

PHYSIOLOGICAL AND PSYCHOLOGICAL  
EFFECTS OF NOISE ON MAN

A Literature Review

by

T. Glenn Easter II  
Summer Undergraduate Trainee

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## PURPOSE

This literature search for the Virginia Highway Research Council is part of an indepth study of the physiological and psychological effects of noise on man. The ultimate objective of the study is to establish criteria for highway design and location using the effects of the noise generated by the highway as one of the input factors.

Many of the sources used in this literature search were obtained by computer searches. Included were searches of the holdings of the Defense Documentation Center, National Aeronautics and Space Administration, National Library of Medicine, and University of Virginia Medline. Other sources of information came from an open literature search. Approximately 1,500 items were scanned and 100 were thought useful and incorporated in this literature search.



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The human ear is considered to be one of the most complex bodily organs. Ears balance, provide feedback to enable one to monitor his own speech, analyze sounds, and serve as direction and range finders.<sup>1</sup> Ears act as narrow band and discreet frequency analyzers and are capable of picking out harmonic sounds from high level noise. What the ear hears has much more relevance to those suffering from noise than how the ear hears. For this reason, the physiological analysis of the ear will be minimized here. Since the morphology of the auditory system is readily available from many sources, the repetition of this material does not seem warranted. The references compiled in this literature review provide an excellent source for diagrams of the ear and its functions.

Built-in Protective System

The ear has two built-in safety mechanisms to protect it against damage. These mechanisms are known as the aural reflex and the mode of ossicle oscillation. The aural reflex involves the stiffening up of all mechanical parts in the middle ear, which results in a reduction in sensitivity to low and medium frequency sounds. This reflex is promoted by noise greater than 90 dBA lasting longer than approximately 10 milliseconds. A few people have voluntary control of this reflex, which allows them to prepare for the oncoming noise. This reflex cannot be prolonged for any great length of time; thus, the ear is left exposed to damage after a certain length of time. While this system takes over at 90 dBA, the second reflex, which involves the mode of ossicle oscillation, does not operate until a noise of 140 dBA or over is perceived.

"Ossicles" is a collective term for the three tiny bones attached to the eardrum. These bones are known as the malleus, incus, and stapes; more commonly the hammer, anvil, and stirrup. They constitute the middle portion of the ear and increase the pressure from the eardrum to the oval window, the entrance to the inner ear, by a ratio of 20 to 1. The last of the three, the one which contacts the inner ear, is the stapes. The footplate portion of the stapes fits into the oval window. Under normal noise intensity, the malleus and incus vibrate forward and backward with the impingement of sound waves on the eardrum. This vibration pushes and pulls the footplate of the stapes as it contacts the inner ear.

One can imagine what could happen if there were no control system and noise of 140 dBA or greater were picked up by the auditory system. Most likely the footplate of the stapes would be pushed through the oval window and into the inner ear, doing great damage. However, the mode of ossicle oscillation changes from to-and-fro to a side to side motion with impinging noise of 140 dBA or over. The effect is a drop in loudness and prevention of damage. Thus, the ear has two defense systems for different intensity noises.

### Definition of Noise

Noise is generally defined as unwanted sound and may be musical, nonmusical, regular, irregular, or of a distinctly disagreeable quality. Noise may contain distinct frequencies, known as pure tones, or may be just a loud din covering a broad range of frequencies. Most noise is non-musical, irregular, and distinctly disagreeable and is encountered as office, restaurant, and street traffic noise.<sup>2</sup>

With the onset of the industrial revolution, man was introduced to the age of man-made noise. With this age of great material progress, also came the pollution of air, water, and land. Since economic principles have been ranked over consideration for the worker, it is not surprising that two centuries later industrial noise is the greatest danger to the human ear. Noise has always been regarded as a secondary consideration by industrialized society. The primary concern has been the effective performance of the machinery and the effects of noise on man's physical, emotional, and social well-being have received scant attention. Noise has been considered as a health problem affecting two facets of man's life. It may affect man physiologically, as in the case of hearing loss, or it may be annoying and interfere with his privacy and emotional and social well-being.

### Impulsive vs. Continuous Noise

An important property of noise is its continuous quality as opposed to its impulsive quality. Impulsive noise is exemplified by a sonic boom or a large explosion and is usually man-made. Continuous noise is much less loud according to decibel ratings and extends over a much longer period of time.

