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The Public Health Effects of Community Noise

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OBJECTIVE

Noise is "any loud, discordant or disagreeable sound" according to Webster's Dictionary (15, p.1). Another definition would be "unwanted sound". Nearly everyone is exposed to noise at some time in their lives, yet the control of noise is not a top priority for most environmental control programs. Community noise is a very widespread problem that can cause serious public health problems.

It is well-established that noise can cause hearing loss in the workplace, but what are the other effects of noise outside the workplace? The World Health Organization defines health as a state of physical, mental and social well being, not merely the absence of disease or infirmity. This paper will examine the evidence for the effects of noise on the cardiovascular system, the performance of tasks, the unborn and children, social behavior and mental health, sleep, speech communication and hearing. The majority of the analysis will be spent on the cardiovascular effects because they are both the most controversial and the most potentially health threatening.

It is hoped that this examination of the public health effects of community noise will serve as justification for increased priority and effort in noise control at the community, state and federal levels. In addition to noise control programs, this review should also be used to educate the public on the hazards of community noise exposure and how to protect themselves from it.

NOISE AS A STRESSOR

Numerous studies have been done over the last forty years to determine the relationship between noise and various physiological responses. Recent reviewers of this extensive literature still find the results "contradictory" and "inconclusive".

In this section, some of the most recent studies will be critically reviewed and conclusions will be given on the link between noise and such physiological responses as increased blood pressure, elevated heart rate, and increased flow of adrenalin. First, the physiological responses of the body in contact with a stressor such as noise will be described.

The Body's Response to Stress

The body has several levels of transient response to stress. These responses occur involuntarily and happen even when the person is asleep. The changes occur because the auditory system is closely linked to the autonomic nervous system. When the body responds to a stressor such as noise, two main hormone groups are released, catecholamines and cortisone (1).

The first group, the catecholamines, composed of adrenalin and noradrenalin, are responsible for mobilizing the body for instantaneous action. The catecholamines cause the heart rate to increase, the blood vessels to constrict, the muscles to tense, the lungs to breathe faster and the blood to clot should bleeding occur. The release of catecholamines is also responsible for dilation of the pupils for better vision and increases in the senses of hearing, smell and touch. The palms and soles of the feet also perspire to allow for efficient waste removal. These responses are beneficial in the short run, but are dangerous when they occur over and over again.

Cortisone, the other major hormone released into the blood, is even more closely associated with people who experience chronic stress. Cortisone stimulates the release of rennin in the kidneys which causes an increase in blood pressure. It also causes tears in the arterial walls which are then repaired by deposits of cholesterol. When a build-up of cholesterol plaque occurs, the heart is subject to increased stress. Hardening of the arteries or heart attack may occur. Another response due to cortisone is the inhibition of the activity of vitamin D which is needed to bring usable calcium into the bloodstream. Too much cortisone can therefore lead to osteoporosis.

Cortisone also inhibits the work of the defensive cells of the body which fight disease and infection. A continuous level of cortisone will increase the likelihood that a person could contract a major illness such as cancer, although the link between stress and cancer has not been conclusively proven.

Another result from the release of cortisone is the production of glucose in the liver which the body needs for quick energy in emergencies. Yet chronic stress can lead to the production of too much glucose and the risk of contracting diabetes. Cortisone also slows down the digestive system and may lead to irritation of the lining of the digestive tract and eventually, ulcers of the stomach and small intestines.

Response to stress occurs in several steps. The first response is the "startle reaction", experienced by the voluntary muscles. This reaction is characterized by body movements such as eyeblink, flexing of the arm, arching of the torso and widening of the mouth. These behavioral responses cannot be overcome, even with the knowledge of upcoming noise. For example, an experienced marksman will still show the eyeblink response in firing his weapon (6).

The next response to stress comes from the smooth muscles and glands. Constriction occurs in the peripheral blood vessels (also called total peripheral resistance or TPR or vasoconstriction), which may lead to increased blood pressure (either diastolic, systolic or both), and/or increased heart rate, cardiac output or stroke volume. Hypertension has been defined by the World Health Organization to be a systolic blood pressure greater than 160 mmHg or a diastolic blood pressure greater than 95 mmHg. Vasoconstriction can occur beginning at noise levels of 70 decibels on the C-scale (dBC) (6, p.279). High blood pressure causes increased cardiovascular morbidity and mortality.

Other changes at this point included changes in the resistance of the skin to electric current, breathing rate, motility of the gastrointestinal tract, pupil size and saliva secretions.

The third level of response involves the neuro-endocrine system. This response includes changes in hormone levels and blood composition. These biochemical changes can cause associated electrolytic imbalances (potassium, calcium, sodium, magnesium) and other changes in the blood glucose level as described above (67, p.35).

Other physiological responses cited as related to noise as a stressor are lowered resistance to disease and decreased ability to recover from it, increased blood cholesterol and other health disturbances such as sore throats, headaches, fatigue and nausea. Extremely high noise levels, typically 110 decibels on the A-scale (dBA) or more, have also proven to cause vertigo, nystagmus (a fast movement back and forth of the eyeballs), and problems with visual acuity and color vision (39, p.450-2).

Animal Studies

Peterson et al. (56) carried out and animal study on four rhesus monkeys. Two of the monkeys served as controls and two were exposed to realistic (for humans) patterns and levels of noise for nine months. The 24-hour average energy noise level or Equivalent Level (Leq) was set for 85 dBA and was meant to resemble the exposure of a worker in a noisy industry.

Peterson found that both experimental animals exhibited sustained increases in mean blood pressure. Compared with the control animals, the increase was 22.9%. Comparing the experimental animals' increases with their pre-exposure levels, blood pressure elevations of 41.8% and 15.6% were found. These blood pressures remained elevated for the 27 days that responses were monitored after the noise was turned off.

The cause-effect relationship between noise and blood pressure was studied by varying the noise exposure intensity and studying the resulting change in blood pressure. There was a correlation between elevated blood pressure and the most intense noise levels.

Another interesting result of Peterson's work was that the monkeys did not suffer any loss of auditory sensitivity. Therefore, it is possible for an effect such as increased blood pressure to occur without a simultaneous loss in hearing, and this effect may occur at levels lower than those prescribed to protect against hearing loss.

Two possible criticisms of Peterson's work is the small sample size and the use of chair-restrained animals. The cost and logistical problems involved with a larger sample are considerable. In regards to the use of restraint, the control animals were also restrained, so any stress from the restraint would have been felt in them also. Despite these criticisms, Peterson's work is important in showing a sustained elevation in blood pressure and having that effect without an accompanying loss of hearing.

Another study on monkeys was conducted by Kirby and associates (37) to study blood pressure responses in offspring of monkeys with high blood pressure. Sixteen monkeys were used-eight of parents with high blood pressure and eight of parents with normal blood pressure. They were exposed to 30 minutes of broadband noise at 95 dBA.

The offspring of monkeys with high blood pressure had higher resting mean arterial blood pressure (MBP) than the control animals. During the noise exposure, their MBP increased significantly while the offspring of parents with normal blood pressure did not show a significant increase.

The main result of this study is to show that offspring of hypertensive parents may be particularly susceptible to getting high blood pressure from noise exposure. Of course, it is unclear whether hypertension in monkeys is physiologically equivalent to human hypertension, which is a problem with any animal study. Also, this study was done with a very short exposure time (30 minutes) at a relatively high intensity that is not common in community noise exposures, although it is found in industrial settings. The study did not detect any physiological effects in the control animals.

Turkkan et al. (71) did a long term study of cardiovascular effects from industrial noise on four baboons. They were exposed to an 8 hour a day industrial noise sequence for different time periods ranging from one week to four months and blood pressure and heart rate were continuously monitored during this time. After the noise was stopped, cardiovascular levels were monitored for an additional two weeks.

The noise sequence used by Turkkan (71) was the same industrial noise sequence used by Peterson (56). The baboons were exposed to levels of 83, 93 and 97 dBA. Acute blood pressure increases were observed, the magnitude of which were directly related to the noise intensity.

The chronic effect of continued exposure to noise was to lower blood pressure, heart rate and catecholamines. This result is different than the results of most other human and animal studies which generally have showed either no change or increases in cardiovascular and hormonal levels. This discrepancy is probably due to the use of sub-adult baboons, a different primate species from humans and Peterson's monkeys. Also, the rhesus monkeys used by Peterson were adults, so the lowering of blood pressure in the baboons may have been due to their young age.

Criticisms of this study carried out by Turkkan include the small sample size and the invasive technique (surgery) used to measure the blood pressure. Also, there was concern that the noise may have become a conditional stimulus for food, since the noise sequence was paired with food presentation. The general conclusion expressed in the paper was: "In all, our studies point to a more complex effect of noise on the cardiovascular system than has been hitherto suggested" (71, p.25).

The obvious concern with any of these non-human primate studies is how the results correlate with human responses. The non-human primate studies are considered to be more appropriate than the previously popular rodent studies. Several early rodent studies did show an increase in blood pressure after several months of exposure to noise. However, these studies used unrealistically high noise levels (above 100 dBA).

Rodents are not considered good models for the auditory system because the structure and function of their auditory systems differ from that of humans. Also, they experience stress reactions to noise that include convulsive behaviors called audiogenic seizures that sometimes lead to death. So, even though rodents are adequate models for the cardiovascular system, they may not be suitable for noise studies.

One rodent study was done by Okada et al. (52) in which the dose-response relationship between noise and biological reactions was studied as well as the mechanism by which these reactions occur. This study used 44 male Wistar rats that were exposed to continuous repetition of recorded traffic noise at 60 dBA, 80 dBA and 100 dBA for 240 minutes. Then the response of the sympathetic nervous system was measured by DBH, an enzyme. The results led to the conclusion that the sympathetic nervous systems brings about the response to the stressful noise stimulus.

Another study done by Armario, Castellanos and Balasch (8) on rats studied the effects of acute and chronic noise on their serum levels of pituitary hormones. Acute noise did increase serum levels of corticosterone, prolactin and luteinizing hormone and decrease levels of serum growth hormone. These responses were diminished by chronic noise, indicating some degree of adaptation. However, the degree of adaptation varied among the different hormones.

Markiewicz (57) reported on a rodent study at the International Congress on Noise as a Public Health Problem (57). A series of experiments were done on white rats during which they were exposed to noise levels of 100 to 130 dBC at frequencies of 50, 4000, 16,000 and 20,000 Hertz (Hz) for three hours daily. The results showed an increased concentration of adrenalin over the course of the 24 week study. The increase in catecholamines such as adrenalin was found in the urine at all levels of exposure, and high levels of exposure led to increases of catecholamines in the blood and brain as well.

A fourth rodent study by Chohan, Singh and Rai (16) exposed female albino rats to a continuous noise of 110 dBA over three weeks. This study specifically examined the effects of noise on blood coagulation. They found the development of significantly increased bleeding time, raised plasma fibrinogen levels and shortened activated partial thromboplastin time. If these adverse effects on blood coagulation were found in man, it would predispose him to heart problems. However, the correlation to man is uncertain and the noise levels used in this study were very high.

One last animal study to be mentioned is a study done on rabbits (27). They were exposed to noise levels common to very noisy industries for 10 weeks. The exposed rabbits developed a much higher level of blood cholesterol than the unexposed rabbits on the same diet.

Human Laboratory Studies

Generalizations from animal studies to humans are not easy to make, so several noise effect studies have been done on humans in the laboratory setting. One such study was conducted by Osguthorpe and Mills (53) on 35 male college students. Eighteen students were exposed to noise at 84 dBA for 24 hours; 17 students were exposed to 90 dBA for 8 hours then 16 hours in quiet; and 4 students from the 90 dBA group were then confined for 24 hours without noise to serve as controls. The noise was low frequency, centering at octave bands 63, 125 or 250 Hz.

A decrease in heart rate and an increase in blood pressure were observed only in the 90 dBA group and it was not statistically significant. The catecholamines, epinephrine and norepinephrine did not show a significant elevation either. However, plasma cortisol was elevated in both groups and significantly elevated in the 90 dBA group even 16 hours after noise termination.

The interesting thing about this study was the use of low frequency noise which is not considered to be the most annoying to humans. In fact, the 84 dBA group were able to continue the reading and sleeping activities seemingly without distraction. The 90 dBA group was less tolerant, but still not significantly disturbed except for the elevated cortisol levels indicating that the hypothalmopituitary system did not adapt.

Another point about this study and any laboratory study is the fact that although the subjects cannot control the noise, they know that it is only for a specified time period so they do not perceive it as a threat. It is often fear in animals and a lack of control over the noise in humans that causes the stress reaction to noise.

A series of studies was performed by Andren (2) on the cardiovascular effects of noise. In the first two studies, the subjects rested on a bed in a room with loud speakers built into the walls that emitted broadband noise at 75, 85 or 95 dBA. In three additional studies the subjects were exposed to 100 dBA broadband noise through a pair of earphones.

In the first study, eighteen normotensive (those with normal blood pressure) males with normal hearing were exposed to 95 dBA for 10 minutes. In the second study, fifteen normotensive males were exposed to 95 dBA for 20 minutes. The 10 minute group showed a significant increase in diastolic (11%) and mean arterial (6%) pressure. There was also a significant increase in total peripheral resistance and a significant reduction in stroke volume and cardiac output. Figures 1 to 3 show the results at 75, 85 and 95 dBA. The changes remained unaltered 5 minutes after exposure, but had disappeared after 10 minutes of quiet.

The 20 minute exposure group did not show any statistically significant changes in the stress hormones such as noradrenalin, prolactin, cortisol and adrenalin. Plasma noradrenalin and prolactin concentrations did increase by 6% and 3% respectively, but these increments were not statistically significant.

In the third study, nine males with essential hypertension were exposed to 100 dBA noise for 10 minutes. This exposure led to a significant increase in diastolic (7%) and mean arterial (4.3%) pressure and total peripheral resistance. See Figure 4. These changes had disappeared after 5 minutes of quiet at 40 dBA.

Similar results were found with thirteen patients in the fourth study. They had mild essential hypertension and showed a significant increase in systolic (7%), diastolic (9%), and mean arterial (6%) pressure after exposure to 100 dBA noise for 10 minutes. They also showed significant increases in total peripheral resistance and plasma noradrenalin (20%). See Tables I and II.

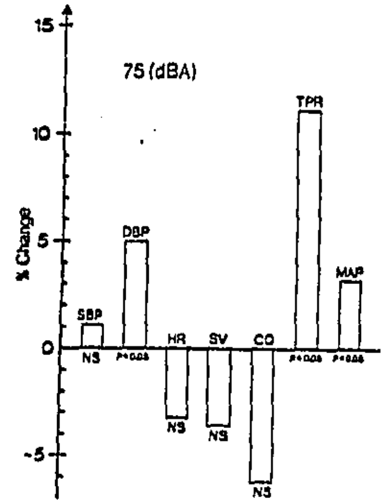

Figure 1 - Hemodynamic Changes during Exposure to 75 dBA (2)

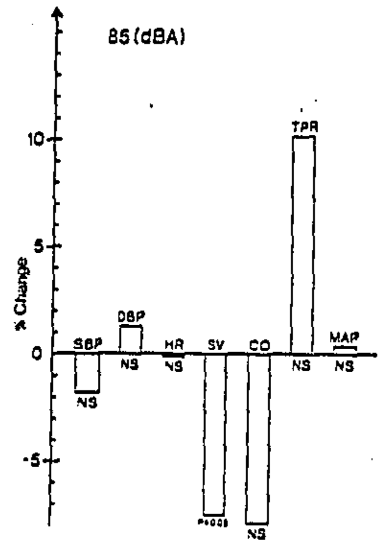

Figure 2 - Hemodynamic Changes during Exposure to 85 dBA (2)

<u>Legend</u>: DBP=Diastolic Blood Pressure, CO=Cardiac Output, HR=Heart rate, MAP=Mean Arterial Pressure, NS=Not Significant, SBP=Systolic Blood Pressure, SV=Stroke Volume, TPR=Total Peripheral Resistance

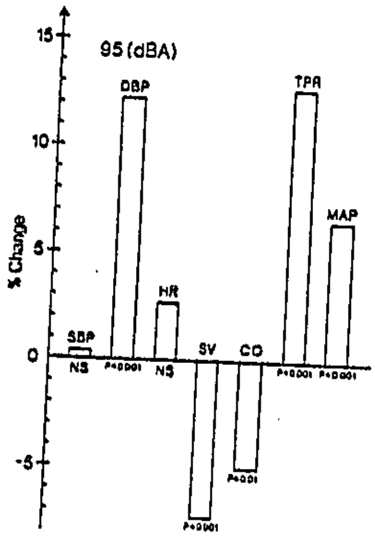

Figure 3 - Hemodynamic Changes during Exposure to 95 dBA (2)

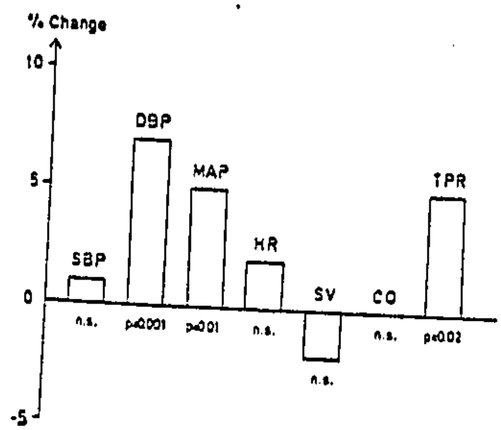

Figure 4 - Hemodynamic Changes in Hypertensive Males during Exposure to 100 dBA (2)

<u>Legend</u>: DBP=Diastolic Blood Pressure, CO=Cardiac Output, HR=Heart rate, MAP=Mean Arterial Pressure, NS=Not Significant, SBP=Systolic Blood Pressure, SV=Stroke Volume, TPR=Total Peripheral Resistance

Let's protect our earth

Thomas H. Kean
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NEW JERSEY NOISE CONTROL COUNCIL
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September 11, 1987

Dr. Don Franklin
Director, Noise Abatement
EPA
Office of Fdoral Activities
A-104
Washington, DC 20460

Dear Dr. Franklin:

Enclosed please find a copy of my master's essay titled, "The Public Health Effects of Community Noise." This paper is a literature review of the latest research on noise health effects and I hope you will find it interesting and beneficial.

