf persons were paranoid and 21% had affective disorders (65).

On the other hand, noise-related annoyance in itself probably is not a cause of mental illness, although psychiatric patients do constitute a vulnerable group to the adverse effects of noise. Somatic and emotional symptoms associated with annoyance by noise are significant, however (45). The consumption of tranquilizers and sedatives has been used as an index of these symptoms resulting from noise exposure. Greater usage of these medications have been found in air and road traffic areas exposed to high levels of noise (69, 99, 108, 109).

**Noise and Cardiovascular Disorders.** There is a consistent correlation between prolonged exposure to high intensity industrial noise and an increased prevalence of hypertension, as demonstrated by over 40 studies (110). The risk increases with advancing age and increasing years of employment for both men and women. The risk also is greater under circumstances of intermittent impulse or impact sound than continuous or relatively steady sound. There is significant confirmation under actual living and laboratory conditions of the association between high intensity sound and cardiovascular disorders in children and adults (10, 69, 111, 112).

More specifically, prolonged noise exposure produced sustained elevations in blood pressure in a controlled experimental study of Rhesus monkeys. A carefully designed and monitored study of mon-

keys exposed for nine months to a continuous noise environment simulating that of urban factory workers disclosed significant, sustained elevations in blood pressure levels and alterations in diurnal blood pressure rhythms (113). These changes persisted after discontinuing exposure to the noise environment, suggesting a basis for long-term noise effects on the cardiovascular system in humans. Since Borg's study disclosed that lifelong exposure to high noise levels did not produce hypertension in rats (114), this study of primates is important because it bears a closer relationship to the human situation.

The fact that all persons exposed to noise do not show cardiovascular disorders is consistent with the likelihood that noise affects the health of susceptible individuals when combined with other stressors, such as work pressure and population density. Furthermore, environmental stressors are most likely to affect people who are unable to control them. Thus, people in institutions, with low incomes and low levels of education and children are especially likely to show adverse reactions from noise exposure (10).

**Noise and Gastrointestinal Disorders.** The data presently available are insufficient to justify judgments about the role of long term noise exposure in gastrointestinal disorders (110). The European literature on industrial noise, however, strongly suggests such a relationship (10, 101).

**Noise and Neurological Disorders.** A number of investigators report neurological changes associated with long-term occupational noise exposure (110). The principal signs include: autonomic imbalance such as dermatographism, hyperreflexia, hyperhidrosis, and hand and eyelid tremors; an altered sense of balance; decreased tactile sensitivity of the hands and feet; decreased stimulus reaction time; a decreased reactivity to visual stimuli; and obscuring of regional activity in the electroencephalogram.

An uncommon neurological disorder that is directly affected by auditory stimulation is the audiogenic seizure syndrome (43). In individuals with this disorder seizures are precipitated by certain sounds.

**Noise and Fetal Abnormalities.** The human fetus perceives and responds to environmental sound in utero as reflected in motor activity and heart rate change. In the last trimester of pregnancy, the fetus can be conditioned by external sound stimuli. Maternal anxiety related to noise can produce increased fetal activity. A possible subtle prenatal effect of maternal anxiety induced by noise exposure could be infants who are hyperactive and have dysrhythmic temperaments (115).

In experimental animals, maternal and fetal abnormalities have been linked to noise (116). At this time, however, the evidence of the adverse effect of noise on the human fetus is suggestive but not established (117, 118).

In summary, the data on the health effects of noise indicate that sound exposure of more than 3 to 5 years with intensity levels of 85 dBA to 90 dBA is associated with increased health risk. Furthermore, the adverse physiological effects of noise surface before damage to hearing appears suggesting that attention to the physiological effects of noise may well enhance the prevention of noise induced hearing loss.

The effects of noise on children deserve special attention because children do not spontaneously report them, have little awareness of their significance and cannot significantly influence their environments. The evidence is that children may be particularly susceptible to noise-induced developmental and learning impairment which have long-range implications for later life (10).

For those who choose to question the health implications of noise, we must recognize that positive proof of cause and effect between a stimulus and human disease can never be established in the strictest experimental sense because of the multitude of intervening variables. Research in the health sciences differs fundamentally from that of the physical sciences. In even the most sophisticated epidemiological survey, a correlation remains a correlation. Species differences always exist and must be considered in even the most convincing animal study. For ethical reasons these are the only kinds of research evidence we are likely to have. We need further research to illuminate specifics but not to prove that noise is a significant threat to human health.