Impulsive noises are usually not expressed in decibel ratings but can be converted into these units for comparison and convenience. When noting the effects on people, impulsive noises are usually measured in

Newtons/m<sup>2</sup> so that one knows the exact peak pressure exerted by the wave.<sup>3</sup> The peak over pressures required to rupture an eardrum and damage a lung are 35,000 and 100,000 Newtons/m<sup>2</sup>, respectively.

Impulsive noise supersedes the aural reflex system. By the time 10 milliseconds have passed and the system has come into action, the damage may already have been done. Therefore, an impulsive noise over 150 dBA would probably be spontaneously damaging to the ear. However, impulsive noise has been shown to be much less of a factor than continuous noise in regard to their effects on humans.

Authorities agree that less damage is done by impulsive noise as compared to that by continuous, high intensity noise.<sup>4</sup> Thus, it seems much more relevant to examine the effects of continuous noise rather than impulsive noise on the auditory system of man as well as man as an entity. The minor effects of continuous, high intensity sound create a condition known as "temporary threshold shift." To experience this effect one generally must be exposed to sound pressure levels of 90 dBA or more in the intermediate to high frequency range for at least several minutes. Temporary threshold shift results when the former lower level of auditory perception, the normal threshold of a particular frequency, is raised after exposure to a sufficiently loud noise for a specified duration of time. Frequency is normally expressed in hertz or cycles per second. Thus, the intensity decibel rating of the sound must be raised while the frequency is kept constant to represent the same tone.

#### Experiencing Temporary Threshold Shift

For example, a person may normally be able to hear a 5,000 hertz tone at a sound pressure level of 6 dBA under properly controlled conditions with sufficiently low noise levels. Exposure to noise in the 1400-2700 Hz range for 10 minutes at a sound pressure level of 110 dBA might cause a loss of hearing sensitivity such that the tone at 5,000 Hz would now have to be raised to 24 dBA before it would be audible to the listener. Thus, a threshold shift from 6 dBA to 24 dBA was observed to occur after a frequency of 5,000 Hz.

Fortunately, this effect is not permanent and tends to wear off within approximately 30 minutes. Permanent threshold shift from this short-term exposure is not observed to be significant. Although not fully understood, it has been observed that the frequency of the noise that causes the greatest shift to occur is less than the frequency of the original tone.

The greater the increase of exposure time and the noise level the greater the threshold shift, and consequently the greater the recovery time required. Threshold shift is only temporary, however, when exposure to such noise is not regular. Repeated exposure can result in permanent damage that may become severe and chronic.<sup>5</sup> Perhaps one of the very bad aspects of this type of a hearing loss is that the individual who is readily exposed to noise sufficiently loud to incur permanent damage has little or no idea as to his losses. Some authorities have even observed situations where the victim would deny that there was anything abnormal about his hearing. Often the victim will agree that the noise level is high, but the general response of these unsuspecting individuals is that they have adjusted to the noise level and have built up some type of tolerance.

#### Effects of Temporary Threshold Shift

Many authorities feel that what actually happens in a threshold shift is that the individual arrives at work or elsewhere in the noisy environment and is not accustomed to the noise.<sup>6</sup> After the first day he has an extra heavy dose of temporary threshold shift, possibly accompanied by a ringing in the ears, commonly known as tinnitus. After the exposure, all surrounding noise seems subdued around 4,000 Hz if he were normal under exposure. High frequencies may be louder than usual due to a contrasting to his loss around 4,000 Hz. . The following day the victim will experience partial recovery. On this and subsequent days he will not experience as loud a noise because he now has a threshold shift. There is a possibility that the victim may recover his hearing loss wholly or partially if he is removed from the source of noise before a period of up to one year. With the onset of permanent damage, the victim notices the first signs that his hearing is impaired. His speech becomes less intelligible, the volume of the television must be turned up very loud, even to him, to be heard distinctly.

#### Physical Limits

The limits of noise to which one should be subjected are now fairly clear as a result of many research efforts. Generally, if the noise level is sufficiently high that conversation is difficult and if exposure is continuous for 40 hours a week, permanent hearing loss may be sustained if exposure continues for more than one year.