If you would like to discuss any parts of the paper with me, please feel free to contact me at 609-443-1397. Thank you for your interest in noise control.

Sincerely,

Carol S. Pennenga

Carol S. Pennenga
Member
Noise Control Council

CSP:vn
encl.

Table I - Hemodynamics at Rest (40 dBA) and during Exposure to Noise (100 dBA) (2)

	40 dBA	100 dBA
SBP (mm Hg)	126 ± 2.8	135 ± 3.5*
DBP (mm Hg)	82 ± 1.8	89 ± 1.9**
MAP (mm Hg)	98 ± 1.3	104 ± 2.0**
HR (beats/min)	60 ± 2.2	61 ± 2.6
SV (ml)	114 ± 7.4	110 ± 7.9
CO (l/min)	6.7 ± 0.4	6.6 ± 0.5
TPR (units)	15.1 ± 0.9	16.9 ± 1.3*

Mean ± SEM; *$p < 0.05$; **$p < 0.01$. Comparisons with resting values.

<u>Legend</u>: SBP=Systolic Blood Pressure, DBP=Diastolic Blood Pressure, MAP=Mean Arterial Pressure, HR=Heart rate, SV=Stroke Volume, CO=Cardiac Output, TPR=Total Peripheral Resistance

Table II - Noradrenalin Concentration in Venous Plasma and Plasma Renin Activity at Rest (40 dBA) and during Exposure to Noise (100 dBA) (2)

	40 dBA	100 dBA
Noradrenalin (nmol/l)	1.10 ± 0.13	1.32 ± 0.16*
Plasma renin activity (µg/l · h)	0.48 ± 0.07	0.52 ± 0.05

Mean values ± S.E.M. are shown. *$P < 0.05$. Statistical comparisons with resting values.

Table III - Family History of Hypertension (2)

	Negative		Positive	
	40 dBA	100 dBA	40 dBA	100 dBA
Systolic blood pressure (mm Hg)	117 ± 3.1	118 ± 3.1	119 ± 3.1	120 ± 2.1
Diastolic blood pressure (mm Hg)	67 ± 3.1	72 ± 2.8**	72 ± 2.4	77 ± 2.5**
Mean arterial pressure (mm Hg)	84 ± 2.8	88 ± 2.6**	88 ± 2.4	91 ± 2.2**
Heart rate (beats/min)	57 ± 2.1	58 ± 1.6	63 ± 5.3	61 ± 4.4
Stroke volume (ml)	122 ± 4.2	124 ± 4.4	117 ± 4.4	114 ± 4.3
Cardiac output (l/min)	7.0 ± 0.4	7.2 ± 0.3	7.2 ± 0.5	6.8 ± 0.4
Total peripheral resistance (units)	12.2 ± 0.6	12.3 ± 0.4	12.6 ± 0.8	13.7 ± 0.8*

Hemodynamic variables at rest (40 dBA) and during exposure to noise (100 dBA). Mean values ± S.E.M. are shown. $^{*}P < 0.05$; $^{**}P < 0.01$. Statistical comparisons with resting values.

The effect of family history of hypertension on the noise exposure versus stress results was examined next. Twenty-two normotensive people were exposed to 100 dBA broadband noise for 10 minutes. Eleven subjects had one parent with hypertension, while eleven had no family history of hypertension.
Diastolic and mean arterial blood pressure showed a statistically significant increase in both groups. The subjects with heredity for hypertension also had a significant increase in total peripheral resistance. See Table III for complete results.

Andren concluded that loud noise at 95 or 100 dBA caused an increase in blood pressure in both normotensive subjects and patients with mild hypertension. Lower levels of noise (75-85 dBA) caused a more variable response in blood pressure so a linear relationship was not observed.

The increase in blood pressure in the subjects with essential hypertension and in the normotensive subjects with a family history of hypertension was caused by peripheral vasoconstriction. In the normotensive subjects without a family history of hypertension there was no significant increase in peripheral resistance so the increase blood pressure was caused by cardiac mechanisms such as increased cardiac output. These results could be interpreted as showing that there are inherited differences in the cardiovascular response to stress.

In discussing the variability of results from studies of the effect of noise on hormones such as adrenalin, noradrenalin, cortisol, prolactin and the growth hormone, Andren offers two explanations. One explanation has to do with methodological differences. It is more reliable to observe the acute effects of noise on hormone levels by measuring plasma levels instead of urinary levels. It is also very difficult to separate the effects of stress from anxiety and expectancy during the test from stress due to noise. This is a problem in all noise versus stress studies performed in the laboratory.

For example, anxiety in the laboratory can be caused by the methods used to measure the hemodynamic variables. Blood pressure was measured noninvasively using an automatic blood pressure recorder. Stroke volume, heart rate and cardiac output were observed by using impedance cardiography which involves the subject being hooked up to four electrodes. Blood samples for the catecholamine and hormone measurements were taken several times during the studies. The anticipation and performance of these techniques certainly added to the stress experienced by the subjects.

Despite these uncertainties, Andren's conclusions were as follows:

"It is obvious from the present work that noise increases blood pressure temporarily in man. Short-term exposure to noise several times daily would then cause repeated increments in blood pressure. Long-term exposure to noise, e.g. 8 hours a day for decades, could certainly be expected to cause a higher blood pressure during the actual exposure time. . .A concluding hypothesis therefore is that noise could be a risk factor for hypertension in man" (2, p.39).

Similar results were obtained in another study done by Andren along with Hansson, Eggertsen, Hedner and Karlberg (4). They exposed thirteen patients with mild essential hypertension to 100 dBA of noise for 10 minutes. This exposure caused a significant increase in total peripheral resistance (12%), and in systolic (7%), diastolic (9%) and mean arterial blood pressure (6%). There was no significant change in heart rate, cardiac output, stroke volume or the plasma levels of adrenalin and renin. Plasma noradrenalin increased significantly (20%). These responses confirmed Andren's previous hypothesis that the blood pressure increase in subjects with mild hypertension was caused by the increase in total peripheral resistance from either an increase in sympathetic nervous activity or elevation of circulating catecholamines. Once again, the conclusion was drawn that noise may be considered an environmental risk factor for hypertension.

Kryter (39, p.407), in his discussion of the Andren studies, proposes the hypothesis that the constriction of blood vessels that leads to increased blood pressure is due to a "nonstressful reflex response, perhaps associated with the aural reflex or ear protective reaction rather than being a part of a general, nonspecific stress reaction". He finds support for this hypothesis in the fact that noise did not cause a significant increase in the "stress" hormones in normotensive subjects and only an increase in noradrenalin in subjects with mild hypertension. However, the fact that blood pressure is increased due to noise exposure is the important thing, whatever the mechanism is that causes the increase.

One other study that used exposure to broadband noise in the laboratory was performed by Antikainen and Niemi (7) to study neuroticism and the pupillary response to noise. Ninety-five undergraduates were screened using the Eysenck Personality Inventory. The eight subjects scoring the lowest on the neuroticism-stability scale were labeled the stable group. The eight subjects with the highest scores were designated the neurotic group. Both groups were subjected to 10 second bursts of 80-100 dBA broadband noise, and pupil dilation was observed. The higher noise levels caused greater pupil dilation. The dilation was greatest at the onset of noise and then decreased during the experiment.

The neurotic group displayed greater pupil dilation at all noise levels. This result supports the hypothesis that neuroticism can cause an increase in autonomic arousal in stressful situations. Antikainen and Niemi further conclude that their study demonstrates the importance of individual differences in the study of noise effects. This study also demonstrated that pupil dilation is an <u>automatic</u> response to sudden, loud noise experienced by all people.

Previous laboratory studies discussed have used broadband noise as the source. In another study performed by Andren, Hansson, Bjorkman and Jonsson (3), recorded industrial noise was used. Eighteen males were exposed to 95 dBA of noise for 20 minutes and 75 dBA and 85 dBA of noise for 10 minutes. The 95 dBA exposure to industrial noise caused significant increases in diastolic and mean arterial blood pressure and total peripheral resistance and statistically significant reductions in stroke volume and cardiac output. These changes were seen throughout the noise exposure and for 5 minutes of quiet afterwards.

Exposure to noise at 75 dBA also caused a statistically significant increase in diastolic blood pressure although 85 dBA did not. See Figure 5. Again, these findings agree with previously discussed results that showed the increased blood pressure is due to increased total peripheral resistance. This response is typical of the "defense reaction" and again, no linear relationship between noise level and blood pressure response was found. So their conclusion was that short exposure to industrial noise does cause an acute rise in diastolic blood pressure and it is possible that repetition of this exposure could be a factor in the development of hypertension.

Kryter described a relevant study in his book (39) that was conducted by Slob, Wink and Radder. They looked specifically at the presence of corticosteroids, adrenalin, and noradrenalin in urine samples of 10 males exposed periodically to 80 dBC of 1/3 octave band noise centered at 4000 Hz. Over a two day period there was little difference in hormone levels between the experimental and control groups except for a slight difference during the noise exposure on the second day.

Slob's explanation for these poor results was that possibly the level of noise was too low to cause a response in the autonomic system. He also repeated the concern that stress due to the test would negate or mask the stress due to the noise.

Another study by Andren, Wadenvik, Kutti and Hansson (5) took a different approach to the problem. They studied platelet activation in 10 males who were exposed to 100 dBA noise for 10 minutes. Usually stress accompanied by increased secretion of adrenalin leads to platelet activation. The aim of this study was to see if moderate stress from noise without adrenalin secretion could still cause platelet activation.

The exposure to the 100 dBA noise did cause significant increases in the diastolic and mean arterial blood pressures, which is again believed to be mediated by the sympathetic nervous system. There was not any significant increase in either venous platelet count or plasma concentrations of platelet factor 4. Therefore, it was concluded that noise stress causes blood pressure elevation due to sympathetic nervous system activity without any activation of the adrenal-medullary system and platelet activation does not occur without an increase in adrenalin.

A study by diCantogno, Dallerba, Teagno and Cocola (25) used recorded road noise to study the effects of noise on cardiocirculatory activity and blood chemistry indices such as blood sugar, insulin, uric acid, total lipids, cholesterol, triglycerides and urinary catecholamines. Thirty-three subjects

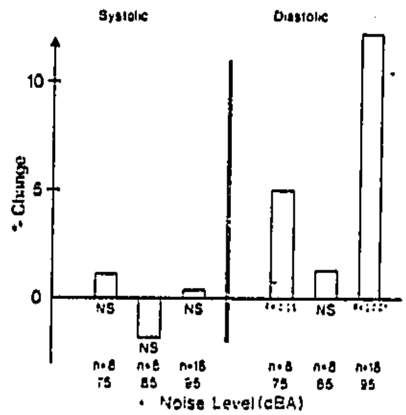

Figure 5 - Changes in Systolic and Diastolic Blood Pressure during 75, 85 and 95 dBA Compared with Initial Levels (3, p.494)

were exposed to road noise and eleven served as controls. Among the experimental subjects, 11 were "normal", 11 were diabetic and 11 were coronaropathic.

The subjects were exposed to 10 minutes of traffic noise at 73 dBA Leq. The following results were found:

blood sugar - an immediate increase particularly in coronary and dysmetabolic patients, varied with age

insulin - increase in both normal and dysmetabolic patients, decrease in coronary group, again influenced by age

total lipids - increase in coronary and dysmetabolic patients, no change in normal patients, not dependent on age

triglycerides - decrease in dysmetabolic subjects, more apparent in patients over 45 years old

blood cholesterol - increase in normal and coronary patients, not dependent on age

uric acid - increase in all subjects, especially dysmetabolic group, higher increases in younger group

catecholamines - increase in dysmetabolic group, however, the limitations of this measurement were stressed

measurement of coronary flow by calculating frequency times systolic pressure - increase in this index for normal and dysmetabolic patients; coronary patients had a more significant increase for a longer period.

This study had some interesting results coming from a short-term exposure to noise. However, several criticisms were found. Dr. Thompson (70) in her evaluation of studies relating to the effects of noise on the cardiovascular system found that not very much information was given about the subjects such as social class, medication recently taken or previous noise exposure. The terms used to describe the subjects, "coronaropathic" and "dysmetabolic/diabetic" were not defined.

The control group was younger than the experimental group and no statistical analysis of the significance of the changes was given. The groups were quite small and the techniques used were not fully described. Despite these criticisms, however, Dr. Thompson concluded that the study did a fairly good job of reporting noise parameters based on short-term noise exposures.

A study performed by Sonnenberg, Donga, Erckenbrecht, and Wienbeck (65) looked at the effect of mental stress from noise on gastric acid secretion and mucosal blood flow. First, they did a pilot study to observe the effect of 90 dBA broad frequency noise for one hour on blood pressure, heart rate and respirations. The results of this pilot study showed increased diastolic and systolic blood pressure, but no change in respirations or heart rate.

During the study, systolic blood pressure increased significantly from 105 mm Hg to 120 mm Hg, but there was no change in gastric secretion, "neutral red clearance" or the "R-value". The terms, "neutral red clearance" and "R-value" were not explained, but several theories for the lack of response of these variables to noise were given by the authors. One theory was that the stress caused by noise was too weak to have a measurable effect. Another explanation suggested that the stress from the invasive techniques overcame the stress from the noise. However, the authors felt that the most likely conclusion was that mental stress does not affect gastric secretion or mucosal blood flow.

Despite the small sample size and lack of negative effects found, this study did show in its pilot study that noise can increase blood pressure. The authors also mentioned that they believe that mental stress from noise increases intestinal motility.

All of the human laboratory studies described in this section had interesting results despite criticisms particular to their experimental designs. Cohen, Krantz, Evans and Stokols (19) in their analysis of noise effect literature criticize all laboratory studies for using short-term exposure to relatively high levels of noise. Therefore, the implications of these results to those who are exposed to noise on a long-term basis are uncertain. They believe that laboratory studies are best used to determine which health and behavior effects should be studied outside the laboratory.

Dr. Arline Bronzaft of Lehman College in her testimony before the New Jersey Noise Control Council in April 1986 (14), also was critical of laboratory studies because they create an artificial setting, they are performed on a short-term basis and the subjects know it is only for a short time. However, if you keep that perspective in mind, laboratory studies can yield useful information.

This discussion of human laboratory studies shows that the effects of noise on blood pressure, heart rate, catecholamines, and other stress responses should be examined in other studies performed on humans outside the laboratory. Thus far, increased blood pressure and a resulting risk of hypertension is the strongest cardiovascular effect of noise.

Human Workplace Studies

The workplace is another important setting for determining the effects of noise on health. It has already been shown in the workplace that continued exposure to noise over 85 dBA can cause permanent hearing loss. It is estimated that over 1.5 million workers in the United States have a detectable noise-induced occupational hearing loss (15). The effects of noise as a stressor have also been studied in the workplace and several of these studies will now be reviewed.

In general, industrial studies have shown higher incidence of circulatory problems and heart disease as well as more cases of high blood pressure. One study that examined high blood pressure was done by Parvizpoor (55) on 821 weavers in Iran. These weavers were chosen from employees of three textile mills and only males with no family history of hypertension and cardiovascular disease were selected. A control group of 412 people of similar socioeconomic status but no exposure to intense occupational noise was used.

The weavers were exposed to an average noise level of 96 dBA in the mills. Blood pressure was measured on everyone after 5 to 10 minutes in a quiet room before work. It was found that 8.5% of the weavers were hypertensive (systolic blood pressure 160 mm Hg or more or diastolic blood pressure 95 mm Hg or more) and 12.4% were borderline (systolic blood pressure 140 mm Hg to 160 mm Hg or diastolic blood pressure 90 mm Hg to 95 mm Hg). This was a significantly different result from the control group where only 2.4% were hypertensive and 4.6% borderline.

There was also a difference in when age became linked with hypertension. In the control group the association between age and hypertension started in the 40-49 years age group; whereas in the weavers the association started younger, in the 30-30 years age group. An association was also found among the weavers between length of employment in the mills and incidence of hypertension. It was found that 26.1% of the weavers with more than 20 years of employment were hypertensive. The fact that this number is not even higher suggests again the role played by individual reactivity.

While these results were conclusive, Parvizpoor himself admits that other environmental factors in the textile mills such as high temperature, cotton dust (concentration = 7.8 mg/M^3), and high humidity may have influenced the incidence of high blood pressure among these weavers. Dr. Thompson (70) added some other criticisms to the study: the noise exposure given was the average for the three mills rather than an individual exposure; the number of controls was much less than the number in the experimental group; there was no examination of the controls as to history of cardiovascular disease, antihypertensive medication, nonoccupational noise exposure or length of employment; and the procedure for measuring blood pressure was not standardized.

Dr. Thompson concludes that the study presents "some evidence in favor of a noise - blood pressure relationship after age is controlled". However, she felt that the exposure data was inadequate to support the conclusion that noise above 85-90 dBA produces nonauditory effects. Even though the study has some data flaws, the trend of higher blood pressure among the weavers in the noisy workplace, whatever the exact sound pressure level, is too strong to dispute.

Another occupational study was conducted in West Germany by Bolm-Audorff and Siegrist (11). They used data from the social security system which provides medical and social rehabilitation services after severe illness such as acute myocardial infarction (MI). The case group for the study was 22,689 males who first experienced acute MI between the ages of 35 and 64 years. The control group was the total West German male working population between the ages of 35 and 64 years. The workers were classified by the system into 86 occupations.

The number of case group members in a given occupation was then statistically compared to the number of control group members in that occupation to see if the case group was over- or underrepresented. Among blue collar occupations, metal workers, sawyer and wood-working machinists, precision-instrument makers, unskilled workers, miners and furnacemen were significantly overrepresented. Farmers, gardeners and construction workers were among the underrepresented blue collar occupations. The occupations in the white collar group that were overrepresented included technical assistants, air-traffic controllers and pilots, porters and guards, sales managers, and bank and insurance brokers. The underrepresented white collar occupations were clergymen, soldiers, teachers and administrators.