## Implications

Our thesis is that research on, and efforts to prevent or minimize, the harmful effects of noise have suffered from the lack of a full appreciation of the ways in which humans process and react to sound. In an effort to stimulate more comprehensive approaches, we have described an integrated model of the auditory processing of sound based upon current knowledge of neuroanatomy, neurophysiology, neuroendocrinology and human stress.

Piecemeal research on narrow aspects of noise-related problems has led to conflicting conclusions that either minimize or exaggerate the significance of noise for physical and mental health. The designation of the general physiological effects of sound as "nonauditory" has been particularly misleading

to the general public. Because of this fragmentation and ambiguity, definitive action has been stymied by misunderstanding of the economic, social, and personal costs of noise control efforts. Underlying the confusion is the failure to appreciate that, beyond human communication, sound plays a vital role in the physiological functioning of the body.

As is true with other human problems, additional inevitable resistances to facing and remediating the untoward effects of noise have been encountered. This is particularly because the root causes of noise pollution are the imposition of modern technology and population pressures on natural human living conditions. Solutions accordingly require adjustments in styles of behavior and living. Even though short range inconveniences may lead to long range benefits, the human tendency is to resist change and maintain the status quo. Workers fail to wear protective hearing devices, manufacturers do not acoustically condition products and government does not adequately enforce standards. Moreover, the human capacity to adapt to noisy environments masks the magnitude of the problem. Hearing loss in itself further may reduce awareness of noxious sounds. These resistances are important determinants of ambiguities in the measurement of community responses to noise (119).

We believe that the paralysis of effective action is not a result of lack of knowledge but of a failure to integrate and articulate existing knowledge so that compelling reasons can stimulate the motivation needed to implement changes. For this reason, education of the public and workers in the field is the most important need today.

The compelling reasons for action are the facts that substantial groups of the population are vulnerable to adverse health effects from noise, that the quality of life is generally eroded by annoyance from noise, that sleep is disrupted, that productivity is reduced, and that the education of children is affected by noisy environments.

Without question noise can be a stressor and consequently an important underestimated pollutant of modern society as are chemicals and particulate matter that pollute the air, water, and food. Moreover, noise significantly affects the human nervous and endocrine systems. Because these systems are capable of sophisticated short range adaptive maneuvers, the harmful effects of noise, like other pollutants, usually become evident at later points in time. Noise is one of the main sources of sensory overload for city dwellers and industrial workers (19).

More than other pollutants noise interacts with other sensory stressors, population density, life change and life circumstances. Thus, noise plays an

aggravating role in addition to stress generated by environmental conditions and attitudes toward them. These complex interactions have led to despair in ferreting out the exact role of noise in stress induced dysfunctions. When seen in the context of all of these factors, however, noise often emerges as the one most accessible to preventive and remedial action. This is reflected in the already existing federal, state, and local noise control measures. Actually, there is little more that needs to be known. The problem lies in the lack of coordination between acoustical engineering, urban planning, health, architecture, audiology, and other related professional disciplines.

There are essentially three points of intervention in noise control: reducing sound emission from the source, blocking sound transmission from the source to the ear, and protecting the ear itself from receiving the sound. Practical considerations limit the reduction of sound emission from industrial, traffic and aircraft sources. Still, acoustical conditioning of working and living environments can effectively reduce transmitted sound. Finally, sound can be effectively blocked at the level of the ear through protective hearing devices. By intervening at any or all of these levels there are few noise problems that cannot be effectively managed today. Thus, the problem is not that remedies are unavailable or too costly, but that the least expensive ones are not being used.

The multifaceted nature of solutions to the noise problem involves the cooperation of those who generate and those who are affected by noise. We cannot realistically expect dramatic reductions in the sources of noise pollution (120). Unlike other forms of environmental pollution, however, individuals can minimize the adverse effects of noise upon them. To the extent of economic feasibility industry should more actively reduce noise emission at the source by machines, vehicles, and appliances. Beyond that point, individuals can and should protect themselves from harmful sounds through acoustical conditioning and sound occluding ear devices.

The fundamental problem is one of attitude at the levels of government, industry, consumers, and health care workers. Noise already has been identified as a national hazard by Congress in the form of the Noise Control Act of 1972 and the Quiet Communities Act of 1978. Federal standards for new product noise emission, labeling requirements, and state and local regulations are being promulgated (121-123). Yet unachieved, however, is public awareness of the significance of noise pollution. An attitude of helplessness prevails leading to either resignation to the existence of noise or escape from it by

moving out the urban areas or changing jobs. Unappreciated is the fact that citizen initiatives, community organization, labor union bargaining, consumer demand, and personal efforts can create a climate in which an attitude of mastery over noise rather than helplessness can be achieved.