#### Effects on Other Systems

The stimulation of the auditory system by noise is accompanied by many effects on other systems. These other systems are usually considered

as non-auditory although they are affected by the auditory system, since they are capable of functions not part of hearing. Since most of the information received by the auditory system is transmitted to the brain, it is reasonable to expect that the nervous system must be most affected by auditory transmission. These neural systems include the autonomic nervous system, the reticular nervous system, and cognitive areas of the brain.<sup>7</sup>

### Noise Tests

In tests for noisiness, it has been observed that the effects of sex and occupation have had little effect on experiments involving perceived noisiness where subjects were selected from a group of college students and adults.<sup>8</sup>

In an effort to duplicate noise in the lab that is absolutely rated with the same perceived noisiness as the source being examined, it has been observed that lab simulated noises give results remarkably like the actual source.<sup>9</sup>

### Transportation Noise

Hearing loss can occur in some typical transportation vehicles. Permanent hearing loss in the high frequency range may occur with daily exposure. This has been observed in airline stewards and stewardesses.<sup>10</sup>

Numerous surveys have been made of environmental sounds that annoy people. Studies of offensive sound have included almost every imaginable source including rain, thunder, dogs, birds, factories, cars, trucks, and aircraft.<sup>11-18</sup> It is beyond the scope of this survey to examine all sources; therefore, only those considered to be of major importance will be discussed.

Airplanes and vehicles for flight into outer space constitute the most prolific source of air noise.<sup>19-20</sup> The major source of annoyance in neighborhoods surrounding airports is reported to be the noise resulting from aircraft passing overhead and engine warm-up on the ground.

Transportation noise causes the greatest number of court cases. The jet liner probably represents the most common kind of offensive sources. Many citizens and individuals have regarded the noise of jets as so intolerable that lawsuits have been brought against the airlines and their operators.<sup>21</sup> Jets and aircraft in general represent a substantial

increase in noise over that produced by surface transportation vehicles. The duration of flyover time can be unusually long in areas surrounding airports.<sup>22</sup>

In launching vehicles for flight into outer space, considerable external engine noise is created even at distances of several miles. As the sound pressure level increases, the principal sound frequency becomes lower. Although there is little known effect on man, the auditory system seems to be less affected by sound as the spectral frequency is decreased. Sounds of low frequency are usually considered to be 50 Hz or less. The other known effect on man is the bodily vibration which results with frequencies in the proximity of 20 Hz.

In a comparison study,<sup>23-27</sup> the data revealed that the normal peak over pressure at which subjects rated sonic booms, subsonic aircraft noise equal in acceptability was 1.69 lbs. per sq. ft. Conclusions which may be drawn from experiments indicate that the subjective tolerance to sonic booms decreases faster than the tolerance to subsonic noise when the intensity is increased equally.

In recent surveys,<sup>28-42</sup> in a number of cities, substantial sociological information has been summarized. Sonic booms were found to increase the annoyance level in each city. Mean annoyance was found to increase as a function of economic level.

### Noise Masking

Noise can jeopardize human life by interfering with and masking audible messages. Impact or impulsive noise can endanger human life by causing the collapse of structures. Noise may also threaten one's job security and earning power by causing a permanent hearing loss.<sup>43</sup>

A relatively recent example of noise masking a danger alert involved the death of two persons and injury to two others during the passage of the late Senator Robert Kennedy's funeral train through Elizabeth, New Jersey, in 1968.<sup>44</sup> Helicopters carrying newsmen and secret service agents noisily obliterated the warning blast of an approaching train.

A more common type occurrence of noise masking warning signals is that in which the noise of truck exhaust, gears, air intake, and, at higher speeds, tire and wind conflict with the sirens of emergency vehicles. For this reason, some state officials feel more lives are lost than are saved by speeding rescue vehicles.<sup>45</sup>

### Possible Solutions

Those persons living adjacent to a busy highway are acutely aware of the noise created by heavy traffic. Possible means of overcoming the noise include building barriers and insulating buildings. The best solution, however, is to stop or restrict noise emissions by the chronic offenders.

### Vehicle Classification

Highway vehicles may be divided, for the purpose of this discussion, into cars, motorcycles, and trucks. Most new cars are reasonably quiet when maintained properly and not modified. Motorcycles are somewhat more offensive, but those that are most destructive and abusive have been modified for such purposes.

Without doubt, trucks are the worst noise offenders.<sup>46,47</sup> Due to high interior noise levels the driver can detect the siren of an emergency vehicle for only about 3 seconds.<sup>48</sup>

### Noise Distraction

Besides masking, noise can also be distracting. In addition to engine and other associated noises previously mentioned, the most distracting are stereophonic tapes, radio units, and air conditioners. Noise from these sources can greatly impair a driver's auditory and visual attention.