Bolm-Audorff and Siegrist concluded from this analysis that it gives evidence of occupational coronary risks, particularly intense exposure to noise. The overrepresented blue collar occupations were exposed to excess noise among other possible cardiotoxic substances. The white collar overrepresented occupations are more difficult to analyze since their stress may be due to psychosocial pressures such as heavy responsibility, time pressure and job insecurity.

The authors offer several criticisms to their study. For instance, there is some distortion in the occupation selection process because after the first MI, many patients retire or change jobs. The authors attempted to correct this by getting occupational data directly before the first MI. However, people may have already changed jobs due to symptoms leading up to MI. Other criticisms are the lack of specificity in occupational classification and a possible bias due to occupational groups that do not participate in the rehabilitation and would not therefore be included in the records. The study was interesting but it was unable to pinpoint noise as the occupational risk factor in causing the increased prevalence of MI, even though the authors feel that it did.

A study by Malchaire and Mullier (40) looked at hypertension in two groups of workers exposed to sound pressure levels of 95 dBA versus a control group. One of the case groups was made up of 1030 car assembly line workers subjected to noise levels between 92 and 100 dBA. The other group consisted of 581 workers in a wire mill with noise levels between 93 and 97 dBA. Using dosimeters, an average equivalent noise level of 95 dBA +/- 1 dBA was found in both workplaces. Excluded from the study were people with histories of cardiovascular problems and non-noise related hearing impairments. The control group was made up of 510 workers in one of the industries who had no occupational noise exposure. All of the subjects were male and from the same social stratum. The data used was company records kept over the 3-4 years prior to the beginning of the study.

The subjects were separated into three age groups, two hearing deficit groups and three blood pressure groups based on the World Health Organization's definition of normotensive, hypertensive and borderline. Significant relationships were found between age and blood pressure for all three groups and between age and hearing deficit for the two case groups. Comparisons of hypertension between the case and control groups did not lead to any significant increases in hypertension among the noise-exposed case groups. However, this study was conducted on the "normal" population and therefore the conclusion may not hold for the general population which would include people predisposed to cardiovascular problems.

Again, a criticism of this study is the small number of controls compared to the experimental group. Dr. Thompson (70) in her review adds further criticisms: subjects were not identified by year of employment so potential bias from exclusions could not be determined; persons with known high blood pressure may have avoided the study; methodology for measuring blood pressure not given; did not consider other confounding factors such as previous noise exposure, blood pressure medications and obesity. Dr. Thompson states that reanalysis of the data using subjects in both plants and defining hypertensive to include borderline subjects, shows an increase in the percentage of hypertensives within each age group from the "not noise exposed group" to the "noise-exposed but no hearing loss group" to the "noise-exposed with hearing loss group". She concludes that the "evidence is very weak for concluding that noise around 95 dBA cannot 'cause' hypertension." Therefore this study does not dispute conclusively the possibility of a relationship between noise and high blood pressure.

Similar blood pressure - hearing loss - noise studies were performed by Jonsson and Hansson (36), Hedstrand _et al_. (34), and Takala _et al_. (66). Jonsson and Hansson looked at 196 male industrial workers and measured their hearing acuity and blood pressure. Seventy-four had normal hearing and forty-four had severe noise-induced hearing loss; the other seventy-eight had various forms of hearing impairment and were not further analyzed. Blood pressure was significantly higher in those with noise-induced hearing loss than the 74 men with normal hearing of the same age.

The authors state that "obviously, it cannot be claimed with absolute certainty that exposure to noise caused the increased blood pressure. . .On the other hand, there were no other obvious differences between the two groups that could easily explain our findings" (36). They further acknowledge that brief exposure to loud noise causes an acute rise in blood pressure. They explain their present findings by saying that noise may have caused repeated rises in blood pressure leading to "circulatory adaptations" and a permanent increase in blood pressure.

Criticisms of this study include small sample size, no details on noise exposure and imprecise measurement of blood pressure. Dr. Thompson (70) concludes in her analysis of the study that the "study design provides inadequate baseline, exposure and response data to support the major conclusion that hearing loss was associated with noise exposures and permanent rise in blood pressure."

Hedstrand et al. (34) in reply to Jonsson and Hansson's findings, described a study of their own done on 2202 men aged 49-50 years. Using Jonsson and Hansson's criteria, they found 393 men with noise-induced hearing loss and 376 men with normal hearing. They also used the same criteria for hypertension and found no significant difference in the prevalence of hypertension between the group with hearing loss and the group without a loss.

Takala et al. (66) also wrote in reply to Jonsson and Hansson. They screened a middle-aged population in two municipalities in Finland for hearing loss and hypertension. They also did not find any differences between the mean blood pressure of those with noise-induced hearing loss and those with normal hearing. They stated, however, that their men with noise-induced hearing loss were about 10 years younger than those in Jonsson and Hansson's study so perhaps a longer exposure is needed for the permanent elevation in blood pressure. However, they feel that the coincidence of high blood pressure and a hearing problem from noise does not indicate a causal relationship.

Takala's study can also be criticized since very little information is given about the individual's exposure to noise, medical histories or the methodology. Dr. Thompson (70) concludes that because of these criticisms, "the study contributes little to assessing the effects of noise on the cardiovascular system."

Kryter's (39) conclusion based on his review of the studies by Jonsson and Hansson (36), Hedstrand et al. (34) and Takala et al. (66), is that exposure to noise such that noise-induced hearing loss results does not lead to blood pressure or other cardiovascular problems. Studies that show these problems could be due to other environmental factors. He says, "it is, of course, possible that an additive effect of all adverse conditions, including that of noise, takes place."

Carl-Olof Delin (24) did a noise versus blood pressure study on 112 men who worked in the engine room of a ship. He looked at correlations between noise exposure, hearing loss, blood pressure, age and weight. The noise level in the engine room varied between 100 and 115 dBA and in the control room between 75 and 80 dBA. He found no significant difference between those with impaired hearing and normal hearing with respect to blood pressure and there was no greater frequency of hypertension among those with greater total noise exposure. There was a significant correlation between hypertension and obesity.

The details of this study are sketchy, but Delin reports that when interviewed, the men indicated that they tolerated the noise and did not find it stressful. Therefore Delin suggests that the degree of stress is more important than the noise level. He further suggests that the relationship between noise and blood pressure cannot be determined from single audiograms and blood-pressure measurements. This, of course, is a very valid point. However, with regard to stress versus noise leading to hypertension, it would seem that the people who do experience high blood pressure from noise are experiencing stress from the high noise levels. Delin's study was done on a small group of men and details such as the number in the control group were not given. It is also risky to base conclusions on interviews - do people really learn to "tolerate loud noise"? Therefore, it is hard to evaluate the significance of his results although, again, they do not conclusively dispute the possibility of noise leading to increased prevalence of high blood pressure.

Here in the United States, Alexander Cohen (57) did a retrospective study using worker files from two manufacturing firms. The files were for the years 1966-1970 prior to the establishment of a hearing conservation program. Work areas at the firms were divided into high noise (95 dBA or higher) or low noise (80 dBA or lower) classification. They evaluated 500 workers with prolonged experience in noisy jobs and 500 workers with comparable experience in quiet jobs. Medical, attendance and accident files were examined.

The results showed that a higher proportion of workers in the high noise group had accidents, health disturbances, and absence than those in the quiet jobs. See Figure 6. Using the medians of the curves, the typical worker in Complex A in the noisy workplace had 8-9 more accidents, 3-4 more diagnosed medical problems, 40 more days of absence and 25 more discrete occurrences of absence than a counterpart in a quiet area of the same facility. All of these differences were statistically significant. In the other industry, Complex B, the differences were not as great but still statistically significant.

Other observations were: the number of accidents per worker was highest for the younger and less experienced workers in the noisy jobs; younger workers in noisy and quiet areas had the greatest number of diagnosed medical problems and sick absences and absenteeism decreased for middle age workers and increased among older workers. Cohen interpreted these observations to mean that the younger workers had initial strain adapting to a

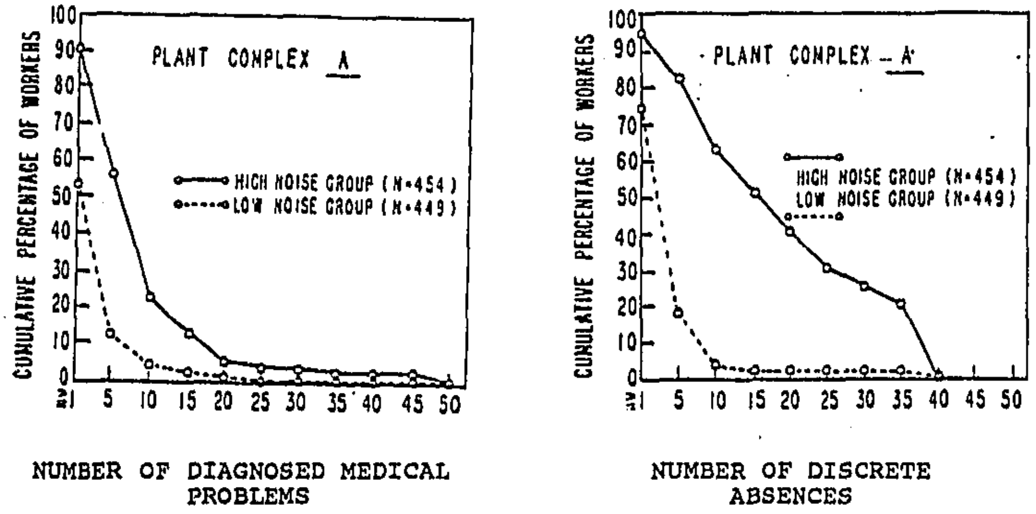

Figure 6 - Cumulative Percent Frequency Distribution of Workers in High and Low Noise Groups (57, p.446)

job with intense noise and other stressors. In regard to the type of medical problems, workers in the high noise areas had more respiratory cases involving hoarseness, sore throats and laryngitis, and more disorders in the allergenic, musculoskeletal, cardiovascular and digestive categories.

One criticism of the study offered by Cohen was the inability to match quiet area and noisy area jobs exactly; he suggests it would be better to measure the same workers before and after a noise reduction. Another criticism is the difficulty in controlling other workplace stressors which is, of course, a problem with any workplace study. This study could also have a problem with absences that are not really due to sickness. In general, however, the study did show an increased trend toward health problems and accidents among workers in intense noise.

Cohen et al. (19) report on a literature review of foreign industrial noise studies that showed an increased prevalence of cardiovascular disorders, gastrointestinal complaints and infectious disease among people with occupational noise exposure of 85 dBA or more for at least 3 years. The review concluded that this noise exposure may lead to a doubling of risk of cardiovascular disease. Absenteeism and accident rates were also found to be higher for workers in high noise than unexposed workers or those with ear protection.

Cohen et al. conclude that impaired regulation of blood pressure especially hypertension is the best documented effect. They found more than 15 studies that reported an increase in prevalence of hypertension of at least 60% for workers chronically exposed to noise over 85 dBA. However, they also caution about the many flaws in workplace studies such as not controlling for confounding factors, and not having adequate control groups.

Cohen and Weinstein (21) also note that a review of foreign literature showed increased morbidity among workers exposed to 85 dBA or more for at least three years. This elevated morbidity increases with age and years of employment, and tends to be greater under intermittent or impulsive sound exposure than continuous, steady sound exposure. It also affects those who do mental work more than those performing manual work.

Cohen and Weinstein believe that the flaws found with many workplace studies can be overcome with prospective research. Other studies that they mentioned linked industrial noise with lowered resistance to infectious disease, decreased fertility, and gastrointestinal problems such as ulcers and chronic gastritis. Some studies failed to find a link between noise and ill health. Their conclusion was that more research is needed in this area.

Kryter (38) and (39) further describes the problems with workplace studies. One problem is the difficulty in equalizing socioeconomic and family medical histories. There are also varying workplace conditions between noisy and quiet jobs: noise may be from moving machinery which would be a danger in itself and the work may require the perception of certain sounds which noise makes difficult, leading to stress. In addition, there are other factors such as air pollution and other physical conditions that can cause stress and health problems.

Kryter's conclusion is that "noise can create conditions of psychological stress because of its meaning (indicative of danger) or because it interferes with the hearing of wanted auditory signals. . .This psychological stress can, in turn, cause physiological stress reactions that can be detrimental to physical and psychological health" (38, p.14). So he in effect believes that stress from noise is caused indirectly rather than directly. However, if it is the noise, directly or indirectly, that is causing the stress, then noise is a public health problem.

Community Studies

Effective community studies are an ideal way to study the health effects of noise because we are interested in the effects of noise on the average person in his or her everyday life. However, community studies along with all previously discussed studies have their flaws. Even so, community studies are a valuable source of data on the cardiovascular effects of noise.

One community study described in Thompson's review (69) was conducted by Knipschild in a community around the Schipohl Airport in Amsterdam. He conducted a survey of contacts with general practitioners. In this survey he found that the contact rates for cardiovascular diseases (for example, heart trouble and hypertension) increased from low noise to high noise areas. A second survey was a cross-sectional survey of the community that suggested a dose-response relationship where the percentage of people with hypertension increased with increased aircraft noise. Those in the high noise area are also more likely to be taking drugs for cardiovascular problems and to have other cardiac abnormalities such as pathologically shaped hearts than those in low noise areas.

Both of these surveys used the descriptor, Noise and Number Index (NNI) to describe the aircraft noise exposure over a six year period for the subjects. The community survey had 2233 participants in the high noise area and 3595 in the low noise area which is a participation rate of only 39% in the high noise area and 43% in the low noise area. Low noise areas were exposed to 46 to 55 dBA and high noise areas showed noise levels of 67 to 75 dBA (23, p.36).

Cardiovascular response was determined by blood pressure (hypertension was defined as systolic blood pressure over 175 mmHg and/or diastolic pressure greater than 100 mmHg), diagnosis of angina pectoris, pathological electrocardiogram and heart shape and the taking of cardiovascular drugs. The conclusion of the community survey was that the prevalence of cardiovascular disease appeared to increase with increase in noise levels, making aircraft noise a causal factor in cases of cardiovascular disease. See Table IV.

Dr. Thompson (70) had several criticisms of Knipschild's community survey, some of which could be applicable to community studies in general. For example, there was a low participation rate among the population in the studied community and questions about what the actual exposure to noise was from the source in question and from other sources such as occupational exposures. It is also difficult in general and a problem with this study to compare the characteristics of the subjects in the high noise versus the low noise areas.

Another criticism of this study in particular is that the low noise group was subjected to less aircraft noise not little or no aircraft noise. In addition, a bias was possible due to a prevalence of response in the high noise area from people with problems, whereas in the low noise area, predominantly healthy people may have participated. Also, age and sex was controlled, but it is unclear whether smoking, obesity and social class differences were controlled or merely analyzed.

Despite these criticisms, a large group of people of all types were surveyed and Knipschild did find a trend toward more cardiovascular disease in higher noise areas. Although more details would be nice, especially to determine a dose-response relationship, an important trend was still observed in this study.

The survey by Knipschild on contact rates with general practitioners had the following conclusion: "in studying cardiovascular disease for persons aged 15-64 years it was found that a contact rate in the exposed area was almost twice as high as the contact rate in the nonexposed area. In accordance herewith the taking of antihypertensive agents among the 15-64 year old patients was much higher in the exposed area, especially for the female patients. This last finding may be explained by the fact that the women, being at home and not working in neighboring Amsterdam, were exposed more...This general practice survey indicated strongly that aircraft noise increases the contact rate with the G.P. for psychological and some psychosomatic problems" (70, p.B-67). See Table V.

This study covered 17,500 people in the low noise area and 12,000 in the high noise area. Dr. Thompson (45) again had several criticisms including the possibility that individuals may have sought medical care outside the area and that different doctors have different criteria for diagnosis. Again, there was little data on actual exposures to aircraft noise and no data on non-aircraft noise exposures, and age and sex were the only factors controlled for despite definite socioeconomic differences between the villages. Knipschild felt that although the people in the low noise areas may have been more affluent, this difference was not enough to explain the differences found in health problems between the two groups. Dr. Thompson concluded that although the data was not statistically significant, it did show a gradient of increasing contact rates for cardiovascular disease from the low to the high noise areas.

Table IV - Results of the Community Cardiovascular Survey (39, p.493)

Cardiovascular condition	Participants[a], percent, affected by L_{dn}, dBA, of—		Fisher's test for significance
	<62.5 (3595)	>62.5 (2233)	
Angina pectoris	2.8	3.0	Not significant
Medical treatment of heart disease	1.8	2.4	0.04
Use of cardiovascular drugs	5.6	7.4	.003
Pathological ECG	4.5	5.0	Not significant
Pathological heart shape	1.6	2.4	0.01
Hypertension[b]	10.1	15.2	<.001

[a] *Number of participants given in parentheses.*
[b] *Blood pressure >175/100 mm Hg or use of antihypertensive drugs or both.*

Table V - Results of the General Practice Survey (39, p.496)

Reason for physician contact	Population[a], percent, contacting physician for L_{dn}, dBA, of—			χ^2 test for linear trend
	<60 (14625)	60-65 (4050)	>65 (3650)	
Psychological problems	0.65	1.13	1.75	<0.001
Psychosomatic problems[b]	1.12	1.54	1.69	.001
Cardiovascular disease	.46	.60	.82	.004
Hypertension	.25	.31	.43	.03
Total, stress effects	2.48	3.58	4.69	
Total, contacts	5.71	7.97	9.34	<0.001

[a] *Population at risk given in parentheses.*
[b] *Consist of low back pain, spastic colon, stomach complaints, allergic diseases, tinnitus, dizziness, and headache.*

Another study in the same area by Knipschild (19) was not influenced by the socioeconomic differences between the villages since he looked at the same village with and without night flights. In this case, he found that increases in the purchase of cardiovascular drugs was related to the number of night flights. See Figure 7.