The basis now exists for public, consumer and labor expectations that acoustical conditioning be given priority equivalent to air conditioning in housing and industrial construction and in machine and appliance manufacturing. The problem lies simply in a lack of awareness of the importance of these factors. People have become accustomed to accommodating to noise through bodily defense mechanisms and lack an understanding of the personal and governmental resources available to them. Citizens do not fully appreciate that, negative research findings and preoccupation with the details of measuring community annoyance notwithstanding, they have the right to determine the quality of their lives and to be free from the harassment of noise generated by industrial, vehicular, office, airport, and household appliance sources.

## Summary

The fundamental purposes of hearing are to alert and to warn. The auditory orienting response, startle reflex and defensive response translate sound stimuli into action and sometimes into stress induced bodily changes. In the course of human evolution the additional purposes of communication and entertainment developed as sound assumed symbolic meaning.

The brain's processing of sound has been outlined as the biological and psychological basis for the effects of sound on the body. An integrated model then was presented for analyzing the impact of sound as a stressor on the body and for identifying key variables for research on the health effects of noise. In addition to the characteristics of the sound stimulus, a variety of personal and social factors determine whether or not noise becomes a stressor. The cognitive state, defense mechanisms, psychophysiological responses and stimulus and response regulation techniques of the individual person play vital roles. When the tension induced by sound persistently alters the homeostasis of the neuroendocrine system, a state of stress results with accompanying dysfunction in hearing, sleep, task performance, speech communication, and emotional state. When dysfunction leads to the assumption of the patient role, stress induced illness can be identified in the form of the suggested syndrome of "noise sickness;" cardiovascular, neurological, and gastro-

intestinal disorders; and possibly aggravated mental illness and fetal abnormalities.

Noise is a stressor and an important, largely unrecognized, pollutant of our environment. Our quality of life generally is eroded by annoyance from noise, and substantial segments of the population are vulnerable to its adverse health effects. More specifically, sleep is disrupted, productivity is reduced and the education and development of children is affected by noisy environments.

The prevention and reduction of noise pollution need not await further knowledge. The technology for reducing noise emission, acoustically conditioning environments and protecting hearing now exists. The problem is the lack of public awareness of the significance of noise pollution and solutions to it. The challenge is to convert through education a public attitude of helplessness to one of mastery through citizen initiatives, labor union bargaining, consumer demands and personal efforts to adopt the most feasible noise and noise response control measures.

## REFERENCES

1. Moller, A. Review of animal experiments. *J. Sound Vibr.* 59: 73-77 (1978).
2. Stevens, S. S., and Warshofsky. *Sound and Hearing.* Time-Life Books, New York, 1975, pp. 31-38.
3. Tumarkin, A. Evolution of the auditory conducting apparatus in terrestrial vertebrates. In: *Hearing Mechanisms in Vertebrates*, A. U. S. DeRenck, and J. Knight, Eds., Little, Brown, Boston, 1968.
4. Cohen, A. Extraauditory effects of acoustic stimulation. In: *Handbook of Physiology-Reactions to Environmental Agents.* American Physiological Society, Bethesda, Md., 1977.
5. Frankenhaeuser, M. Psychoneuroendocrine approaches to the study of emotion as related to stress on coping. In: *Nebraska Symposium on Motivation*, H. E. Howe, and R. A. Dienstbier, Eds., University of Nebraska Press, Lincoln, Nebraska, 1979.
6. Zubek, J. P. *Sensory Deprivation: Fifteen Years of Research.* Appleton-Century-Crofts, New York, 1969.
7. Davies, D. R., and Tune, G. S. *Human Vigilance Performance.* Staples Press, London, 1970.
8. Glass, D. C., and Singer, J. E. *Urban Stress: Experiments on Noise and Social Stressors.* Academic Press, New York, 1972.
9. Welch, L. Physiological and psychological effects of noise. In: *Physiological and Psychological Effects, Public Hearings on Noise Abatement and Control*, Vol. III, U. S. Environmental Protection Agency, No. 5500-0056, Washington, D.C., 1973.
10. Cohen, S., Glass, D. C., and Phillips, S. Environmental factors in health. In: *Handbook of Medical Sociology*, H. E. Freeman, S. Levine, and L. G. Reeder, Eds., Prentice-Hall, Englewood Cliffs, N.J., 1979.
11. Anticaglia, J. R. Extraauditory effects of sound on the special senses. In: *Physiological Effects of Noise*, B. L. Welch and A. M. S. Welch, Eds., Plenum Press, New York, 1970, pp. 143-150.