### Performance of the Deaf

One unusual yet interesting bit of information suggested by some authorities indicates that deaf drivers may perform in a superior fashion in comparison with normal drivers under the same conditions.<sup>49-51</sup> While some studies reveal that deaf drivers perform at least as well as normal drivers, Canadian studies show that deaf students are significantly better drivers. The same results are observed in industry. Freed reports that deaf people have fewer accidents.<sup>52</sup> He proposes this may be a consequence of decreased distraction.

However, deaf people usually are placed in lower paying jobs when compared to people with normal hearing and comparable intelligence.<sup>53</sup> It is known that the employer is apt to discriminate against the deaf person because of high insurance rates.<sup>54</sup> This is contrary to the purpose of

workmen's compensation rates, which supposedly are based on the risks attending work in a given industry.<sup>55</sup>

#### Principles Which Affect Biological Functions

Before further examining the biological effects of noise pollution on man, it should be helpful to present those principles which affect the successful biological functioning of the general organism.

1. A given sensory receptor, in this case the ear, is more responsive to the particular form of energy that activates it than is any other sensory receptor or part of the organism.

2. A sensory receptor does not transmit the energy it receives directly but transmits what one may call a photocopy as a coded nerve impulse.

3. A sensory receptor can be damaged by an overexposure to the specific energy to which it is particularly sensitive before other constituents of the organism can be affected adversely by this same energy.

4. A sensory system is self-preserving and will not damage other components of its constituent organism.

5. Through responses to normal stimulation, the unit of parts and mechanism of the organism will be increased.

6. Unuseful responses will tend to be inhibited by the organism.<sup>56</sup> From these hypotheses it may be inferred that the ear cannot through normal stimulation directly activate components of the neuromuscular or glandular systems in man to cause detrimental effects.

#### Sound as a Warning System

The close connection between the ear and the autonomic nervous system is evidence that the ear may have developed as a warning system to aid in preparation for action. Sound has properties which make it very suitable as a warning system; it can be heard night and day and is capable of bending around objects. As a warning signal, sound must not be an adaptable stimulus except for nondangerous stimuli. If sound were not adaptable for nondangerous stimuli, then the ear would probably be too tired to respond to dangerous stimuli.<sup>57</sup>

There have been extensive studies in the United States and Europe on the effect of sound on certain non-auditory physiological reactions of man.<sup>58-74</sup> These widespread bodily responses, which have been observed to display considerable individual variation, become more prevalent for more intense sound and discontinue by adaptation to long-term exposure. Some investigators wonder whether somatic responses are part of an effort by the body to adapt to the noise distress and achieve homeostasis.

An interrelated network of responses, referred to collectively as the end response, involves changes in blood circulation, breathing rate, galvanic skin response, skeletal-muscle tension, gastrointestinal mobility, and blood and urine content due to glandular stimulation.<sup>75</sup>

The end response is not affected by sound stimulation exclusively and gives slightly different responses when evoked by other stimuli. Blood circulation response is characterized by rates of constriction of the peripheral blood vessels. The effect is to increase blood flow to the brain, whose vessels do not constrict under stimulation. To activate the end response, a sound of about 70 dBA and tone of 1,000 Hz are required. If the given sound pressure level is sustained for a long enough period, the effects on the listener are a temporary threshold shift and a noise induced permanent threshold shift.<sup>76</sup>

#### Physical Effects of Sound

High intensity noise and mechanical vibration can be considered analogous since both create resonance in the body. The effect of noise on the body is a general stimulation of all sensory receptors affecting touch, pressure, and movement of joints. Mass sensory stimulation is normally observed if the body is in contact with the resonating surface, and it results in sensory fatigue of the body.

Disorientation is reasoned to result from vibrations occurring in the fluid of the inner ear which affects the labyrinthine balancing mechanism. It is also suspected that nausea may be another symptom resulting from such vibrations. Although it is difficult to confirm these effects due to the stimuli which provoke them, they are generally accepted as being true experiences due to their periodic appearance.

Intense noises of low frequency have been observed to cause painful sensations resulting from chest movements. Some persons experience facial pain, which is thought to be induced by a vibration in the upper respiratory tract involving the nasal and proximal cavities. Another effect of abnormal

stimulation of the balancing organs may be manifested in exaggerated head movements and feelings of giddiness.