DeJoy (23) describes some other studies performed in the field. Battig et al. studied people living around Zurich airport by recording their electrocardiogram, electromyogram, skin conductance and respiration in their homes while aircraft flew overhead. The subjects also did a concentration task during the noise exposure and completed a questionnaire. The results found that physiological adaptation was not complete even among those chronically exposed. However, no clear-cut relationship between noise level and physiological response or subjective complaints was found. Physiological response did vary as a function of type of activity being performed and individuals with higher overall autonomic reactivity appeared to be more susceptible to the stress-related effects of noise. These are very interesting results that deserve further study.

Guski studied physiological responses to roadway noise. He found significant relationships between annoyance levels and increases in heart rate. The annoyance level was correlated with noise level, although the noise level did not correlate directly with the physiological responses, so annoyance appeared to be an important intervening factor.

DeJoy concluded from the studies he reviewed that "the findings from these laboratory and field studies are more provocative than definitive. Nevertheless, this literature does contain some data which suggest that valid relationships may exist between noise and various cardiovascular system responses. These findings also serve to demonstrate the importance of nonacoustic and individual difference variables in understanding this category of noise effects" (23, p.37).

Cohen et al. (19) report on several studies performed on children affected by noise in the community. Karagodina et al. did a study suggesting that 9-12 year old children around nine airports showed blood pressure abnormalities, higher pulse rate, cardiac insufficiency, and local and general vascular changes. However, this report had little information on the control population or measurement procedures.

A German study by Karsdorf and Klappach also showed higher systolic and diastolic blood pressure for 7th through 10th grade children from noise-affected schools. Similar results were found in a controlled longitudinal study on elementary schoolchildren done by Cohen et al. around the Los Angeles International Airport. In this study socioeconomic condition, age and race were controlled. Children attending the noise schools where overflights occurred approximately every two-and-a-half minutes with peak sound level readings of 95 dBA, had higher systolic and diastolic blood pressure than matched counterparts in quiet schools.

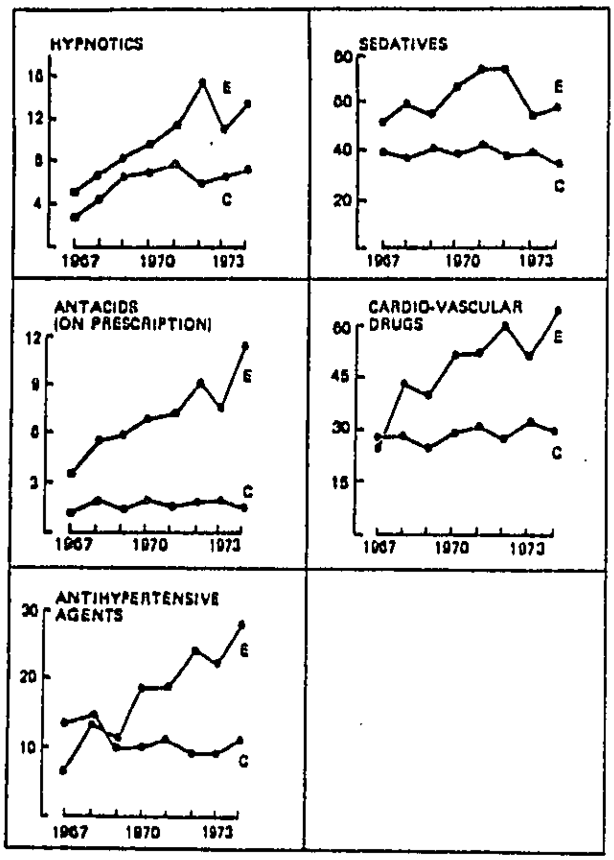

Figure 7 - Number of Certain Drugs per Adult per Year. Area C - L_{DN} < 51 dB; Area E - L_{DN} < 51 dB (1967-1969) and L_{DN} > 64 dB (1969-1974) (39, p.498)

These data therefore show that children as well as adults show cardiovascular effects from noise. In fact, children may be at greater risk because they are psychologically less able to deal with a continuous stressor.

Cohen and Weinstein (21) further mention studies that associate noise with increases in nervous and gastrointestinal diseases, consumption of sleeping pills and visits to doctors, and self-reported incidence of a variety of chronic illnesses. They conclude that as a whole the studies they reviewed are only suggestive of possible pathogenic effects from community noise exposure. They would like to see replication of the studies to further validate the findings.

Kryter (39, p.490) describes three interesting airport noise studies. One was performed by Karagodina et al. who looked at the adult population around nine Soviet airports. Examination of 145,000 medical diagnostic records showed that people living with 6 km of the airport had 2 to 4 times the amount otorhinolaryngological, cardiovascular, nervous and gastrointestinal diseases than those living beyond that perimeter. They concluded based on this and other related studies that the maximum permissible exterior level of aircraft noise should be set at 85 dBA during the day and 75 dBA at night. Unfortunately, they did not establish specific dose-response relationships.

Another study described by Kryter (39, p.490) was performed around the Munich airport where 192 men and 200 women were given certain clinical medical tests. The conclusion was that no major clinical disorders were present due to aircraft noise, but there were sleep disorders and an increased risk of hypertension among those more heavily exposed.

Koszarny et al. administered a health questionnaire to 256 people in an area with aircraft noise over 100 dBA and to 255 residents of a quieter area (80 to 90 dBA peak noise). There were no statistically significant differences between the men in the two areas probably because they all work in noisy industries and spend less time at home. However, there were statistically significant differences between the women, with the women in the higher noise area having more complaints related to the cardiovascular system, digestive system, nervousness, and frequency of taking medication for heart problems or headaches.

Kryter concludes, after a brief look at studies with roadway noise, that "street traffic noise in residential areas is generally not sufficiently intense to cause cardiovascular stresses in adults, but aircraft noise can be" (39, p.500).

One interesting traffic noise study described in Dr. Thompson's review (69) was done by Von Eiff and Neus in Bonn, Germany. A high noise area was defined by sound levels of 66-73 dBA and a low noise area had a noise level maximum of 50 dBA. Four hundred fifty-eight men and 473 women were randomly contacted by letter and interviewed in their homes. High noise area residents had hypertension more often than low noise area residents. Age and sex were controlled, but the groups differed on social class and smoking. The authors concluded that a prospective epidemiological study was warranted.

In another article, Kryter (38) summarizes the criticisms of community studies. For instance, results can be significantly influenced by factors such as socioeconomic conditions, population selection influences, air pollution and other non-noise environmental factors. Even when investigators attempt to control for these factors, they may not be completely successful. In fact, Kryter speculates that there may be a synergistic effect between poor socioeconomic conditions and noise such that both conditions are necessary to get a statistically significant effect. Again, this is a poor argument because the effects would not happen without the noise.

Bronzaft (14) had a more positive view of community studies. She acknowledged that all the confounding factors may not be held constant in correlation studies; yet many great studies, including cancer studies, have been correlation studies. She further notes that the many studies cited above show cardiovascular ailments from noise even when noise is not very loud since people are being stressed by it. As the number of correlation studies increases, you tend to accept that there is a cause-effect relationship.

Indeed, the preponderance of evidence in these community studies shows that noise in the community, particularly aircraft noise, acts as a stressor and can cause medical disorders particularly to the cardiovascular and gastrointestinal systems. It is disappointing, however, that we do not have a handle on dose-response relationships so we can determine what sound level would be "safe" for a community.

Conclusions on the Cardiovascular Effects of Noise

The definition of stress is "the response of the body to any demand that we perceive is beyond our resources to cope with" (1). Stress response depends on the kind of event, duration or frequency of the event and our evaluation or interpretation of the event. Noise is an "event" that can cause stress in many people.

One reason that people experience stress from noise is inherent to the definition of noise as unwanted sound - people interpret noise as something they do not want and, many times, have no control over. Dr. Bronzaft put it this way, "...noise that can't be controlled. That's what really gets you upset. It's when your neighbor's noise can't be stopped that you get bothered; the trains or the planes or the cars coming in at regular times so people cannot control it. It's not their noise and there's another reason, people get stressed by other people's noise. It's not just control" (14, p.77).

Dr. Bronzaft also points out in her article in the Harvard Medical School Health Letter (15) that the sound may be even more irritating when the source of noise is particularly disliked. In addition, stress reactions are more severe and more likely when the noise is perceived as something you cannot get away from and something you cannot do anything about. Cohen and Weinstein further emphasize this point by saying that studies have shown "that people who have a positive attitude toward the source of noise are less annoyed than people who think the noise source serves no useful purpose or who believe that the authorities are not making a genuine effort to control the noise" (21, p.51).

Cohen et al. further state that people who continually encounter stressful events such as noise that they can do nothing about display "motivational, cognitive and emotional disturbances" associated with "learned helplessness" (19, p.530). DeJoy notes that "at least one study has indicated the possible ameliorative effects of having control over the noise" (23, p.38). Of course, people's interpretation of noise events as aversive depends on their values, beliefs and attitudes, showing once again that the response to noise is highly individual.

Kryter takes this issue of control/interpretation of noise one step further and says that the autonomic system reactions to noise are not caused by the noise except when the noise is psychologically meaningful (38, p.14). I do not completely agree with this since I feel you can experience the stress effects of noise even when the noise is something you like such as music of your choosing. In any case, the stress reactions would not occur in the absence of noise, whatever the individual's interpretation of the noise is.

Another important issue in regards to the cardiovascular effects of noise is whether an individual adapts to a noise with continued exposure. Miller's conclusion on this issue is, "there is little evidence that annoyance due to community noise decreases with continued exposure. Rather, under some circumstances, annoyance may increase the longer one is exposed to it" (43, p.755). By their very nature, the physiological stress responses are supposed to diminish when repetition of the stimulus signifies that the noise does not represent a threatening condition. However, it may be that our modern environment presents us with constant auditory stimulation such that our arousal responses are chronically maintained. This constant maintenance of an arousal condition can lead to what are known as diseases of adaptation. This includes such medical disorders as gastro-intestinal ulcers, high blood pressure, and arthritis (43, p.760).

In addition to the possibility of the occurrence of these diseases of adaptation, several conclusions can be made from the studies discussed in this section on the cardiovascular effects of noise. The strongest case can be made for noise affecting blood pressure. The literature seems to suggest that there is a dose-response relationship between noise and high blood pressure, although it has not been quantified. This effect is particularly in question at levels below 85 dBA.

Noise has been shown to be a potent stressor. One animal study even showed the elevated blood pressure from noise to be a permanent condition. Other cardiovascular effects such as elevated heart rate, increased adrenalin flow, constriction of blood vessels and increased blood cholesterol levels have also been shown to a limited extent. These effects may be limited and dependent upon the individual, but it seems certain that they can be harmful particularly to the person already at risk or who already has chronic neurologic, cardiovascular and/or gastrointestinal problems.

Dr. Thompson (69) in her conclusions about the English and translated studies that she reviewed also concludes that the strongest evidence for noise as a cardiovascular risk factor came in its effects on blood pressure, although some studies showed no adverse effects. Studies using parameters other than blood pressure had more fragmentary evidence. However, she felt there was some indication of a dose-response relationship between noise and all the cardiovascular effects.

Forty-four of the 55 blood pressure studies showed an adverse association between noise and blood pressure (69, p.4-13). However, most of the studies are cross-sectional in design and several of the more rigorously designed studies suffered from small sample size and other design problems. The cross-sectional studies are a problem because it is impossible to determine from them whether the noise exposure precedes the cardiovascular response and it is difficult to control for possible confounding factors. However, Dr. Thompson concludes that the elevated blood pressure results are important because high blood pressure is a risk factor for stroke and ischemic heart disease and in the United States these two diseases account for 50% of the mortality (69, p.4-17).

So, where does this leave us? The studies performed so far - animal, laboratory, workplace and community - all suffer from some sort of design problem. However, the preponderance of evidence and the biological plausibility of the cardiovascular effects of noise leads us to believe that these effects exist. In fact, noise appears to be an important factor in the development of adverse health effects from industrial exposure. Since present studies are not adequate to establish a quantitative dose-response relationship and therefore, a health standard, we need further investigation of these effects.

Future research should focus on obtaining this quantitative data. One option is to do intervention studies where the effect of noise before and after exposure can be measured with no competing explanations for the effects. There is also a need for chronic exposure results as well as confirmation of the results obtained so far. Dr. Thompson states that priority should be given to epidemiologic studies that can offer the strongest evidence for a causal association between noise and the cardiovascular responses. She recommends designs such as large retrospective cohort studies with continued follow-up in selected samples of the population or occupational groups exposed to varying levels of noise and intervention studies in industrial settings (69, p.4-41).

I feel that the literature reviewed here has clearly shown that blood pressure elevation results from noise. At what level the effect begins to occur and whether it is just a short-term response is unknown, although it seems likely that chronic exposure to noise above 85 dBA will lead to a permanent blood pressure elevation and an increased risk for cardiovascular disease. Also, it is clear that there are individual differences in response to noise. Those with heredity or disposition towards hypertension or cardiovascular disease are more at risk. Therefore, I strongly believe that more research with the tighter designs described above should be performed to quantify the dose-response relationship and strengthen the evidence for the cardiovascular effects of noise.

EFFECTS OF NOISE ON PERFORMANCE

The effects of noise on performance are difficult to assess and vary widely, depending on the type of task, the individual, the noise characteristics, and the situation under which the task is being performed. In fact, noise can have either a detrimental or beneficial effect on the performance of a given task. Many of the findings in this area are contradictory, but several general conclusions can be made from the many laboratory and workplace studies that have been done.

One type of task that will definitely be affected by noise is one which involves the use of auditory signals, speech or nonspeech. If noise is of sufficient intensity to mask or interfere with the perception of the auditory signal, it will interfere with the performance of the task.

Miller (43) offers the following general conclusions about the effects of noise on tasks not involving auditory signals:

1) Steady noise without special meaning do not seem to interfere unless the A-weighted noise level exceeds about 90 dB.
2) Irregular bursts of noise are more disruptive than steady noise and may interfere at A-weighted levels below 90 dB.
3) High-frequency components of noise, above 1000 Hz, may interfere more than low-frequency components.
4) Noise does not seem to influence the overall rate of work, rather it may increase the variability of the rate of work such that there are "pauses" in the performance and then compensating increases in rate.
5) Noise is more likely to reduce the accuracy of work than the quantity of work.
6) Complex tasks are more likely to be adversely affected than simple tasks.

Miller continues by stating that the effects of noise on human performance can be divided into three general classes: arousal, distraction and specific effects. Arousal refers to the body's response to a stressor and has either detrimental or beneficial effects on performance. For instance, tensing of the muscles may interfere with delicate movements, but arousal may also cause a sleepy person to do a better job. Distraction from the task can be caused by the loudness or annoying characteristic of a noise and can have a physiological effect or a psychological one in response to the message given by the noise. Specific effects include auditory masking, muscular startle response to impulsive noises like gunshots and so forth (43, p.758).

The effects of noise on performance are further generalized by Kryter (39) who states that noise can create feelings of annoyance or anger because the individual feels that the noise is damaging the ear or is interfering with sounds he wishes to hear or because the individual feels helpless and unable to control his environment. Noise can also neurologically compete for and somehow preempt the nonauditory neural pathways involved in the performance of some nonauditory tasks or neural pathways involved in the internal rehearsal of words related to the memory of words required in some mental tasks (39, p.344). Therefore, one can begin to see that the effects of noise on performance is a complex subject, with many factors entering into the final results of whether the performance of a task will be hindered or helped.

Tasks Affected by Noise

Any task involving the perception of auditory signals is likely to be adversely affected by noise. One study that looked at this effect examined changes in the time of reaction to light and sound signals in the presence of urban traffic noise (60). Rossi et al. used ten subjects aged 20-25 years and a sound recording of traffic noise played behind the subjects head with a Leq of 72.1 dBA. At the appearance of either a light or sound signal, the subject was told to move his right hand to break a ray of light striking a photoelectric cell attached to a reaction meter. Two types of reactions were investigated: a simple one where the subjects arm was alongside his body and he simply had to flex his forearm, and a more complicated one where his hand had to cross his body and touch his shoulder to break the light ray.

The study looked at performance during maximum exposure and then with attenuations of 5, 10, 15 and 20 dBA. In general it takes less time to respond to an acoustic signal than to a light signal. In this study the reaction time to the light signal did not change since the information for the light signal and the noise are collected by different receptors and move along different neural pathways. However, when the auditory signal was used, the reaction time increased as much as 20% with both the simple and complicated motor reactions. The incremental attenuation brought corresponding decreases in reaction time, showing interference between auditory stimuli in proportion to the intensity of the competing signals. Although this study was performed on only a small number of subjects, it seems clear that noise will interfere with the reception of auditory signals.

Another group of tasks affected by noise are complicated tasks, as opposed to simple ones. A study (33, p.60) was done on 80 women in which 40 women were instructed to do the simple task of adjusting a monitor dial, while 40 women were instructed to complete a difficult puzzle. Both groups did their tasks in a quiet environment and a noisy one. The results showed that the simple task performance with the nonmusic, monotone noise playing was actually enhanced. In contrast, the complex task performance was significantly hindered by the noise. The authors therefore concluded that noise can hinder a person's problem-solving skills, particularly with complex tasks. Many details are missing from the description of this study, such as the intensity of the noise level, but the results clearly indicate that noise can hinder the performance of complicated tasks.

Tasks involving the use of short-term memory are also affected by noise. This can occur both in the workplace and in private life. The effects of noise on short-term memory were examined carefully in a study by Wittersheim and Salame (57, p.417). The use of short-term memory is divided into the following phases: acquisition of material, retention - a short phase where material may be rehearsed, reproduction or response, and expectation - a phase before feedback of information. This study looked at what effect 95 dBC pink noise had on the different phases of short-term memory.

Twenty-one subjects were used and they performed a sequential machine-paced memory task where a design was presented and they were told to reproduce it as quickly as possible using keys on a keyboard. They also filled out a questionnaire. The results showed that performance, indicated by accuracy, was significantly decreased when noise was present during the acquisition or retention phases, but there was no effect when the noise was given during the response or expectancy phases.

The questionnaire responses indicated that the subjects found the sessions most unpleasant and difficult when noise was presented during the acquisition phase and the judged memorization to be most difficult under that condition. They also felt that memorization was aided when noise was present during the response phase. This study was very interesting and although it had a small sample size, it showed that noise can interfere with the translation of visual messages into auditory messages which are processed and stored by the brain. Of course, this interference would be even more significant if the noise were a human voice giving competing information for the brain to process.