12. Davis, R. C., Buchwald, A. M., and Frankmann, R. W. Autonomic and muscular response and their relation to simple stimuli. In: *Psychological Monographs, General and Applied*, Whole No. 405, 1955, pp. 1-71.
13. McClean, A. Noise, Stress, Hearing Deficits. In: *Occupational Stress*, A. McClean, Ed., Charles C Thomas, Springfield, Ill., 1974.
14. Kryter, K. D. Extraauditory effects of noise. In: *Effects of Noise on Hearing*, D. Henderson, R. P. Hamernik, D. S. Dosanjh, and J. H. Mills, Eds., Raven Press, New York, 1976.
15. Cohen, H. H., Conrad, D. W., O'Brien, J. F., and Person, R. G. Noise and task difficulty. In: *Effects of Noise Upon Human Information Processing*, NTIS Report N74-31576, 1974, pp. 16-54.
16. Blazekova, L. Effect of noise on the vegetative reactions of the blood vessels. In: *Proceedings of the Second International Industrial and Environmental Neurology Conference*, Prague, Czechoslovakia, 1974, pp. 412-413.
17. Kubic, S., and Blazekova, L. Complex influence of noise on human organism. From *Noise 2000 (Proceedings of the 5th and 6th International Congresses of the Association Internationale Contre le Bruit)*, London and Groninger, 1970.
18. Selye, H. *The Stress of Life*. McGraw-Hill, New York, 1976.
19. Lipowski, Z. J. Sensory and information input overload: behavioral effects. *Compr. Psychiatry*; 16: 199-221 (1975).
20. Environmental Protection Agency. *Noise-Quiet: Toward a National Strategy for Noise Control*. Office of Noise Abatement and Control, Washington, D.C., 1977.
21. U.S. Census Bureau. *Annual Housing Survey, 1976, Part B—CB78-133*. Washington, D.C., 1978.
22. Hattis, D., and Richardson, B. Noise, General Stress Responses, and Cardiovascular Disease Processes: Review and Reassessment of Hypothesized Relationships. Center for Policy Alternatives, Massachusetts Institute of Technology, Cambridge, Mass., 02139, CPA/WP-79-1, 1980.
23. Welch, B. L., and Welch, A. M. S. *Physiological Effects of Noise*. Plenum Press, New York, 1970.
24. Cantrell, R. W. Prolonged exposure to intermittent noise: audiometric, biochemical, motor, psychological and sleep effects. *Laryngoscope (Suppl. 1)* 84: No. 10, Part II, (1974).
25. Rahe, R. H., and Arthur, R. J. Life change and illness studies: past history and future directions. *J. Hum. Stress*, 4: 3-15 (1978).
26. Lazarus, R. S. Stress as a psychological problem. In: *Psychological Stress and the Coping Process*, R. S. Lazarus, Ed., McGraw-Hill, New York, 1966.
27. Bergamasco, B., Benna, P., and Gilli, M. Human sleep modifications induced by urban traffic noises. *Acta Otolaryng. Suppl.* 339: 33-36 (1976).
28. Sharp, L. F., Swiney, J. F., Dansby, M. R., Hyatt, S. C., and Schimmel, D. E. Behavioral and Physiological Correlates of Varying Noise Environments. Environmental Protection Agency, Contract No. IAG-D4-0537, 600/1-77-038, Washington, D.C., 1977.
29. Spreng, M. Objective Neuroelectrophysiological evaluations of noise effects. In: *Proceedings of the 3rd International Congress on Noise as a Public Health Problem*, American Speech and Hearing Association, Washington, D.C., 1980.
30. Kohut, H., and Lavarre, S. On the enjoyment of listening to music. *Psychoanal. Q.*, 19: 62-87 (1950).
31. McLean, E. K., and Tarnopolsky, A. Noise, discomfort and mental health: a review of the socio-medical implications of disturbance by noise. *Psychol. Med.* 7: 19-62 (1977).
32. Glass, D. C., Singer, J. E., and Friedman, L. N. Psychic cost of adaptation to an environmental stressor. *J. Pers. Soc. Psychol.* 12: 200-210 (1969).