Note "adapt" does not mean that one is just as well off as before. After being subjected to loud noises over a period of time, one becomes somewhat less affected. However, the actual startling never ceases. It is in this sense that "adapt" becomes misleading. Physiologically one may cease completely to respond to a given intensity as one ceases to react as readily to other intensities that do have an effect. This same type of adaptation can be experienced when one pricks his finger with a pin, noting that pain decreases with each repetition. The lack of pain does not mean that no further damage is being done. In the same way the human mind is being continually probed by similar phenomena as part of its daily experiences. For this reason, it has been said that living with noise is like living with an electric shock.

Vasoconstriction is theorized to be related to annoyance.<sup>77</sup> When constriction occurs there is a decrease in the amount of blood and circulation. The direct effect at the cellular level is a decrease in oxygen and a buildup of carbon dioxide. Also the nutrient supply is restricted, with a resulting accumulation of other metabolic wastes. When circulation is cut off, the result is a pins and needles sensation as when one's foot "goes to sleep" from sitting cross-legged. Studies by Lehman indicate that boiler factory workers who are continually exposed to loud noise suffer from inadequate circulation.<sup>77</sup> A chronic state of restriction may destroy cells in the inner ear as well as cause bodily harm at the tissue and organ level.

As proposed, vasoconstriction would establish a biological and physiological basis for annoyance. Vasoconstriction is also a likely cause of annoyance because it accounts for individual reaction variations. As a function of frequency, intensity, duration, and suddenness, the organ is deprived of blood flow. The effects range from very mild, from the point of not being noticed by the individual, to slightly choking, where a mild sense of annoyance is developed, to continuous choking, with severe blood flow restriction resulting in cell death.

Further research is needed, but it is encouraging that the vasoconstriction theory of annoyance is considered amenable to testing through research.<sup>79</sup>

### Study of Involuntary Changes

Intensive investigation has been made to detect involuntary changes in man's body as a result of exposure to noise. Dr. Gerd Jansen received a research commission to study the behavior of steel workers constantly exposed to loud noises. Jansen noticed from their pale skin, the dry and pale mucosa of their mouths, and their irregular heartbeat that men were under circulatory tension. He ran experiments on animals to determine if it was possible for annoyance to cause hypertension in man. The results of the experiments were so positive that he chose to continue his work with human subjects under less severe experimental conditions than for his animal experiments. Jansen chose white noise of 90 dBA. Later investigations showed that white noise produced the same results as industrial noise. Previously, in his animal experiments, he had used noise of 150 dBA. Due to a decrease in sound pressure, the effects on his human subject were minimal, but consistent. A slight change occurred in the diastolic pressure of the heartbeat, the time when the heart is in the relaxed state; nevertheless, no noticeable effect was perceived on the systolic pressure of heartbeat, which is the time when the heart is contracted or actively pumping blood.

Under the same conditions, Jansen also tried to detect a change in heartbeat similar to that found in the steel workers. The pulse would quicken only slightly, however, when the noise began, and return to normal within a few seconds after exposure.

Jansen felt that this survey showed that noise could cause a physiological rather than psychological response, but if it had meaning it aroused anger or fear, or caused opposition. The result on the individual would be an increase in blood pressure and pulse rate.

Probably Jansen's most significant findings were from his work with the effects of noise on the blood supply. His introductory test in this area employed the technique of transillumination, which involved measuring the redness of the cheeks from the outside by shining a light inside the mouth. A direct correlation was made between the redness of the subject's cheeks and the amount of blood that was present. Jansen concluded that when a subject was exposed to noise, his cheeks became visibly paler, indicating a substantial decrease in blood supply. Jansen also measured skin temperatures under controlled humidity and temperature. A decrease in skin temperature of one to two degrees centigrade was observed when subjects were exposed to noise. Thus, the skin temperature fluctuated, which also indicates that noise decreases the blood supply to the periphery of the body.

Similar results were obtained on further refinement of the above experiment in which Jansen used two electrical contacts placed approximately 2 in. apart on the skin of the arm. While one contact measured the temperature of the area to which it was attached, the other provided a constant amount of heat. Jansen showed that the actual heat loss between points was proportional to the amount of blood present between the two contacts. As expected, when the noise increased, the warmth increased, which suggested a decrease in blood flow for the measured region.