Another study that dealt with the importance of short-term memory was done by Wheale and O'Shea (74) and looked at the performance of a four-choice psychomotor task. They started with the theory that high noise levels produce high arousal levels and thereby affect the efficient performance of tasks. They used 20 subjects and exposed them to four types of noise at 100 dBA-teletype, intermittent, jet-cockpit and helicopter-cockpit.

None of the four types of noise caused a <u>significant</u> decrease in performance, although the intermittent noise did increase the number of errors compared to the other noise conditions. Arousal level as indicated by heart rate also did not increase significantly. Again, this study suffered from a small sample size and heart rate is not a totally conclusive indicator of arousal. In fact a small increase in performance was observed under the steady noise conditions, making it possible that the noise masked distracting sounds and allowed better concentration.

The authors concluded that the subjects may not have had their performance hindered by the noise because they converted the task from one involving linguistic processing to one involving a rapid visual transformation, thereby eliminating the need for the use of short-term memory. Therefore, the authors feel that tasks involving the use of short-term memory will be affected by noise, even in relatively moderate noise conditions (74, p.1062).

Memory is also cited as the component of mathematical tasks that cause them to be affected by noise. Indeed, conventional mental arithmetic tasks have not been found to be affected by noise until a short-term memory component is included (67, p.121). Swedish experiments also suggest that performance of mathematical tasks is adversely affected when the subject has to make decisions about whether to add or subtract (9, p.67).

Another category of tasks often believed to be affected by noise are multiple source tasks in which two tasks are performed simultaneously or several inputs from the same task are processed together. In many of these cases it has been shown that more effort is applied to the primary task or cue at the expense of the secondary ones. However, later results suggest that this maximizing of effort toward the primary task can be affected by the instructions given to the subjects, the difficulty of the various tasks and the probability of needs for action.

A series of experiments done to examine the effects of noise on task priority was performed by Smith (63). In the first experiment 45 subjects were asked to recall eight words shown in four locations on a screen. Half of the subjects were told that their main goal was to recall the order of the words and a secondary aim was to recall the location. The other subjects had reversed priorities. Each subject performed the task in both quiet and noise at 78 dBA. The results showed that in noise subjects in both groups performed better at the primary task and worse at the secondary. This study therefore replicates a similar study performed by Hockey and Hamilton (63, p.250).

In the second experiment, no priority instructions were given; the subjects were just told to remember order and location and one or the other would be asked for first. Forty subjects were used and the only significant effect found was that recall was better for the first task than the second. The authors concluded, therefore, that priority instructions are needed to observe an interaction between noise and parts of the task.

The third experiment examined the importance of priority instructions versus noise by having the primary task carried out after the secondary task. In this experiment 17 subjects were told that remembering the order was their most important goal, but that they were to recall location first. The results showed that carrying out the secondary task first eliminated the effect of the priority instructions. So noise will not always benefit the primary task and impair the secondary one. In fact, the differences between the various studies of the effects of noise on the performance of multiple tasks may be due to a variation in instructions given.

Smith (63) further concludes that moderate noise in general will push the allocation of effort toward the task with the best payback. In the case of a complex task, the parts that will improve in noise depend on many factors including difficulty, the instructions given and the type of stimulus. For example, verbal stimuli are more affected by noise than other types of stimuli. In order to determine the effects of noise, therefore, one has to look at the structure of the task being performed, not just the overall performance. Smith suggests that future studies in this area should further vary the factors involved and also see what effect there is after people have performed in noise for a long time.

Another important type of task that can be affected by noise is the vigilance task which require constant monitoring of faint, infrequent signals. This type of task is important to industrial quality control and military radar monitoring. According to Cohen and Weinstein (21, p.42), studies of this task show that performance can actually improve under low levels of noise, but it is detrimentally affected at levels over 95 dBA. Noise appears to reduce the frequency of uncertain judgments and increase the frequency of confident ones. So tasks that require one to report all judgments are adversely affected, while those requiring only confident judgments are benefited.

In general, noise may not affect the average efficiency in performing tasks, but it may produce a variable performance where moments of inefficiency are mixed with compensating spurts of activity. This could lead to serious problems of product quality and accidents in industry. Smith (62) looked at moderate intensity noise to see what effect it had on the processing of information in a serial reaction task.

Previous studies using high intensity noise showed an increase in the number of errors and gaps in response. Smith did not find this with the lower level noise. However, he did find that under 85 dBC noise, 22 subjects showed decreased response time to high probability signals, but increased response time to less frequent signals. Again, not a decrease in average efficiency, but an effect on performance nonetheless. Smith also found that the subjects would adopt one mode of response during the noise and continue using that strategy even when the noise is removed. So the effect of noise on performance may continue even after the noise is stopped, a phenomenon called an aftereffect.

Noise can also affect accuracy and manual dexterity. Aetna Insurance Company did a study that showed a sharp rise in efficiency when office noise levels were decreased 14.5 percent. Although noise levels were not given, typists' errors decreased 29 percent, machine operators' errors dropped by 52 percent and absenteeism declined 37.5 percent (42, p.24).

Distraction or decreased attention is another by-product of noise exposure. A coal industry study showed that intermittent noise during mining caused more distraction which lead to poorer work (27, p.15). Decreased attention could be due to a strategy to decrease the amount of information being processed while being exposed to noise. This can also lead to other effects such as exhaustion, mental strain, absentmindedness and absenteeism.

A related effect would be an increase in the number of accidents on the job found in an industrial study by A. Cohen of the National Institutes for Occupational Safety and Health as described by Broadbent (12, p.16). He looked at workers in a plant where some were exposed to levels over 90 dBA and others were exposed to levels under 85 dBA. Those exposed to the higher noise levels had far more accidental injuries than those in the quieter areas. Of course, one wonders whether this difference was due to the noisy area having more dangerous machinery and moving parts. Subsequently, hearing protection was introduced and the number of accidents went down in the noisy areas. So both the number of accidents and the possibility of hearing loss declined.

Noise has also been found to affect time judgments. Steady noise above 90 dBA causes a listener to overestimate the amount of time that has passed. Noise under 90 dBA has the opposite effect of causing time passed to be underestimated (43, p.758).

Tasks Unaffected by Noise

Some tasks are less likely to be affected by even high levels of noise. A rule given for this type of task is, "almost any task in which a person has to react only at certain definite times, receives a clear warning of the need for reaction, and receives an easily visible stimulus will show no effect in continuous loud noise" (21, p.40). For example, any task that requires the sole use of visual functioning will not be affected by noise.

Smith and Broadbent (64) found that noise had different effects on the reading of color names than on the naming of colors. Neither task was affected when the noise was first turned on and the reading of words was only affected later, probably because the subjects tended to focus their eyes on words ahead of where they were reading, thus slowing them down when reading aloud.

Milosevic (45) found no effect by noise on a visual vigilance task. He had 12 subjects perform a visual task under two conditions - 70 dBA and 100 dBA. No effect on overall performance was observed. Again, the number of subjects was very small and only overall performance was looked at, but it is less likely that purely visual task like this will be affected.

Tasks requiring repeated movements and reactions are also less likely to be affected. A study conducted by Fisher (28) showed that reaction times for a 2-choice discrete reaction task were not affected, but the subjects felt that they had been slower. Seventy subjects were used (42 controls) and they were shown a digit on a screen and had to determine whether it was odd or even. The experimental group was given 100 dBA of noise via headphones and the control had 55 dBA of masking noise. After the test, the subjects were asked to fill out a questionnaire rating their own reaction times and many perceived them to be slower in noise.

A similar result was found by Gawron (31) who studied the effects and aftereffects of noise on 48 undergraduate students performing simple pencil-and-paper tests in 85 dBA and 45 dBA noise. She did not find any difference in performance between the two groups or, in fact, any effect upon performance due to noise. However, she did find that those in noise did show a change in their affective states as measured by such tests as the environment rating scale (ERS), comfort rating scale (CRS) and noise rating scale (NRS). Basically, the noise led to negative moods. Gawron suggests that these scales be used in future research to examine the effect of noise as an environmental stressor. These results from Gawron and Fisher are fascinating because even though there was no actual effect on performance, the subjects felt there was, which may lead to frustration or fatigue in the long run.

Performance and Noise Theories

The previous discussion has shown that noise can affect performance in many ways. Many people, particularly those in management concerned with efficiency, would like to be able to predict when noise from a given source will affect a specific task. To that end, several theories have been advanced by people in the field. These theories have evolved over the years, and often are found not to cover all situations.

Broadbent originally theorized that noise had a distracting effect. Then he modified his theory to include a model where noise acts by increasing the arousal level of the individual, which in turn affects the individual's performance of various tasks. In this regard, Broadbent categorized noise along with other stressors such as heat, sleep deprivation and demand, that affect arousal and therefore performance. He theorized that the increased arousal results in the individual setting a strategy to optimize results by selecting certain inputs to respond to and filtering out others (74, p.1054).

Basically, this filtering leads to a narrowing of attention. Therefore, any task that involves a restricted range of inputs may improve in noise where such a narrowing of attention will block out irrelevant information. However, other tasks such as multi-source tasks or dual-task performance will suffer under this narrowing of attention. Broadbent concludes that the optimal level of arousal varies with the complexity of the task and is lower for complex tasks. So noise is more likely to affect a complex task (21, p.39). In addition, intermittent noise would cause more harm because it would be more distracting and more likely to produce overarousal.

Broadbent's theory is often believed to be inadequate to explain all the experimental results found. Indeed, some tasks have been found to be affected by noise without the individual's arousal level being increased. In fact, the experimental results with noise do not match similar studies with other stressors such as stimulating drugs (67, p.90).

One person who has argued vigorously with Broadbent in this area is Poulton. Poulton believes that although arousal may increase when noise is first turned on, it decreases over time, and in fact, the initial arousal may actually lead to a beneficial effect on performance. In contrast, Poulton theorizes that decreased performance in continuous noise occurs because the individual cannot hear acoustic cues, including his own internal speech. The interference of intermittent noise, he believes, is due to the distraction it causes at the onset (21, p.40).

Poulton believes that the masking by noise occurs immediately and continues for the duration of the exposure. Therefore, his theory covers the observation that noise can both benefit and adversely affect a task. When the noise is first turned on, the initial arousal will cause an improved performance. As the noise continues, the arousal will lessen and the masking effect will come to dominate, causing a decrease in performance (74, p.1054). Therefore, in contrast to Broadbent, Poulton believes that continuous noise would have a more profound effect on performance than intermittent noise due to the unceasing masking of auditory feedback and inner speech. However, again, Poulton's theory does not fully explain all the experimental results in this field.

One other theorist that should be mentioned is S. Cohen who also believes along with Broadbent that noise tends to focus attention. This occurs in order to decrease the amount of information for the individual to process when noise overloads his capacity. This information load under noise, Cohen believes, is due more to the meaning of the noise in the given situation than the level of noise. He particularly believes that the predictability and controllability of noise are important factors in how it will affect performance.

Factors to Consider in the Effect of Noise on Performance

Cohen's theory on noise and performance brings up a very good point: many factors can determine what effect noise will have on a given task. Therefore, it is unlikely that any one theory will cover all situations. Cohen and Weinstein conclude that noise is more likely to have a detrimental effect if it is unpredictable or "perceived as disruptive of an important goal, unnecessary, representative of something that is feared or loathed and is produced without concern for the respondent" (21, p.61). Therefore, a brief look at the factors that can enter into the effect noise will have on performance is warranted.

One of the factors is the predictability of noise. If a noise is regular or predictable, strategies may be learned to avoid the adverse effects on performance. In other words, if the person knows the noise is coming, he may be able to prepare for it. Glass and Singer (57, p.411) cited studies that showed exposure to unpredictable noise caused greater impairment of task performance and decreased tolerance of the frustrations after the noise exposure. In fact, even though the adaptation to the noise in the given task was the same for both unpredictable and predictable noise, the adverse aftereffects were much greater after the unpredictable noise.

The ability to control the noise is also an important factor to consider. If the subject feels he is unable to control the noise, then he feels a loss of control over his environment. This feeling can lead to depression and decreased motivation and may ultimately lead to aftereffects such as decreased performance after the noise ends (19, p.528). A study in this area was performed by Glass and Singer (67, p.125-6). They found that subjects tended to exhibit the aftereffect of being less persistent in problem solving after the noise was removed. This aftereffect was eliminated when the subjects were able to turn off the noise at any time they wished during the experiment. Therefore, perceived control (even when not exercised) over the noise eliminated the aftereffect of exposure to 108 dBA noise.

Figure 8 shows the results of another study by Glass and Singer (57, p.414) in which the subjects' tolerance for frustration was increased by perceived control over the noise. Glass and Singer conclude that unpredictability and uncontrollability lead to adverse effects because they cause a feeling of helplessness. This helpless feeling causes a decreased motivation in subsequent task performance, an aftereffect of noise.

The type of noise will also be a factor in whether it will adversely affect performance. It has already been mentioned that intermittent noise will have a different effect than continuous noise. Certainly, novel or unusual noise will interfere with performance the first few times it is heard. The message conveyed by the noise will also be a factor. For instance, speech will be much more disturbing than general noise. That is why some people believe that laboratory studies using broadband noise will not correspond to actual workplace experiences where much of the noise may be due to conversation.

Also previously mentioned is the fact that the level of noise will affect how it interacts with performance. While noise above 95 dBA may nearly always affect performance, levels below this may or may not. An important variable may actually be the change in intensity.

Hartley (57, p.379-87) had another viewpoint on the type of noise versus the effect it will have. His studies showed that noise can have two different types of effects depending on the duration of the exposure. One effect is the annoyance due to the loudness experienced by intermittent or short exposure to noise. Long-term exposure, on the other hand, led to a feeling of isolation and monotony. Therefore, he concludes, "the effect of loudness on performance may predominate in the short exposure, whereas the adverse effect of perceptual isolation and monotony may predominate following many minutes of exposure to continuous noise" (57, p.385).

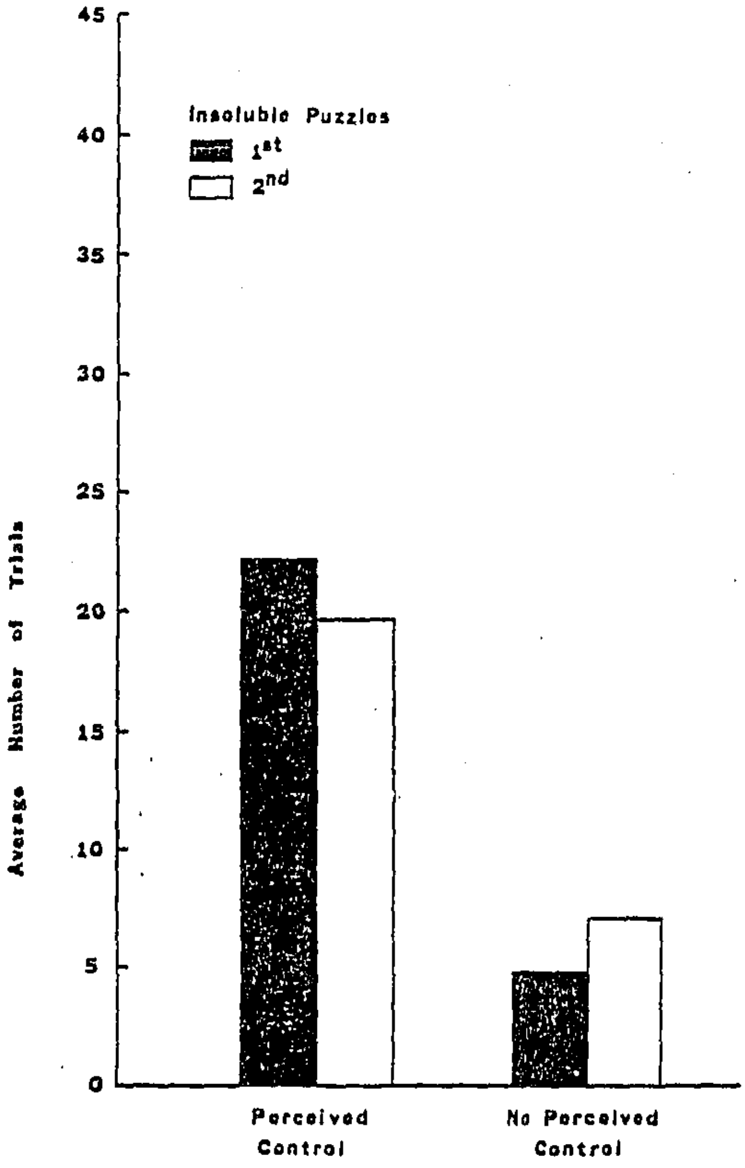

Figure 8 - Average Number of Trials on the Insoluble Puzzles for Perceived Control and No Perceived Control Conditions (57, p.415)

The characteristics of the individual exposed to the noise will also be a factor in the effect the noise has on task performance. Hansell (33) cites Lipscomb's factors that relate to an individual's psychological response to noise: "1) the noxious aspect of the sound source; 2) the relative pleasure or displeasure the person is experiencing at the onset of the noise; 3) the person's basic anxiety level; and 4) the evaluation of his/her total situation at the time that noise occurs" (33, p.60). If a person is healthy and in a familiar environment, he is more likely to be able to cope with noise than an ill person in a unfamiliar environment like a hospital. Therefore, a person's mental and physical health at the time of noise exposure will be a factor in how the noise affects his task performance.

The type of personality the individual has will also play a role. It is obvious that different people will react to noise in different ways. Moch (46) looked at the reactions of Type A and Type B personalities to steadily increasing noise (68-110 dBA) in performing both a simple and a complex task. During the simple task, no difference was found between the two groups (20 subjects in each group). However, during the complex task, the Type A personalities performed much better, suggesting that their greater desire to succeed lead them to deny the acoustic stress even though they actually manifested more physiological arousal. Even their subjective evaluations showed that they ignored the stress from the noise. Although the Type A people did not show adverse effects on their performance, one has to wonder at what cost to their physical conditions they achieved this result.