33. Hanson, J. D., Larson, M. E., and Snowdon, C. T. The effects of control over high intensity noise on plasma cortisol levels in rhesus monkeys. *Behav. Biol.* 16: 333-340 (1976).
34. Lundberg, V., and Frankenhaeuser, M. Psychophysiological reactions to noise as modified by person control over noise intensity. *Biol. Psychiat.* 6: 51-59 (1978).
35. Weinstein, N. D. Individual differences in critical tendencies and noise annoyance. *J. Sound Vibr.* 68 (2): 241-248 (1980).
36. Sorenson, S. On the possibilities of changing the annoyance reaction to noise by changing the attitudes to the source of annoyance. *Nor. Hyg. Tid. Suppl.* 1: 00-00 (1970).
37. Morieria, N. M., and Bryan, M. E. Noise annoyance susceptibility. *J. Sound Vibr.* 21: 449-462 (1972).
38. Elliot, C. D. Noise tolerance and extraversion in children. *Brit. J. Psychol.* 62: 375-380 (1971).
39. Bergamasco, B., Benna, P., Covacich, A. M., Gilli, M., and Rossi, G. Behavior of CNV during exposure to urban traffic noise. *Acta Otolaryngol. Suppl.* 339: 27-29 (1976).
40. Bergamasco, B., Benna, P., Furlan, P., and Gilli, M. Effects of urban traffic noise in relation to basic personality. *Acta Otolaryngol. Suppl.* 339: 37-38 (1976).
41. Arguelles, A. E., Martinex, M. A., Pucciarrelli, E., and Disisto, M. V. Endocrine and metabolic effects of noise in normal, hypertensive and psychotic subjects. In: *Physiological Effects of Noise*, B. L. Welch, and A. M. S. Welch, Eds., Plenum Press, New York, 1970, pp. 43-56.
42. Rehm, S., and Gros, E. Physiological effects of noise in critical groups. In: *Proceedings of the 3rd International Congress on Noise as a Public Health Problem*, American Speech and Hearing Association, Washington, D.C., 1980.
43. Forster, F. M. Human studies of epileptic seizures induced by sound and their conditioned extinction. In: *Physiological Effects of Noise*, B. L. Welch, and A. M. S. Welch, Eds., Plenum Press, New York, 1970, pp. 151-158.
44. Lader, M. H. The responses of normal subjects and psychiatric patients to repetitive stimulation. In: *Society Stress and Disease*, L. Levi, Ed., Oxford University Press, New York, 1971, pp. 417-432.
45. Tarnopolsky, A., Barker, S. M., Wiggins, R. D., and McLean, E. K. The effect of aircraft noise on the mental health of a community sample: A pilot study. *Psychol. Med.* 8: 219-233 (1978).
46. Krushinsky, A. L. V., Molodkina, L. N., Fless, D. A., Dobrokhotova, L. P., Steshenk, A. O., Semiokhina, A. F., Zorina, V. A., and Romanova, L. G. The functional state of the brain during sonic stimulation. In: *Physiological effects of noise*, B. L. Welch, and A. M. S. Welch, Eds., Plenum Press, New York, 1970, pp. 159-183.
47. Bergamasco, B., Gilli, M., and Rossi, G. Changes in cortical responsivity to multisensorial stimuli during exposure to urban traffic noise. *Acta Otolaryngol. Suppl.* 339: 24-26 (1976).
48. Ising, H., and Melchert, H. U. Endocrine and cardiovascular effects of noise. In: *Proceedings of the 3rd International Congress on Noise as a Public Health Problem*, American Speech and Hearing Association, Washington, D.C., 1980.
49. Dicara, L. V. Learning and the autonomic nervous system. In: *Human Physiology and the Environment in Health and Disease*, Scientific American, Washington, D.C., 1977, Chapt. 17.
50. Kaplan, N. M. Stress, the sympathetic nervous system and hypertension. *J. Hum. Stress*, 4: 29-34 (1978).
51. Lazarus, R. S. Psychological stress and coping in adaptation and illness. *Int. J. Psychiat.* Med. 5: 321-333 (1974).
52. Lazarus, R. S. Cognitive and coping processes in emotion.