#### Related Experiments

Jansen did other experiments to measure the stroke volume of the heart. Using a ballistocardiogram, a gauge for measuring the heart recoil of each beat, on a subject lying on a suspended platform, he found that there was a decrease in the volume of blood pumped by the heart when the subject was exposed to noise.

The response that Jansen observed for the particular group of experiments described above is normally evoked in a stress situation and is known as vasoconstriction, a reflex action triggered by the sympathetic nervous system. The sympathetic nervous system evokes this response when activated by the hormone "adrenaline," or "epinephrine," secreted by the adrenal gland. The adrenal gland reacts to all general stress situations, including exposure to noise as demonstrated. It is noteworthy that the adrenal gland is not limited to stimulation by noise stress but is a general alert system.

A later study by Jansen involved observation of subjects during periods of rest, work, and noise.<sup>80</sup> The ancient principle of the plethysmograph was employed to measure the amplitude of the pulse in the finger. Subjects were periodically exposed to noise and quiet while resting or working. As expected from previous study, the blood volume decreased under noisy conditions. However, several results of interest were obtained that were not indicated from previous experiments.

The work task had a more significant effect on the flow of blood in the finger than did the noise. The overall dilation of the blood vessels due to the work was greater than the constriction due to the noise.

While there was no adaptation to the dilation response caused by work, there was some adaptation of the constricting response caused by the noise. From prolonged work, blood vessels were actually observed to enlarge slightly. This may be accounted for by the increase in body heat. Constriction decreased

somewhat after about the first minute of noise. It could not be concluded whether a complete adaptation to the noise might eventually occur, since Jansen used only one to two minute exposure times.

In other experiments by Jansen, at Dortmund, a mathematical relationship was established between the time of noise exposure and the duration of response. Jansen accounted for both duration and intensity and found that the response lingered on for long periods after the stimulus noise had been discontinued. For an exposure of several minutes, the ratio of the duration of response to stimulus was observed to approach 4 to 1. There was also evidence that the wider the spectrum of noise used the greater was the response elicited.

A major factor substantiating the validity of studies by Jansen and others is the wide range of subjects used. The three major groups of volunteers included steel workers, college students, and members of an African tribe, the Mabaans.<sup>81</sup> It was observed that students gave the same response on exposure as steel workers who had been exposed to noise for about ten years. Also, the degree of the involuntary reflex reaction elicited by noise exposure did not fluctuate throughout the experiments. Therefore, Jansen concluded that the adaptation that occurred was mental rather than physiological, since the body never loses its ability to respond to a noise stimulus. In establishing his conclusions, Jansen defined "adaptation" to mean the loss of reaction to a stimulus.

#### The Mabaan Tribesmen

The third group of test subjects proved invaluable as part of a comparative study.<sup>82, 83</sup> The Mabaan tribe, natives of Sudan, Africa, were visited by Dr. Samuel Rosen and others, including Dr. Jansen. Dr. Rosen made his first of four visits to the Mabaans in December through January of 1960-61. He established that the cultural development of the tribe placed them in the late Stone Age. The tribe had no guns, but hunted and fished with spears. The average sound level was about 40 dBA in the village, except for occasional provocations from a domestic animal or when the villagers engaged in singing and dancing. Hearing acuity was observed by Dr. Rosen to be significantly more acute for Mabaans than for American industrial people of the same age between 10 and 70. He found that the average 75 year old Mabaan could hear as well as the average 25 year old American. The Mabaans were also observed to converse 100 yards apart without raising their voices.

Dr. Rosen felt that the absence of high level noises was largely responsible for the superior hearing of the Mabaans. However, the quiet

environment of the Mabaans compared to the generally noisy American environment is not the only factor involved.

Rosen found that the Mabaan had a generous supply of blood reaching those parts of the ear critical for good hearing. This observation held true for all ages. The general blood supply depends on the condition of the cardiovascular system. Rosen found that Mabaans had an unusually low incidence of arteriosclerosis, a condition known as hardening of the arteries, and a very low incidence of heart attacks. Also vascular hypertension, duodenal ulcers, allergies, bronchial asthma, and stress and strain are virtually nonexistent among the tribesmen. Results of both Rosen's and Jansen's work indicate that maintenance of the elasticity of the circulatory system helps account for the healthy conditions of capillaries supplying the inner ear. Jansen concluded that the condition of the blood vessels and the lack of noise have kept the blood vessels open and the blood supply more than adequate.