This difference in personality will also manifest itself in the arousability of an individual. Different people will have different basal levels of arousal and different rates at which they will be aroused. If a person enters a situation at a low level of arousal, noise may actually cause his performance to improve.

Differences in intelligence may also determine a person's reaction to noise. It is assumed that less able subjects would be more susceptible to the harmful effects of noise because they would have less resources to call upon and are more dependent on receiving relevant information (35, p.277).

The last factor to be mentioned in determining what effect noise will have in a particular situation is the number of other stressors present. Other stressors such as heat, sleep deprivation, drugs such as alcohol and vibration can all contribute to the effect noise will have on performance. In addition, other more subtle variables such as the knowledge of results, the amount of demand on the individual, and monetary incentives can also play a role. How these variables interact with one another can be very complex and depend, again, on the individual. Therefore, many factors enter into how noise will affect the performance of a given task.

Aftereffects of Noise and Adaptation

The aftereffects of noise have been mentioned previously and refer to the effects on human performance that occur after the noise ends. For example, in the previous section, Glass and Singer's experiments with the predictability and controllability of noise showed adverse aftereffects from the noise. Glass and Singer (57. p.416) conclude that although the subjects may adapt to the noise, it is not the adaptation that causes the adverse aftereffects. Rather, they believe that it is the cumulative exposure to the noise that leads to the changes in behavior after the noise is terminated.

Aftereffects can manifest themselves in two ways: an adverse effect on performance or fatigue and frustration. Post-stimulation effects on performance are also found from stressors like electric shock, bureaucratic stress and cold. They can be ameliorated by having the noise be predictable and/or controllable since these factors relate more to the occurrence of aftereffects than intensity (21, p.43). The aftereffect of noise on performance is usually decreased perseverance at the task when the noise ends. This effect is often referred to as learned helplessness.

The aftereffect of increased fatigue or frustration is often referred to as "psychic cost". Percival and Loeb (31, p.7) found that 94 dBA noise had no effect on performance during noise, but afterwards the subjects felt more irritated and distracted. In addition, if the subjects expend more energy to maintain a given level of efficiency, then the result will be more mental fatigue and decreased ability to relax at the end of the day or meet further demands.

These aftereffects are important to keep in mind when people say that they adapt to the noise. While adaptation may occur, particularly to continuous noise, it is probably done at a cost to the system that will lead to aftereffects. If the noise is intermittent, unexpected or uncontrollable, adaptation will probably not even occur.

Bronzaft expressed it this way, "If I am working near a noisy source, I may look as if I am producing the work, but I'm probably doing it at a cost to my system. I am probably leaning down more heavily on the pencil. Once I am doing this, I am exerting more muscle tension. You observe that if people are working under a stressful situation, while they may be working and appear to be adapting, they are exerting their body beyond the point that they should if they want to maintain a better health, so adaptation is not getting used to something at no cost. It means getting used to something at a possible detrimental cost" (14, p.78).

Conclusions on the Effects of Noise on Performance

As Hockey (67, p.88) points out, it is fairly simple to demonstrate that noise can affect task performance. However, to generate one theory to cover all the experimental results or to be able to predict whether noise will have an effect in a given situation remains a difficult task. As always, there is no such thing as a perfect study. Many of the performance studies were of short duration only and done on well-motivated adults who may be less likely to have noise influence their actions for the course of the study. Studies in the workplace are hard to do because it is difficult to control the other variables present.

Future studies in this area should be of longer duration to examine what effects noise will have in the long run. Other topics of concern as listed by Davies and Jones (67, p.132) are: the effects of noise on industrial efficiency, an understanding of how the individual's attitude relates to his performance, the duration of the aftereffects of noise, and an analysis of the strategic changes employed in noise rather than the overall evaluation of efficiency.

Noise can have no effect, a beneficial effect or a detrimental effect on the performance of a given task depending on the many factors outlined above. Those concerned with the efficiency of task performance and the general well-being of the individual should keep the possibility of noise effects in mind with the option of being able to prevent adverse effects and aftereffects. In particular, one should be aware that steady noise over 90 dBA and irregular or unexpected noise at all levels can adversely affect the performance of many tasks.

PRENATAL AND CHILDHOOD EFFECTS FROM NOISE

Related to both of the previous sections on cardiovascular and performance effects are the effects of noise on the unborn and on children. The prenatal effects are very much related to noise as a stressor, and many of the effects on children are performance effects, particularly in the area of acquiring language and reading skills.

The Effects of Noise on the Unborn

The most well-documented of the prenatal effects from noise is the increased incidence of low birth weight babies. A Japanese study of over 1000 births showed this increased incidence of babies born under 5 1/2 pounds in noisy areas. This weight is the World Health Organization's definition of premature and gives the child a disadvantaged start in life. This low birth weight effect is believed to be caused by noise acting as a stressor on the mother's body, causing constriction of the uterine blood vessels and thereby restricting the flow of nutrients to the fetus (49).

Two studies described by Kryter (39) confirmed these results in mothers living in areas exposed to aircraft noise. Ando and Hattori (39, p.501) found that the incidence of low birth weight babies increased as the level of the aircraft noise increased (39, p.501). Knipschild et al. (39, p.503) looked at birth weight data from hospitals near the Amsterdam airport. They controlled for family income, birth order and sex of the infant and found 23% of all infants were born below 3000 grams (approx 6.6 pounds) at Day-Night Equivalent Levels (L_{DN}s) of 65 to 70 dBA and 29% were had low birth weights at L_{DN}s of 70 to 75 dBA. At L_{DN}s below 65 dBA, the percentage of low birth weight babies was 18.1% from all areas.

Other effects on the unborn have also been observed. In another study, Ando and Hattori (39, p.501) found that mothers in high aircraft noise areas also had lower levels of human placental lactogen (HPL) in their serum than mothers in quiet area. This effect was found to increase as the pregnancy progressed in the noisy area and it was not dependent on socioeconomic or other environmental factors. See Figure 9. This decrease in HPL is again believed to be due to noise as a stressor, causing fear or annoyance in the mothers. The Japanese study mentioned earlier also found lower hormone levels that are believed to be associated with fetal growth and protein production. This difference between noisy and quiet areas was also found to increase as birth approached (49).

A less well-documented prenatal effect of noise is an increased incidence of birth defects. Again, studies of mothers living near noisy airports found more birth defects than women in quiet areas. Among these abnormalities area cleft lip, cleft palate and spinal defects. It is believed that these defects

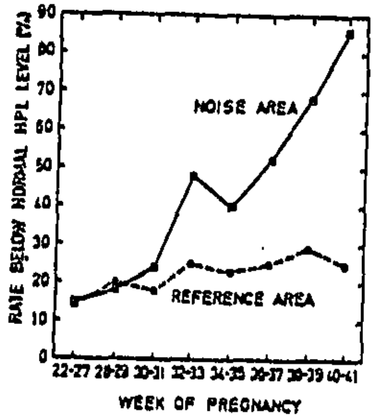

Figure 9 - Percentage of Subjects with HPL Levels More than One Standard Deviation Below the Mean by Stage of Pregnancy (39, p.502)

usually occur early in the pregnancy, at 14 to 60 days following conception, when the women may not yet be aware that they are pregnant. One set of studies in this area was done at Research Triangle Park, North Carolina and found that problems with early embryo development are due to overproduction of corticosteroids (68, p.10).

One animal study done in this area was performed on pregnant mice (22). Cook, Nawrot and Hamm found that exposure to 112 dB of 18 to 20 kHz noise caused decreased fetal and maternal weight. Although this is not very relative to humans because of the high frequency and the use of mice, the results were interesting because the decreased weights were found to be due to increased levels of catecholamines, a stress effect.

The human birth defect studies have a lot of potential problems. Many factors can cause birth defects including heredity and other environmental variables. In addition, the variability in the amount of birth defects in different hospitals is so great that it is difficult to find statistical significance in an increase in birth defects. The National Research Council investigated the reports of increased incidence of birth defects and found that there was not enough conclusive evidence to link noise with the abnormalities. However, the Council did recommend that pregnant women avoid long exposures to very loud noise (15, p.2).

The National Research Council also did a study of its own to see what potential prenatal effects there could be from high intensity noise. They noted that the inner ear and the central nervous system are in place by 26 weeks so loud enough sounds outside the mother's body can be heard by the fetus and cause a response in fetal heart rate or body movements such as kicking.

The Council's report stated that the other prenatal studies available were "limited in number, lack information on individual noise exposures, have inadequate sample populations and do not have appropriate control populations" (49). They recommended that pregnant women avoid long exposures to noise over 90 dBA and had several recommendations concerning future studies. They recommended industrial retrospective studies on pregnant women where careful recording of daily noise exposure was done. They also suggested doing prospective studies with careful monitoring and follow-up early evaluation of the newborns (49).

Some Canadian researchers presented a paper at the 109th meeting of the Acoustical Society of America in 1985 (50) that suggested that the chances of having a child with a high frequency hearing loss increased by a factor of three when the pregnant woman is exposed to daily doses of 85-95 dBA. If there is a strong low frequency component to the noise then the chances increase by a factor of eight because the maternal fluids and tissue surrounding the fetus only attenuate by 10 to 15 dBC at frequencies below 500 Hz. They cited an epidemiological study done by Polish researchers that found "nearly half of the children whose mothers had worked in a textile mill during pregnancy at levels of at least 100 dBA Sound Pressure Level

(SPL), had a high frequency hearing loss which was attributed to that exposure" (50, p.335).

The Canadian study involved 167 children, age 4 to 10 years old who had been exposed before birth to daily noise doses of 65-95 dBA. Their mothers worked in 45 plants where daily noise doses were computed for them at one week, one trimester and nine months of pregnancy. The occurrence of a greater than 10 dB Hearing Level (HL) loss in the child at 4000 Hz was three to five times greater if the mother was exposed to 85-95 dBA Leq. This occurrence was increased eight times when the low frequency noise predominated. They concluded that the industrial standard in Quebec was not sufficient because it did not take into account this problem with low frequency noise. They felt this was particularly important since the proportion of children with a learning problem in the schools was found to be higher for children with a hearing loss at 4000 Hz (50).

So, again, pregnant mothers are advised to limit their exposures to noise over 85 dBA, particularly if there is a low frequency component to the noise. It seems likely that a long exposure will result in noise acting as a stressor and causing a low birth weight child, possibly with birth defects or hearing loss.

Another effect is the possibility of infertility or delayed conception from noise. This effect was only mentioned in one study that looked at several exposures in the Danish workplace (58). They performed a case-control study using 1069 infertile couples and 4305 control couples in Denmark. They found that infertile females had significantly greater odds for industrial noise exposure as compared with control females. The odds ratio was 2.1 for women with hormonal disturbances and 2.2 for women with idiopathic infertility. The amount of noise exposure that these women had was not given. In fact, the authors note that the patients with infertility may have been more likely to report even a minimal exposure in their quest to find a reason for their infertility. In addition, there is a possible selection bias as all couples with infertility problems do not seek medical help. Therefore, the significance of this study is in doubt, although it is worth further investigation.

Cardiovascular Effects in Children

Noise continues to act as a stressor in a person's life after he or she is born. Children have been found in several studies to suffer from high blood pressure due to noise, just like adults.

One of the most extensive studies to look at the effects of noise on children is the Los Angeles Noise Project conducted by Sheldon Cohen and associates (18, 19 and 20). They studied all children without hearing impairment in the third and fourth grades at the four noisiest schools near Los Angeles International Airport. The children were matched on ethnic, racial and socioeconomic level to an equal number of children in three quiet schools. In the noisy schools there was an airplane overflight approximately every two-and-one-half minutes with peak sound level readings as high as 95 dBA. The overall mean peak sound level was 74 dBA in the noisy schools and 56 dBA in the quiet schools. The highest reading in the quiet schools was 68 dBA. After one year, a follow-up study was done after noise abatement was performed in some of the classrooms.

In the original study, children from the noisy schools had higher blood pressure than their counterparts from the quiet schools. Both systolic and diastolic pressure was significantly higher. There was a small influence due to the number of months in school with the greatest systolic pressure difference between the two groups being during the first few years of school (18, p.235-6). See Figure 10. This may indicate an adaptation effect.

In this study, they have controls for all the major variables, except for perhaps age. However, there are little data available on what the children's noise exposure might be at home and the number of years in school is not necessarily the same as the number of years of a given noise exposure. All in all, though, it does show a positive correlation between noise exposure in school and high blood pressure in children. Further, the authors have suggested that children may be more susceptible to increased blood pressure from noise than adults.

The study done a year later looked at children in the noise abated classroom versus the children who had remained in the noisy classrooms. The mean peak noise level in the noisy classrooms was now 91 dBA and in the abated classrooms it was 71 dBA. Blood pressures for children in the noisy schools was still higher than for children in quiet schools, but no significant differences were found in the children who had been switched to the abated classrooms as compared to the children remaining in the noisy classrooms (20, p.342). The results for the three types of classrooms is given in Table VI.

This study was weakened greatly by the fact that many of the noisy school children with high blood pressure the previous year had left. As for the seeming lack of improvement with noise abatement, it may be that it takes more than one year to recover from a previous noise exposure. Also, the children still are exposed to noise outside the school (20, p.344). The abated classrooms still had a relatively high noise level (71 dBA). Therefore, although the longitudinal section of this study was weak, the cross-sectional section once again showed a positive correlation between high blood pressure and noise.

Karagodina's study as described by Kryter (39, p.500) of 9 to 13 years old children around the Moscow airport as compared to control group of children in a quiet area also showed the noise exposed children to have "functional changes in the cardiovascular system and in the nervous system consisting of increased fatigue, blood pressure abnormalities, higher pulse lability and cardiac insufficiency". Karsdorf and Klappach (39,

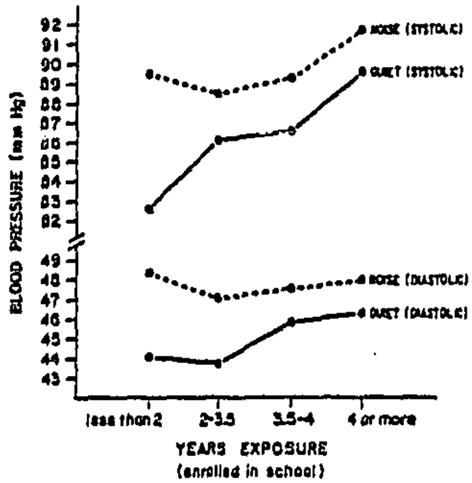

Figure 10 - Systolic and Diastolic Blood Pressure as a Function of School Noise Level and Duration of Exposure (18, p.236)

Table VI - Mean Blood Pressure (mmHg) by Classroom Noise Abatement for Cross-Sectional Data (20, p.342)

	Classroom		
Blood pressure	Quiet	Abated	Noisy
Systolic	86.64	88.69	90.09
Diastolic	44.99	46.77	48.46

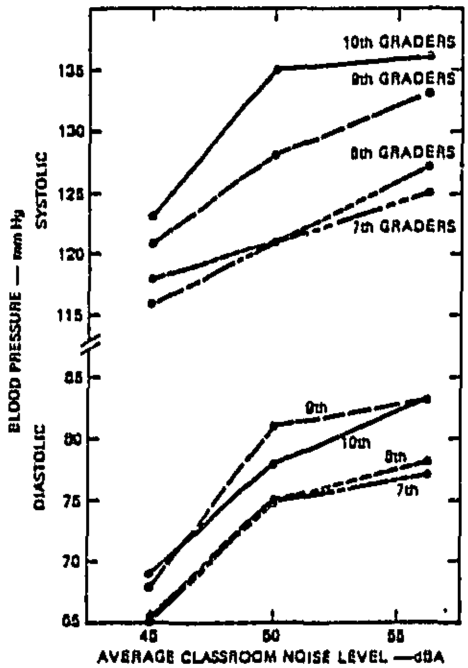

Figure 11 - Blood Pressure of Students as a Function of Noise Level of Intruding Street Traffic Noise (39, p.501)

p.500) also found increased blood pressure levels among high school students exposed to street traffic. Their results are shown in Figure 11.

In general, then, it can be shown that children attending noisy schools and possibly living in noisy neighborhoods are susceptible to having higher blood pressure than their quiet area counterparts. This may start them on life of high blood pressure, leading eventually to serious disease.

Effects of Noise on Children's Learning Abilities

The Los Angeles Noise Project also studied the cognitive and motivational effects of aircraft noise on children. Using the same children described previously from the noisy and quiet schools, Cohen _et al_. (18) looked at the performance aftereffects from noise by administering tasks and questionnaires in a noise-insulated trailer. The children were given two treatment puzzles each. The first puzzle was either soluble or insoluble and the second one was always soluble. The results showed that the children from the noisy schools were more likely to fail the first soluble puzzle than children from the quiet schools (41% failure vs. 23% failure). Again, with the second puzzle, the noisy-school children failed more often (53% failure vs. 36% failure).

The noisy-school children were also more likely to give up with the second puzzle before the allotted time was over. Even an analysis of only the children given an insoluble puzzle the first time showed that the noisy-school children were more likely to give up on the second puzzle (31% gave up vs. 7%) (18, p.238).

Cohen _et al_. also had the children perform tasks while a tape recording of a male voice read a story at medium volume, a distraction condition. The results found that the children from noisy schools were more distractible than the children from quiet schools if they had attended noisy schools for at least two years. Initially, children in noisy schools were less distractible because they try to block out acoustic cues. However, after awhile, they realize this strategy does not work, so they give up and become more distractible. In fact, the authors found that distractibility and the tendency to give up on a task increased with years of exposure to noise (18, p.241). Therefore, no adaptation to noise was found with regard to cognitive and motivational effects.

The second study (20) in the Los Angeles Noise Project, done a year later after noise abatement in some of the classrooms, had similar results. The same tests were administered again and once again, the noisy-school children were not as good at solving the treatment puzzles. They were also less distractible if they had less than 4 years of noise exposure, but more distractible if exposed more than 4 years. A further explanation of this was given that, over time, they become more discriminating in their tuning out and learn to tune out only aircraft noise (20, p.338).