- In: *Stress and Coping: An Anthology*, A. Monat, and R. S. Lazarus, Eds., Columbia University Press, New York, 1977.
53. Milgram, S. The experience of living in cities. *Science*, 167: 1462-1468 (1970).
  54. Brian, M. D. Annoyance effects due to low frequency sound. Proceedings, Autumn Meeting of the British Acoustical Society, 1971, pp. 71-109.
  55. Broner, N. The effects of low frequency noise on people—a review. *J. Sound Vibr.* 58: 483-500 (1978).
  56. Hiroto, D. S., and Seligman, E. E. P. Generality of learned helplessness in men. *J. Pers. Soc. Psychol.* 31: 327 (1975).
  57. Scientific American Publication. *Human Physiology and the Environment in Health and Disease*. Scientific American, Washington, D.C., 1977, Chapt. 4.
  58. Jansen, G. Effects of noise on physiological state. In: *Noise is a Public Health Hazard*, W. D. Ward, and J. E. Fricke, Eds., American Speech and Hearing Association, Washington, D.C., 1969, pp. 89-98.
  59. Antonovsky, A. *Health, Stress, and Coping: New Perspectives on Mental and Physical Well-Being*. Jossey-Bass, San Francisco, 1979.
  60. Kryter, K. D. *The Effects of Noise on Man*. Academic Press, New York, 1970, pp. 487-633.
  61. Mills, J. H. Noise and children: a review of literature. *J. Acoust. Soc. Am.* 58: 767-779 (1975).
  62. Rossi, G., Scevoli, M., and Magliano, C. Temporary threshold shift (TTS) due to exposure to urban traffic noise. *Acta Otolaryngol. Suppl.* 339: 10-13 (1976).
  63. Ramsdell, D. The psychology of the hard of hearing and the deaf. In: *Hearing and Deafness*, H. Davis, and S. Silverman, Eds., Holt, Rinehart and Winston, New York, 1966.
  64. Barbara, D. *Psychological and Psychiatric Aspects of Speech and Hearing*. Charles C Thomas, Springfield, Ill., 1960.
  65. Cooper, A. F., Curry, A. R., Kay, D. W. K., Garside, R. F., and Roth, M. Hearing loss and affective psychoses of the elderly. *Lancet*, ii: 851-854 (1974).
  66. Jansen, G., Rosen, S., Schulze, J., Plester, D., El-Mofty, A. Vegetative reactions to auditory stimuli: comparative studies of subjects in Dortmund, Germany, and the Mabaan Tribe in the Sudan. *Trans. Am. Acad. Ophthalmol. Otolaryngol.* 68: 445 (1964).
  67. Wakstein, C. The noise problem in the United States. In: *Proceedings of the 5th International Congress on Noise Abatement*, London, May 13-18, 1968.
  68. Bradley, J. S. Exterior vehicle noise and its effects: a survey of the research on exterior noise and the effects of noise on people. *Transport Canada, Reports TT154 and CR7-62*, 1975.
  69. Knipschild, P. Medical effects of aircraft noise: community cardiovascular survey. *Int. Arch. Occup. Environ. Health* 40: 185-190 (1977).
  70. Thiessen, G. J. Effects of noise from passing trucks on sleep. Proceedings, 77th Meeting of the Acoustical Society of America, Philadelphia, Pa., 1969.
  71. Wehrli, B., Nemecke, J., Turrian, V., Hogmann, R., and Wanner, H. U. Annoyance by street traffic noise in the night. Dept. of Hygiene and Applied Physiology, Swiss Federal Institute of Technology, CH-8092 Zurich, Switzerland, 1980.
  72. Williams, H. L. Auditory stimulation, sleep loss and the EEG stages of sleep. In: *Physiological Effects of Noise*, B. L. Welch, and A. M. S. Welch, Eds., Plenum Press, New York, 1970, pp. 277-281.
  73. Muzet, A., and Ehrhart, J. Habituation of heart rate and finger pulse responses to noise in sleep. Proceedings of the 3rd International Congress on Noise as a Public Health Problem, American Speech and Hearing Association, Washington, D.C. 1980.