In 1963, tests by Jansen for vasoconstriction at 90 dBA in the Mabaan tribesmen elicited stronger physiological responses than for subjects of Dortmund. All research efforts in this area indicate the necessity for quiet in order for the cardiovascular system to thrive. Dr. Jansen believes that an occasional loud noise will not cause significant damage, but continuous exposure is definitely detrimental to health. Jansen does not recognize the noise illness as such, except for hearing loss, but regards noise as a stress applying to the body often without one being consciously aware of it. Noise can have particularly bad effects on those already suffering from some type of circulatory ailment. Other research efforts have reached similar conclusions concerning the effect of noise on blood circulation.<sup>84</sup> Dr. Kylin of Stockholm found symptoms of vasopastic disease in woodsmen using chain saws, whose blood vessels in their hands contracted so that they often complained of their fingers turning blue and afterwards white. Woodsmen experienced these symptoms in only one hand. A related impairment, known as early as 1811 as Raynaud's disease, was observed since both hands grasped the vibrating machinery.

#### Noise Research in Italy

Research on noise has also been performed at the Institute of Occupational Medicine at the University of Pavia, located in northern Italy, by Professor Dott. Giovanni Straneo, M.D., who first became interested in the subject as a result of the high frequency of high blood pressure among workers in nearby metal fabrication plants. Dr. Straneo conducted his study

of the causes of hypertension under controlled laboratory conditions using tape recordings. Straneo's results for finger pulse completely agreed with those of Jansen.<sup>85</sup>

This was the first visible proof that vasoconstriction did result from noise exposure. Many of Straneo's other experiments paralleled those of Jansen and verified his results.

However, Straneo found that other blood vessels responded in an opposite fashion than those of the conjunctiva. He observed that both the blood vessels of the retina and the blood vessels of the brain dilated when exposed to noise. He concluded that the reason these vessels dilated and peripheral vessels contracted was related to structural differences.

#### Mabaans vs. the Urban Society

Dr. Rosen has presented a pictorial analogy to account for the superiority of the Mabaan tribe's hearing when compared to that of people inhabiting the noisy cities of an industrial society. He compared the effect of an acoustic load on the ear with the wear on a rug covering a flight of stairs in a house, where the rug represents the hair cells within the cochlea portion of the inner ear. High frequency tones as expressed in Hertz or cycles per second use the rug on the lower steps only, while low tones march to the top of the steps. Thus, wear is greater at the bottom of the stairs. The conclusion drawn by Rosen is that high frequency tones break down hair cells more rapidly than do low tones under prolonged exposure.

The loss of hearing with age, presbycusis, has before been regarded as a result of the natural process of aging. Rosen has changed his view of presbycusis to that of a degenerative disease attributable to wear from the noisy environment that surrounds us at an early age.

#### Differences of Opinion

Henry Still disagrees with Dr. Rosen somewhat when he says that noise induced hearing loss can be distinguished from presbycusis, which Still defines as a progressive deterioration of the ability to hear high tones.<sup>86</sup> Still contends that with an increase in age, the intensity of sound must increase for audibility. He notes that losses in the intensity detected because of presbycusis are related to frequency. He says that hearing loss with age can be distinguished from hearing loss due to noise by observing the particular

frequencies which the hearing loss involves. Hearing loss with age involves only high tones while noise induced hearing loss, depending on the type of noise, usually results less from damage in the high frequency areas than from damage in other areas. Presbycusis is caused by deterioration of the middle ear while noise affects the hair cells of the inner ear.

Noise is best considered as a form of physiological stress which can contribute to injury or disease. As in the case of any other stress situation, noise imposes a burden on the organism which reacts to change its environment so that it may operate at a more nearly normal level to perform necessary life functions.

Prolonged adaptive responses to noise can lead to harmful physiological changes. Adaptive responses which allow the organism to continue functioning are often warning signals that further harm may occur should the stimulus noise be prolonged.