The effect of the noise abatement was again marginal. It did have a small ameliorative effect on the children's ability to solve the treatment tasks and math achievement scores were slightly higher after abatement. Despite these seeming lack of benefits from abatement, children did report less trouble hearing their teachers in the abated classrooms. Again, the abatement was felt to be less successful than expected because the noise effects may last longer than one year and the children are still exposed to noise outside the classroom (20, p.344).

Overall, Cohen _et al_. concluded from their studies that children do _not_ adapt to noise over time. Their results may be less than perfect since they worked with groups of children from different schools, taught by different teachers. However, they clearly showed in both studies that noise does have an effect on the children's performance in the classroom and on their blood pressures. They also showed that noise abatement for classrooms may not be enough if the children are still exposed to noise at home. What they recommend is the use of buffer zones between noise sources like airports and the rest of the community to decrease overall community noise levels (20, p.345).

Another study in this area was performed on two groups of students in the same school in New York City by Bronzaft (13). The study was done at Public School 98 which is located within 220 feet of an elevated train track so that half of the classrooms face the track and half of them are on the quiet side of the building. The classroom noise level on the track side rose to 89 dBA when a train passed and this occurred every 4 1/2 minutes for an interval of 30 seconds.

The study used 350 second-, third-, fifth- and sixth-grade children and included a questionnaire to teachers along with the children's reading achievement scores from the California Achievement Test. Children on the noisy side of the school did significantly poorer on the achievement test than children on the quiet side. Children in the second and third grades were two to three months apart on the scores between quiet and noisy areas and children in the fifth and sixth grades were nine months to a year apart. This was explained by the fact that the lower grade teachers spent more time at the students' desks working individually, than the older grade teachers who tended to teach lecture style where a noise intrusion would be more detrimental.

Following the initial study, noise abatement was performed by the New York City Transit Authority and the Board of Education. They installed rubber pads on the tracks and sound absorbing ceilings. These abatement measures reduced sound levels by 6 to 8 dBA in each of the three noisy classrooms. The teacher questionnaires reported that "after the installation of the rubber pads their rooms were quieter, instruction went on with fewer interruptions, students reported quieter conditions, and they could read or lecture to the class for longer periods. In fact, one teacher reported that a particularly noisy train stood out now" (13, p.217).

After the abatement, the reading achievement scores were again taken and now children on both sides of the school were reading at comparable levels. This is a significant effect for the children in the upper grades that had a large gap in reading levels before abatement. Although 81 to 83 dBA is still not an acceptable level, it was probably easier for the children to concentrate after the abatement. Therefore, this study demonstrated both the effect that noise can have on children's learning abilities as well as how it can be ameliorated.

Cohen, Glass and Singer (17) did another study in this area that looked at the effect of noise at home on the auditory discrimination and reading ability of children who lived in a high-rise apartment building near Interstate 95 in New York City. This study looked at 54 second-, third-, fourth- and fifth-grade students who lived on various floors of this 32-story building. In fact, the floor level was taken as an indicator of the amount of noise exposure the child had and varied from 84 dBA on the ground floor to 55 dBA on the top floor. The other independent variable was the length of time the child had resided in the apartment.

The theory behind this study was from Deutsch who believed that children raised in a noisy environment become inattentive to acoustic cues which leads to impaired auditory discrimination. Since they cannot discriminate among sounds, they have difficulty learning to associate these sounds with their appropriate signs and therefore, have difficulty reading (17, p.409).

The authors tested the children using the Wepman Auditory Discrimination Test along with the reading comprehension, word knowledge and reading total scores from the Metropolitan Achievement Test. Each family also filled out a questionnaire that dealt with years of residence, number of siblings, parents' educational level and subjective ratings of the apartment noise level. The 54 children were then divided into two groups - those who had lived there 4 years or more (34 children) and those who had lived there less than 3 years (20 children).

Among the children who had lived there 4 years or more, called the primary sample, there was a positive correlation between floor level and the auditory discrimination and reading score results. No such correlation was found between floor levels and abilities in the secondary sample. Further analysis of the data confirmed that those who lived in the building longer had increased impairment of auditory discrimination ability and a seemingly related impairment of reading skills (17, p.414).

The authors discussed several factors that may have influenced their results. One was social class since the apartments on the higher floors usually have higher rents and may attract families with higher socioeconomic status. However, this did not seem to be a factor in this case for two reasons: one, residency in these apartments is limited by law to middle-income families and two, the range of rents for each type of apartment was very tight. Mother's educational level did correlate significantly with the reading scores, however, floor level was still a primary factor in the auditory discrimination and reading skills results (17, p.416).

Therefore, this study showed that noise adversely influenced auditory discrimination ability which leads to reading deficits. This effect increased with the number of years of noise exposure. So even though the children learn to filter out the noise and adapt, the aftereffects in this case are significant. This also should be viewed in relation to the previously discussed studies performed in schools with noise problems to show that a child with exposures at both home and school would surely have learning difficulties.

One other hypothesis that should be mentioned at this point is an alternative explanation for the children in noisy environments having poor auditory discrimination and thus, poor reading skills. Rather than this being due to the tuning out of sounds, it may be that noise masks speech from parents and teachers so that the children still do not learn appropriate speech cues (19, p.530). The validity of these hypotheses needs to be evaluated with further studies.

Bronzaft mentioned several other studies in her testimony before the New Jersey Noise Control Council (14). One was done by Ted Wax who looked at young children in noisy households. He found that their language development as well as their cognitive development in general was impeded (14, p.80). Another study near elevated train tracks in New York City was performed on nursery school children by Priscilla Hambrick-Dickson. She found that their intellectual skills were impaired on certain tasks (14, p.81).

Green and Pasternak looked at schools near LaGuardia and Kennedy Airports in New York City and found that the closer the schools were to the airport, the lower the reading scores (14, p.83). In fact, they found a positive correlation between noise level as determined by a noise contour map and the percentage of children scoring one or more years below grade level. This results was found after controlling for race and socioeconomic status (21, p.45).

Another study performed near the Seattle-Tacoma Airport, found that children with low aptitudes who attended noisy schools had a cumulative deficit in tested achievement as compared to children in quiet schools. This was not a significant effect until the 10th grade, again showed that length of exposure is an important variable (21, p.45). Still another study was done near Orly Airport in Paris and showed that children from a noisy school had poorer auditory discrimination than children from a quiet school matched on socioeconomic variables. They did not find differences in reading achievement although the children in the noisy school showed less tolerance for frustration (21, p.46).

A different approach was taken by Ward and Suedfeld as described by Cohen and Weinstein (21, p.45). Ward and Suedfeld induced noise effects by broadcasting traffic noise outside an university classroom. They observed less student participation and attention although they had no control group. Similarly, McCroskey and Devens (21, p.45) induced a 4 dBA increase in noise level in fifth- and sixth-grade classrooms where children were being tested. The children in the noisier classrooms showed impaired auditory discrimination, visual discrimination, and visual motor skills than the children tested in the quieter classrooms.

Cohen and Weinstein (21) concluded their review of these effects by stating that there is increasing of performance effects from noise that continue after the noise stops. However, most of these studies have been correlational and involve children. Their suggested explanations for the effects on children's performance are that noise interferes with the teaching-learning process by interrupting, it may interfere with the children's information processing strategies, and it may effect their feelings of personal control or arousal.

Noise clearly disrupts the learning process. The principal at a school in Kearny, New Jersey recently testified that learning in his school is severely impaired by aircraft noise. Similarly in Inglewood, California, aircraft noise disrupted learning so much that new, quieter schools had to be built. Besides the actual interruption, time had to be spent afterward refocussing the children's attention (27, p.13).

Noise in the home also clearly affects the child's language and reading abilities. If the home is noisy, casual conversation is eliminated along with speech models. Dr. Fay expresses it this way, "It has been suggested that the adverse effects of slum rearing on psychological development may lie in stimulus bombardment of the child rather than in stimulus deprivation. In any case, excessive noise may be a factor in the almost universally observed language deficiencies of disadvantaged children" (76, p.557).

Two last studies to mention were performed by Grosjean, Lodi and Rabinowitz (32) and Johansson (35). Although these studies were not too significant since they either suffered from extremely small sample size (Grosjean _et al._) or a very short exposure to noise (Johansson), they did have one interesting result in common. Both showed that less intelligent students were more impaired by noise than intelligent ones. So noise may have an even more serious impact on children who already start the learning process with a deficit.

Conclusions on the Prenatal and Childhood Effects from Noise

Noise exposure by pregnant women can act as a stressor at levels beginning at 70 dBA. This stress can lead to low birth weight babies and possibly, birth defects. In addition, prenatal exposure to noise levels over 85 dBA can result in a high frequency hearing loss in the fetus.

After birth, noise continues to act as a stressor, causing increased blood pressure in children exposed to noise levels of 75 dBA and above.

I believe that the studies described here also clearly show that noise can have an adverse performance effect on children's ability to learn. It can seriously hinder language development and reading skills, abilities that all people to need to live in our world. So noise is giving a severe disadvantage early in life to those children who live and/or go to schools in noisy environments.

EFFECTS OF NOISE ON SOCIAL BEHAVIOR AND MENTAL HEALTH

Social Behavior Effects

Also closely related to the effects of noise on performance are the effects of noise on social behavior. This can range from simply not assisting someone who has dropped his books to shooting a neighbor because of continued excess noise. In this section there are few scientific studies and many anecdotal stories. Yet, it is clear that noise does affect our interactions with each other.

The most well-known and well-designed study in this area was done by Mathews and Canon (41) on the subject of helping behavior. Two experiments were done - one in the laboratory and one in the field. In the laboratory, 52 subjects were present individually when a person dropped some books on the way out of a waiting room. A helping response was noted only if the subject actually got up and helped retrieve the dropped books. The results under three noise conditions are given in Table VII. They found a significant linear relationship between increased noise levels and decreased helping behavior (41, p.573).

The field study was conducted on a residential street with the noise source being a nearby lawnmower which registered 87 dBC at the test site when it was turned on. Eighty male subjects were taken from passers-by and again, books were dropped. This time another variable was used - whether or not the experimenter was wearing a cast, indicating a real need for help. The results are shown in Table VIII. Again, they showed a decrease in helping behavior during the high noise condition. This was particularly significant when the cast was worn, because the subjects were seemingly not picking up on the cue that he especially needed help when they were being subjected to the high noise (41, p.575).

Previous research by the authors had provided some support for the hypothesis that high noise levels can lead to lessened attention to incidental social cues that guide interpersonal behavior (41, p.571). Noise may, in fact, cause a person to become more single-minded and may lead to a state of "deindividuation in which persons treat others as if they were not human beings, as if they had no personal identity" (41, p.572). One other study described by Mathews that supported this idea was done by Stanton who found that more "extreme or taboo" words were used in a free-response situation under high noise levels (41, p.572).

The study by Mathews and Canon (41) also supported this idea of filtering out incidental social cues under high noise. During the ambient noise conditions, most people stopped to help the person with the cast; but under high noise conditions, this incidental cue was not recognized. Therefore, when one's social behavior is dependent on subtle cues and happenings to which one ought to be responding, noise will probably interfere with that

Table VII - Subjects' Helping in the Laboratory Experiment (41, p.573)

Helping behavior	Noise level		
	Ambient[a]	Low[b]	High[c]
Yes	13	10	7
No	5	5	12
% helping	72.2	66.7	36.8

[a] 48 db.
[b] 65 db.
[c] 85 db.

Table VIII - Subjects' Helping in the Field Experiment

Condition	Helping behavior		
	Yes	No	% helping
No cast			
Ambient noise[a]	4	16	20
High noise[b]	2	18	10
Cast			
Ambient noise[a]	16	4	80
High noise[b]	3	17	15

[a] 50 db.
[b] 87 db.

response.

Another study described by Cohen and Weinstein (21) found decreased helping behavior <u>after</u> a noise exposure. In this study, subjects did a demanding task either in soothing background noise or in distracting noise. A third condition had the distracting noise along with the ability to terminate it, which gave the subjects perceived control. After the experiment, the experimenter asked the subjects for some additional help with some materials and found that those exposed to the soothing noise were most helpful, followed by those who had control over the distracting noise then those who were subject to the distracting noise without control.

Sauser, Arauz and Chambers (21, p.48) looked at behavior in the office under noise conditions. They found a lack of sensitivity during a simulated management task performed under 70-80 dBA of noise. Those working in the noise recommended lower starting salaries for new employees when compared with controls performing the task in a quiet atmosphere (21, p.48).

Two other studies described by Cohen and Weinstein (21) looked at effects on social behavior in the community. Appleyard and Lintell (21, p.48) looked at traffic noise in moderate-income residential neighborhoods. One street had higher traffic noise levels than the other. The one with light traffic had more casual social interaction, while the residents of the noisy street said that is was a rather lonely place to live. This study is less significant because it is unknown whether other factors may have affected the interactions besides the noise.

The other neighborhood study was done in a lower-income residential project subjected to traffic noise around 80 dBA in the outer buildings. People in these outer buildings were "arrested more often, were less likely to take care of their entry ways, and were more likely to be truant from school" than the residents of the quieter inner buildings (21, p.48). However, again, there may have been other confounding factors such as family size and age.

Cohen and Weinstein (21) conclude their review of this section by stating that further research should be done to determine more exactly what mechanisms are at work that cause noise to affect interpersonal behavior. The role of decreased attention was discussed above. They also hypothesize that a negative affective state from noise may be the mechanism hindering helping behavior.

This idea of a negative affective state may be evidenced by feelings of frustration and annoyance. How a person responds to these feelings will determine how they are affected by noise. Some people may merely feel less tolerant and less willing to help others. One study looked at two groups of people playing a game. The group under noisy conditions perceived their fellow players as "more disagreeable, disorganized and threatening". Industrial studies show more tension among workers and management, resulting in and increased number of grievances (27, p.19).

Others may respond to the frustration and anger of being exposed to noise more violently. There have been several reports of people getting into fights and even shooting others because of excessive noise (14, p.83). This occurred recently in New York CIty when one homeless person shot another in a dispute over noise from a portable radio. Basically, noise makes people more aggressive and more likely to lose their tempers. Another report states that a night clerical worker shot a boy who was making noise outside his apartment after he asked him to be quiet to no avail (27, p.18). Other people who have been threatened because of their noise production are sanitation workers, construction foremen and motorboat operators.

Effects of Noise on Mental Health

Proving a link between noise and increased mental illness is very difficult. A series of studies have been done on mental hospital admissions around Los Angeles and Heathrow (London) airports to try and show increased admissions and thereby, increased illness.

Meecham and Smith as described in Kryter's review (39, p.483) looked at two groups around the Los Angeles Airport where one group was exposed to much less than 90 dBA from aircraft noise and the other group was exposed to 90 dBA and higher. The two groups were matched for socioeconomic factors and they found that there was a 29% increase in mental hospital admissions for the high noise group over the low noise group which is a significant result. Cohen and Weinstein (21), however, state that poor matching on racial and socioeconomic factors limit confidence in these results.

Similar studies described by Cohen and Weinstein (21) were performed at hospitals around Heathrow Airport in London. One group of researchers (Abey-Wickrama <u>et al</u>.) looked specifically at admissions to Springfield Hospital from noisy and less noisy sections of the same borough. They again found higher admission rates for the noisy area and found that older women who were either single, widowed or separated and suffering from neurotic or organic mental illness were more at risk. These particular results were challenged also for being poorly matched on demographic factors. However, the authors concluded that they did not believe that aircraft <u>caused</u> mental illness, but rather that it is a <u>factor</u> that contributes to increased mental hospital admissions (44, p.123).

Another group of researchers looked at admission rates for several different hospitals around Heathrow. They found that the results varied from hospital to hospital (21, p.55). Cohen and Weinstein (21) conclude, therefore, that these studies "suggest that there may be a small difference between mental hospital admission rates of quiet neighborhoods and neighborhoods subjected to aircraft noise" (21, p.55). However, these studies are retrospective and show very small differences in most cases.

In addition, many people with mental problems may visit their general doctors rather than go to the hospital and the studies do not indicate whether noise causes severe illness in healthy people or just aggravates existing problems. They suggest, therefore, that prospective studies should be done that encompass all aspects of community mental health care (21, p.55).

Another study previously mentioned by Knipschild also is relevant here. He found increased use of sedatives, hypnotics and anti-hypertensive drugs among noise-affected communities around Schipol Airport in Amsterdam. He also found that this drug consumption decreased when night flights were eliminated for awhile. His conclusion was that noise is a public health threat in many aspects, including mental disorders (67, p.41).

There have been other studies in this area as well. Another industrial study showed that workers in the noisiest section of a steel factory had greater social conflicts at home and in the plant. Again, this study is difficult to interpret since they were exposed to other stressors as well. Community noise surveys find an association between noise and feeling tense and edgy, irritability, nervousness, headaches and sleep problems. Surveys have an inherent problem of possibly asking slanted questions, however.

Conclusions on the Effects on Social Behavior and Mental Health

In general, then, noise has been shown to affect social behavior. Each person is different in how they react to the frustration of noise. Some may merely wear ear plugs and write to their government officials. Some may be less likely to stop and help or give directions. Others may react more violently and get into fights and even go so far as to kill or commit suicide. What the exact mechanisms are behind these effects are unknown, but the significance of these effects are clear: noise can seriously and adversely affect our interpersonal relationships and should be eliminated or reduced wherever possible.

Since noise produces feelings of annoyance and frustration, it is very possible, therefore, that it can aggravate existing mental or emotional problems even if it is unlikely that it causes mental illness by itself. Psychological distress may also lead to such symptoms as nausea, headaches, argumentativeness, mood changes, instability, and feelings of anxiety as documented by industrial studies in this area (21, p.54).

It is clear, then, that noise does annoy and frustrate people. Each person reacts differently to this annoyance. People with existing mental disorders who find noise annoying are very likely to have their condition worsened. Whether noise itself can cause mental illness is doubtful, but I do believe that it can be a factor in the development of such disorders.