  74. Griefahn, B. Research on noise disturbed sleep since 1973. Proceedings, 3rd International Congress on Noise as a Public Health Problem, Speech and Hearing Association, Washington, D.C., 1980.
  75. Rossi, G. Urban traffic noise: auditory and extraauditory effects. *Acta Otolaryngol. Suppl.* 339: 5-9 (1976).
  76. Lukas, J. S. Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep. U.S. Environmental Protection Agency 600/1-77-010, 1977.
  77. Blois, R., Debilly, G., and Mouret, J. Daytime noise and its subsequent sleep effects. Proceedings, 3rd International Congress of Noise as a Public Health Problem, American Speech and Hearing Association, Washington, D.C., 1980.
  78. Theologus, B. C., Wheaton, B. R., and Fleishman, E. A. Effects of intermittent moderate intensity noise stress on human performance. *J. Appl. Psychol.* 59: 539-547 (1974).
  79. Stephens, D., and Rood, G. The nonauditory effects of noise on health. In: *Handbook of Noise Assessment*, D. N. May, Ed., Van Nostrand-Reinhold, New York, 1978.
  80. Wohlwill, F. R., Naser, J. L., DeJoy, D. M., and Foruzani, H. H. Behavioral effects of a noisy environment: task involvement versus passive exposure. *J. Appl. Psychol.* 61: 67-74 (1976).
  81. Cohen, S. The aftereffects of stress on human performance and social behavior: a review of research and theory. *Psychol. Bull.* 88: 82-108 (1980).
  82. Koszarmy, A., and Gorynski, T. Psychomotor efficiency and attention processes in school children under different acoustic conditions. *Rozc. Panstw. Zaki. Hig.* 27: 454-455 (1976).
  83. Maser, L. M., Sorensen, P. A., and Kryter, K. D. Effects of intrusive sound on classroom behavior: data from a successful lawsuit. Paper presented at the Western Psychological Association Meeting, San Francisco, April 1978.
  84. Cohen, S., Glass, D. C., and Singer, J. E. Apartment noise, auditory discrimination and reading ability in children. *J. Exp. Soc. Psychol.* 9: 407-422 (1973).
  85. Heft, H. Background and focal environmental conditions of the home and attention in young children. *J. Appl. Soc. Psychol.* 9 (1): 47-69 (1979).
  86. Cohen, S., Evans, G. W., Krantz, D. S., and Stokols, D. Physiological, Motivational and Cognitive effects of aircraft noise on children: moving from the laboratory to the field. *Am. Psychol.* 35: 231-243 (1980).
  87. Cohen, S., Krantz, D. S., Evans, G. W., and Stokols, D. Community noise and children: cognitive, motivational and physiological effects. Proceedings, 3rd International Congress on Noise as a Public Health Problem, American Speech and Hearing Association, Washington, D.C., 1980.
  88. Deutsch, C. P. Merrill-Palmer Quart. *Behav. Development* 10: 277-296 (1964).
  89. Bronzaft, A. L., and McCarthy, D. P. The effect of elevated train noise on reading ability. *Environ. Behav.* 7: 517-527 (1975).
  90. Lukas, J. S., and Swing, J. W. Effects of freeway noise on hearing levels and academic achievement of children—preview of a study. *Internoise*, 1978.
  91. Storoschyuk, K. H. Effect of noise on the nervous system of pre-school children. *Hyg. Sanitation*, 21: 50-54 (1966).
  92. Miller, D. Effects of noise on people. *J. Acoust. Soc. Am.* 56: 729-764 (1975).
  93. Suter, A. H. The Ability of Mildly Hearing-Impaired Individuals to Discriminate Speech in Noise. U.S. Environmental Protection Agency, 55019—78-100, Washington, D.C., 1978.