The body has a variety of neuropsychological responses which may be elicited by noise of various durations and intensities. Some of these bodily responses, when prolonged, can be highly detrimental to the individual and have been postulated to be the source of some psychosomatic disorders, specifically, peptic ulcers and other diseases associated with hypertension. Studies by Michael indicate that high blood pressure, migraine headache, and colitis can be observed after noise exposure.<sup>87</sup> Noise is also damaging to those persons already afflicted with some other disease. It has been observed that intensive care patients and others require significantly longer recovery time when hospitalized in a noisy environment.<sup>88</sup>

Noise may also disrupt digestive functioning. Brief noise exposures may interfere with peristalsis, the contractions that transport food through the digestive system, and the flow of saliva and gastric secretions by afflicting muscular contraction.<sup>89</sup>

### Sex Differences

Differences in hearing between the sexes have also been examined. Many studies have found women to have much more acute hearing than men. Professor William Burns of the University of London attributes the superior hearing of women to the fact that men experience greater noise exposure. He blames small arms fire during wartime, hunting and target practice as an important source of noise induced hearing loss.<sup>90</sup>

### Effect on the Brain

Straneo examined the blood vessels of the brain using a reograph, an electrical device for measuring blood flow. He suggested that a major cause of headaches might be the overdilation of brain blood vessels when exposed to noise.

### Effect on the Heart

While Jansen had observed some effect on the heart using a ballistocardiogram, Straneo used an electrocardiograph to obtain further information. He used a pure tone of 8,000 Hz to observe changes in the electrical impulses of cardiac patients. In some cases there was a significant deterioration of the electrocardiograph tracings, where Straneo observed that deformation time, true isomeric contraction, and isotonic systole were affected. He reasoned that the deterioration of the ECG patterns that he observed could be attributed to dual effects of noise on the heart, one direct and one indirect. These effects involve the vegetative nervous system and vasoconstriction, respectively.

It had been known for some time that blood clotting is often the precursor of heart attacks. Straneo has suggested the possible effect noise may have on small periphery blood vessels that results in vasoconstriction. He postulates that vasoconstriction coupled with a condition known as "blood sludge," an assemblage of red blood cells, may lead to heart attacks. More work, however, is needed to prove that noise actually causes "blood sludge." The concept is certainly realistic and even if proof that blood sludge effects are produced as a direct result of noise is slow in being, the author feels that the vasoconstrictive response greatly increases the chances of clotting since there are indications that other body chemicals may cause clotting when released in the blood. The smaller the diameter of the vessels, the less blood sludge is needed to cause effective clotting. Thus, vasoconstriction should not be overlooked as a catalyst to clotting in an eventual circulatory breakdown.

### The Sympathetic Nervous System

All research efforts relating to the sympathetic nervous system indicate that it is the sympathetic division of the autonomic nervous system that induces the adverse effects of overexposure to noise. Again, Pavia Institute has been the site of much of the research. There Slavatore Magueri, M.D. achieved an effective alleviation of all abnormal symptoms exhibited in 30 patients suffering from Raynaud's disease, or arteritis.

After surgical disengagement of the sympathetic nervous system in these 30 patients, vasoconstriction and the galvanic skin response were no longer elicited as a response to noise.

In Magueri's work with the galvanic skin response, it was observed that with the onset of noise, vasoconstriction and the galvanic skin response were almost instantaneously elicited. With continuation of noise, vasoconstriction continues while the galvanic skin response ceases. If the noise changes in frequency or volume, another galvanic response may be elicited. Further work at Pavia that has proved to be interesting with respect to noise pollution concerns the studies of Dr. Magueri's son, Dr. U. Magueri, who has used an electronic device the size of a medicine capsule to both measure pH and transmit findings in the human stomach. He observed that volunteers with normal stomachs exhibited a mild secretion of acid similar to that observed after consuming an aperitif. However, those individuals whose stomachs were classified as secreting too much acid secreted less than they normally did when noise was introduced.<sup>91</sup>

A response that has been considered to be related to vasoconstriction is the response Dr. Salvatore Magueri calls the electrodermal response, or the galvanic skin response. This response is used in a polygraph lie detector test. This test involves placing two electrodes on the subject. When the body is calm, a galvanometer measures low voltage. Any stimulus, exterior or interior, results in a nervous excitation that increases the electrical conduction of the skin within a two-second interval and the galvanometer records the increase.

#### Concluding Remarks

To this point, there have been discussed those aspects of noise pollution which without doubt have an adverse effect on the human being. Now it is interesting to speculate whether noise pollution will be subjected to the stringent controls that have been imposed upon air pollution. Sadly enough, it is often necessary for deleterious agents in our environment to cause human death before governmental officials and private citizens are aroused to action. For this reason it is particularly relevant that an examination be made of the evidence that indicates noise may cause the death of man.

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