94. Crook, M. A., and Langdon, F. J. The effects of aircraft noise in schools around London Airport. *J. Sound Vibr.* 34: 221-232 (1974).
95. Ahrlin, U., and Ohrstom, E. Medical effects of environmental noise on humans. *J. Sound Vibr.* 59: 79-87 (1978).
96. Cameron, P., Robertson, D., and Zaks, J. Sound pollution, noise pollution, and health community parameters. *J. Appl. Psychol.* 56: 67-74 (1972).
97. Barker, S. M., and Tarnopolsky, A. Assessing bias in surveys of symptoms attributed to noise. *J. Sound Vibr.* 59: 349-354 (1978).
98. Sorensen, S., and Jonsson, E. On the importance of the phrasing of questions in medico-hygienic social surveys. *Environ. Res.* 10: 190-195 (1975).
99. McKennel, O.P.C.S. Second Survey of Aircraft Annoyance Around London Heathrow Airport. Her Majesty's Stationary Office, London, 1979.
100. Wanner, H. U., Wehrli, B., Nemecek, J., and Turrian, V. The annoyance due to noise and air pollution to the residents of heavily frequented streets. Proceedings, 3rd International Congress on Noise as a Public Health Problem, American Speech and Hearing Association, Washington, D.C., 1980.
101. Gulian, E. Noise as an occupational hazard: effects on performance level and health—a survey of findings in the European literature. National Institute for Occupational Safety and Health, Center for Disease Control, U.S. DHEW, Cincinnati, 1974.
102. Krichagin, B. J. Health effects of noise exposure. *J. Sound Vibr.* 59: 65-71 (1978).
103. Frerichs, R. R., Beeman, B. L., and Coulson, A. H. Los Angeles Airport noise and mortality—faulty analysis and public policy. *J. Publ. Health* 70: 357-362 (1980).
104. Andreyeva-Galanina, Ye. Ts., Alexeyev, S. V., Kadyskin, A. V., and Suvorov, G. A. *Shum i Shumovaya Bolenz (Noise and Noise Sickness)*, Meditsina, Leningrad, 1972.
105. Abbey-Wickrama, I., et al. Mental Hospital Admissions and Aircraft Noise. *Lancet* ii: 1275-1277 (1969).
106. Herridge, C. F., and Low-Beer, L. Observations of the effects of aircraft noise near Heathrow Airport on mental health. In: Proceedings of the International Congress on Noise as a Public Health Problem, W. D. Ward, Ed., U.S. Government Printing Office, Washington, D.C. 1973.
107. Herridge, C. F. Aircraft noise and mental health. *J. Psychosom. Res.* 18: 239-243 (1974).
108. Grandjean, E., Graf, P., Cauber, A., Meier, H. P., Muller, R. A survey of aircraft noise in Switzerland. In: Proceedings of the International Congress on Noise as a Public Health Problem. W. D. Ward, Ed., U.S. Government Printing Office, Washington, D.C., 1973.
109. Ralster, E. Traffic Noise Annoyance—The Psychological Effect of Traffic Noise in Housing Areas. Ployteknisk Forlag, Lyngby, 1975.
110. Welch, B. L. Extra-auditory Health Effects and Industrial Noise: Survey of Foreign Literature. Wright Patterson Air Force Base, Ohio, Contract No. 16-BB-7, 1979.
111. Jonsson, A., and Hansson, L. Prolonged exposure to a stressful stimulus (noise) as a cause of raised blood pressure in man. *Lancet*, i: 86-87 (1977).
112. Parvizpoor, D. Noise exposure and prevalence of high blood pressure among weavers in Iran. *J. Occup. Med.* 18: 730-731 (1976).
113. Peterson, E. A., Tanis, D. C., Augenstein, J. S., Seifert, R., Bromley, H. R. Long term noise exposure and cardiovascular function in monkeys. Paper presented at the Model Noise Symposium, National Information Center for Quiet, Washington, D.C. 1979.
114. Borg, E., and Moller, A. R. Noise and blood pressure: effect of lifelong exposure in the rat. *Acta Physiol. Scand.* 103: 340-342 (1978).
115. Sontag, L. W. Effect of noise during pregnancy upon fetal and subsequent adult behavior. In: *Physiological Effects of Noise*, B. L. Welch, and A. M. S. Welch, Eds., Plenum Press, New York, 1970, p. 131-141.
116. Kimmel, C. A., Cook, R. O., and Staples, R. E. Teratogenic potential of noise in mice and rats. *Toxicol. Appl. Pharmacol.* 36: 239-245 (1976).
117. Jones, F. N. and Tauscher, J. Residence under airport landing pattern as a factor in teratism. *Arch. Environ. Health* 33: 10-12 (1978).
118. Edmonds, L. D., Layde, P. M., and Erickson, J. D. Airport noise and teratogenesis. *Arch. Environ. Health*, 34: 243-247 (1979).
119. Borsky, P. N. Review of community response to noise. Proceedings, 3rd International Congress on Noise as a Public Health Problem, American Speech and Hearing Association, Washington, D.C., 1980.
120. Wood, S. G. Traffic noise regulation: a comparative study. *Brigham Young Univ. Law Rev.* 1979: 461-807.
121. Environmental Protection Agency. The Urban Noise Survey. Office of Noise Abatement and Control, EPA No. 550/9-77-100, 1977.
122. Environmental Protection Agency. General provisions for product noise labeling and noise labeling requirements for hearing protectors, Part III. Fed. Reg. 56120-56147, September 28, 1979.
123. Environmental Protection Agency. Noise and environment. EPA Journal 5 (No. 9): October 1979.