EFFECTS OF NOISE ON SLEEP

The effects of noise on sleep is another highly complex subject, but one thing is clear: noise can significantly disturb sleep and thereby have an effect on human health and welfare. Many factors, including characteristics of the noise and the individual, affect how noise will disturb sleep. The disturbance can also occur in various ways by awakening the person, preventing him from falling asleep or causing him to shift from deep sleep to lighter sleep.

Sleep is divided into several stages that are characterized by different wave patterns on an electroencephalogram (EEG). One method of characterizing the stages labels them I, II, III, IV and I-REM where REM stands for rapid eye movement. REM sleep is considered the lightest and stage IV sleep the deepest. Both are needed for restoration of health, particularly the recuperation of the central nervous system. In fact, people cycle through all the stages during the night in a manner illustrated in Figure 12 for different age groups. These cycles are usually 90 minutes in length. Even after one is asleep, roughly 5% of the time is spent awake up to age 40 years. Then the time awake during "sleep" can be up to 20% (43, p.745).

Field and Laboratory Studies

Two types of studies have been done to assess the effects of noise on sleep: laboratory and field. During laboratory studies, subjects sleep in a special room where their physiological states can be monitored closely and exact control can be exercised over the types and duration of noise they receive. However, because these studies are expensive, usually only a few subjects are studied and they need time to adapt to their new environment before the results can be considered valid (43, p.744).

Field studies are performed in the subjects' homes near a noise source such as an airport or highway. One such study was conducted by Ohrstrom and Bjorkman (51) in an apartment building near a major street. They were specifically interested in the relationship between EEG changes and the subjective evaluation of sleep quality by the participants. Three tenants of various ages (23, 53 and 70 years) were studied the week before and the week after the installation of noise insulating windows. They were given a questionnaire to fill out each morning from which a sleep quality index was derived. They also had an accelerometer attached to their beds that recorded their body movements.

The noise levels in the apartments decreased from 35 dBA Leq to 26 dBA Leq after the window insulation. The bed movement and sleep quality index results for the three subjects before and after the insulation are shown in Table IX. All three showed a decrease in bed movements with the decrease being significant for persons 1 and 2. The subjective sleep quality showed a

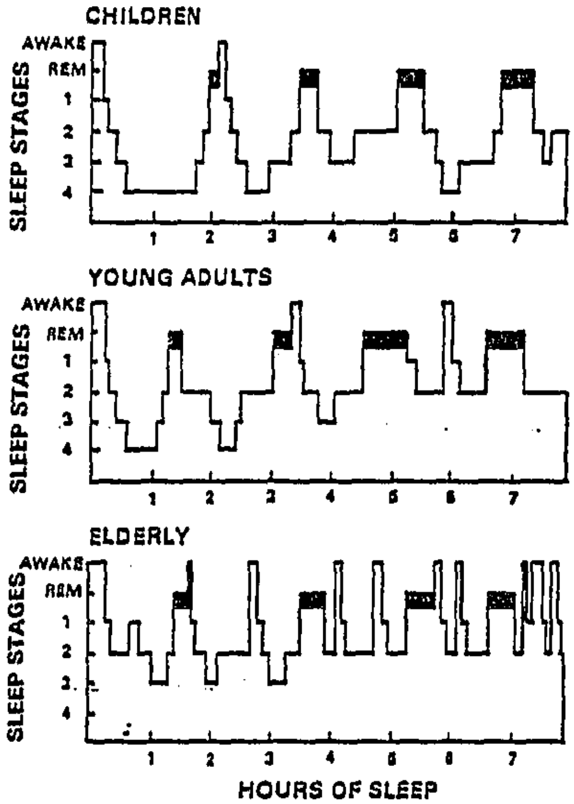

Figure 12 - Normal Sleep Cycles (47, p.52)

Table IX - Bed Movements and Sleep Quality Index (SQI) Before and After Insulation of Windows for Test Persons 1-3 (Figures in Parentheses Indicate Standard Deviation of Four Measurements) (51, p.878)

Subject	1		2		3	
	before	after	before	after	before	after
Movements per sleep hour	19.2 (1.6)	12.1 (2.9)	13.4 (5.0)	5.6 (1.5)	9.6 (1.5)	6.0 (3.3)
SQI	15.7 (2.7)	13.3 (8.6)	−1.0 (0.8)	10.4 (3.2)	13.4 (5.6)	15.9 (0.8)

significant improvement for person 2, a slight improvement for person 3 and a slight decrease for person 1 (51, p.878). Person 1 may have had an unrealistic expectation for the amount of noise reduction due to the insulation. In general, however, the authors found that both subjective sleep quality and the bed movements indicator showed improvement after noise reduction.

Wilkinson and Campbell (75) also did a field study in people's homes near a traffic noise source. The study went three weeks, with the middle week having the bedroom windows double glazed which was removed before the third week. The double glazing resulted in the noise levels being about 6 dBA lower during the middle week. The sleep stages were monitored with an electroencephalogram (EEG), a questionnaire was used along with the Stanford Sleepiness Scale (SSS), and three performance tests were given each morning.

The results showed that the middle week with an Leq level of 40.8 dBA showed a significant increase in stage IV sleep as opposed to weeks 1 and 3 with an Leq of 46.6 dBA. On the performance tests, unprepared simple reaction time was faster during the quiet week for 9 out of the 11 subjects. Since the test was not given in the bedroom, the change in performance seems to be due to the amount of sleep and not the difference in noise level during the test. The four-choice test did not have significant results although 8 out of the 11 subjects did better during the quiet week. Short term memory was not affected as expected since it is not sensitive to changes in arousal (75, p.470).

Two significant results for differences in the individual subjects were found also: the increase in stage IV sleep was greater for the women than the men, and the sleep period was increased more for the older subjects than the younger subjects. These results agree with general findings on the effects of age and sex that will be discussed shortly. Figure 13 shows another important result: there is a correlation between the subjective sleep determination, the EEG results for delta or stage IV sleep and the reaction time. This confirms that all three of these measures are valid for the determination of sleep disturbance.

The authors also concluded that both stage IV sleep and REM sleep can be affected by noise although their literature review did not find stage I or II sleep to be affected (75, p.472). Their literature review also found that based on ten sets of data, a peak of 68 dBA will cause a change in sleep stage in one-third of the population and waken one-tenth of the population, and a peak of 85 dBA will waken one-third of them (75, p.468). However, these sets of data are averages of the results and should only be taken as an approximation.

The authors further note that there have been few studies that look at the relationship between the amount of sleep and performance the next day. In addition, in their study as well as in most studies the subjects are healthy people who are not on medication and are probably not poor sleepers to begin with. Therefore, the results may be even more significant if studies

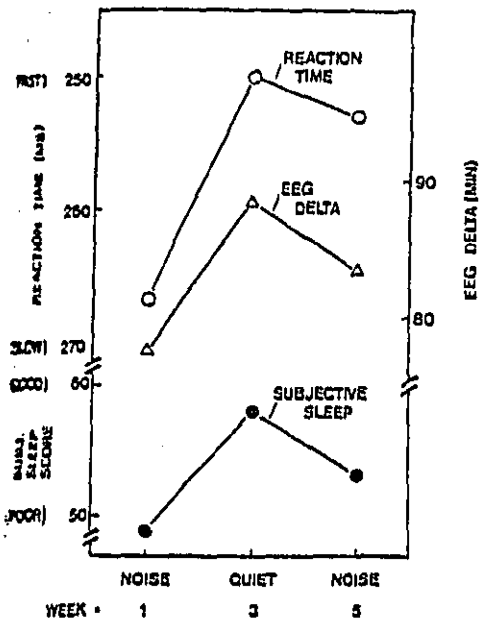

Figure 13 - Indices of Performance in Noise and Quiet Conditions (75, p.471)

were done on poor sleepers.

A third field study performed this time with aircraft noise from Los Angeles International Airport was conducted by Globus et al. (57, p.587). Eleven married couples were studied - six in a neighborhood with a mean level of 77 dBA and five in a control neighborhood with a mean level of 57 dBA. Their sleep was monitored each night for 5 nights and they filled out a questionnaire on sleep quality each morning. The experimental subjects spent significantly less time in deep sleep (stages II, III, IV and REM) than the control subjects and spent a greater proportion of their time in stage I light sleep, waking and movement time.

Tempest (67, p.32) describes an aircraft noise survey performed by the Central Office of Information in the neighborhood of London Airport. They found that 22% of the people living near the airport were sometimes kept from falling asleep due to noise and the proportion rose to 50% with very high noise levels. Noise intensity also correlated with the number awakenings reported.

A laboratory study was performed by Bergamasco et al. (10) using traffic noise of various intensities ranging from 54 to 77 dBA. Five subjects were used and their sleep patterns were monitored and compared to average statistical data. The results indicated both qualitative and quantitative changes to sleep. The arousal phase (both time to get to sleep and awakenings during the night) was of longer duration and stage IV was significantly reduced. As for REM sleep, one subject had a shorter amount and one subject had none at all. These two subjects were found to be of the "anxiety-introversion" type, so the authors concluded that people who have any instability in their emotional control may be more disturbed in their sleep and, in fact, these sleep deprivation may lead to mental disease symptoms (10, p.36).

The literature review by Rossi (59) that accompanied Bergamasco et al.'s study also cited some interesting laboratory studies. Thiessen used recordings of trucks to study sleep and found that a mean noise level of 40 dBA woke 5% of his subjects and a level of 70 dBA woke 30%. Ossipov (59, p.6) found that at 50 dBA it took about 1 1/2 hours to get to sleep and then deep sleep periods were shorter and subjects complained of tiredness on waking. He found 35 dBA to be an optimum level. Similar results were found by Steinecke and Scott (59, p.6).

In another laboratory study described by Vernet (73), Osada found that it takes 2 to 3 times longer to fall asleep at peak noise levels of 60 dBA versus a background level of 40 dBA. He found also that the threshold noise level for people waking up was 60 dBA and the subject is kept awake longer as the level goes above this.

A different type of laboratory study was performed by Fruhstorfer et al. (29). They looked at the effect of daytime noise on subsequent sleep. Six subjects were exposed to 80 dBA of noise for 8 hours a day for 2 days. Then their sleep patterns were monitored by EEG and a questionnaire was filled out. The subjects reported poorer sleep, but they actually experienced increased stage III and IV sleep. This increase may have indicated a need for additional recovery due to the acoustical load during the day. The authors themselves point out, however, that this study has limited value due to the small number of subjects, their young age and the lack of control subjects. It would be interesting to investigate, however, what effect daytime noise would have on the sleep patterns of risk groups such as the elderly and the sick. Also, it would be interesting to know what effect, if any, daytime noise exposure has on the results of all the other studies cited herein.

Three studies were performed by the Navy for periods of 15, 55 and 7 days (57, p.559-573). The men were exposed on a 24 hour basis to pings (impulse sounds) of 80 dBA. Overall, the studies found that there were reports of delayed sleep onset and a decrease in the amount of stage IV sleep. There were no significant changes in performance, but again, the studies were done on young, healthy adults.

The effects of sleep disturbance on subsequent performance was also examined by Herbert and Wilkinson in a laboratory study. Ten subjects were exposed to noise at 65, 75, 80 and 90 dBA over the course of 5 nights. The sleep profiles showed an increase in stage I sleep and time spent awake and an insignificant decrease in REM and stage IV sleep. They did find a small decrease in performance on a vigilance test but only early in the day.

A different type of study was performed in the intensive care unit of a hospital on ten patients. They found that more time was spent in stage I sleep to the detriment of the other stages which are necessary for recovery. Noise disturbance in this case came from the staff and various machinery (33, p.62). Another study in a hospital, this time in a recovery room, revealed a significantly greater use of pain medications during high noise levels (33, p.63). These results illustrate a very serious problem: the more time a patient spends in acute care areas, the more sleep deprivation he experiences and therefore, the longer it will take him to recover. The FAA recommended in their review of aircraft noise effects that interior noise levels for hospital be between 34 and 47 dBA (47, p.57).

The FAA's review also summarized the laboratory data they looked at with Figure 14. They concluded that, depending on various factors, sleep disturbance can occur anywhere from 35 to 70 dBA and they feel that the maximum intrusive level should be 55 dBA (47, p.57).

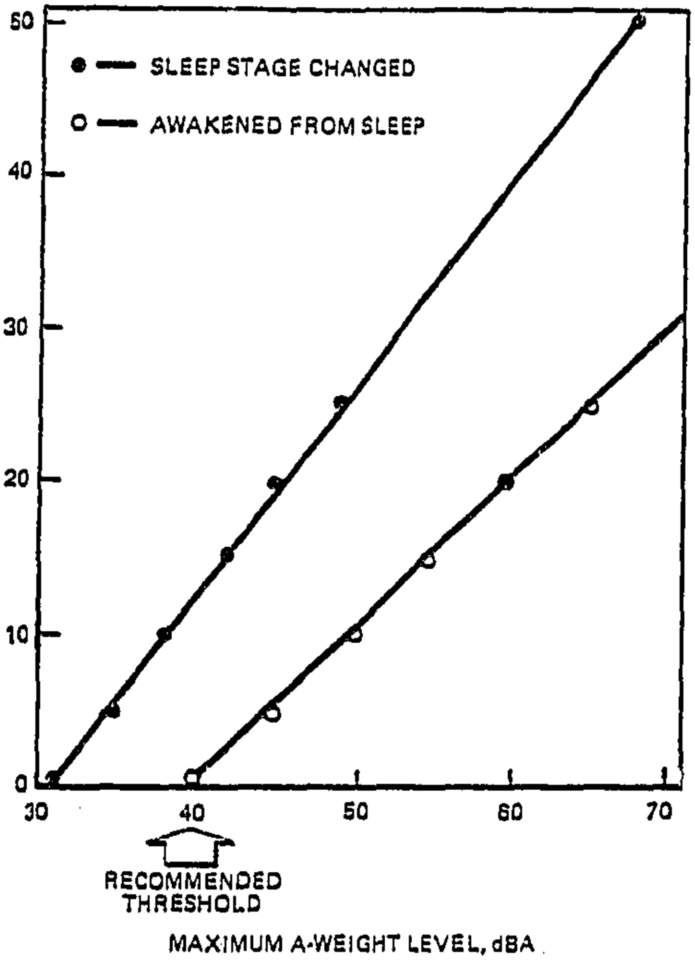

Figure 14 - Composite of Laboratory Data for Sleep Interference Versus Maximum A-Weighted Noise Level (47, p.56)

Factors that Influence the Effects of Noise on Sleep

There are several factors that affect whether there will be sleep disturbance from noise. Two of them have already been mentioned - the age and sex of the person. It is clear that people over 60 years old are awakened more easily and shift towards lighter stages of sleep more often than younger people. These effects can occur over all stages of sleep and once the older person is awake, he has more difficulty getting back to sleep (43, p.747).

Several studies have also verified that women are disturbed more often than men. They tend to wake up more often and shift more easily to lighter stages of sleep (43, p.747). Another individual factor is the amount of sleep deprivation at the time of noise exposure. Those who have been deprived of sleep will need louder noise to awaken them than normally rested people (43, p.747).

The stage of sleep and the amount of sleep the subject has had will also influence the amount of disturbance by noise. Sleep is most easily disturbed in stages I and II, and least easily in stages III and IV. Stage I-REM can go either way. The longer a person has slept, the more easily he will be awakened, no matter what stage of sleep he is in (43, p.748).

Another factor that depends on the individual is the meaning of the sound, its familiarity and the motivation the person has to respond to it. Information from the sense organs continues to reach the highest centers of the brain for processing even during deepest sleep. It is believed that the brain then assesses the significance of the incoming messages and decides whether arousal will take place. The resulting arousal will either result in awakening or a shift to a lighter stage of sleep. The motivation to wake will influence the probability of waking up, although the intensity of the sound will play an important role in whether the motivation will results in awakening (43, p.746). An example of a strong motivation is a mother's desire to respond to her child at night.

A study described by Vallet and Mouret (72) on motivation or the meaning of the sound to influence waking was performed by Oswald _et al_. who read 560 names out loud to sleeping subjects. The subjects were undisturbed until their own name was read to them at the same level. The effect of familiarity of a sound has not been extensively studied, but almost anyone can relate stories of how the sounds in their normal sleeping environment will not disturb them, but sounds in an unfamiliar environment, no matter how quiet, will keep them awake. This is often known as the "first night effect".

Other individual factors include such things as mental and physical disease, the use of drugs, and stress. It has already been noted that sleep can more easily disturb people in hospitals and it is certainly true that noise will have a more profound effect on sleep for those who are ill in general and who are poor sleepers already.

Different characteristics of noise will also be factors in the amount of disturbance on sleep. Obviously, the louder the noise, the more likely it will disturb sleep. If the noise level fluctuates, it will disturb sleep more. Schieber et al. as described by Miller (43, p. 747) did an extensive study in this area using several measures of sleep quality: sleep patterns, number of brief wakings, number of body movements, and the degree of muscular tension. They used artificial crescendos of white noise that rose to 80 dBA to simulate aircraft flyovers or traffic noise. All of the sleep measures indicated that sleep was disturbed by this noise. In fact, low-density traffic noise where the peak noise events occurred less often caused more disturbance than high-density traffic noise.

Steady sounds, on the other hand, are often cited anecdotally as enhancing sleep due to its ability to mask brief sounds. Further investigation along this line is needed to find out at what level steady sounds stop being helpful and begin to disturb sleep and whether steady, rhythmic sound can actually induce sleep.

Adaptation and the Results of Sleep Disturbance

Whether or not a person can adapt to noise so that it will not affect sleep is still a matter of debate. Anecdotal evidence seems to support adaptation, but it is probably true that people who think they are undisturbed are actually waking briefly or shifting to lighter stages of sleep. This probable lack of true adaptation has been borne out by laboratory studies where it is observed that subjects do not realize how often they actually do wake up (27, p.16). There is a "first night effect" where people will have difficulty sleeping initially in an unfamiliar environment, but as the sound become familiar over time, they are not aroused as often. However, Vallet and Mouret (72) in their literature review state, "one of the most consistent experimental results is that noise induces a reduction of delta sleep which does not habituate".

The results of sleep disturbance from noise are also not definite. Several studies cited above did show some performance effects that accompanied sleep disturbance. Certainly, if the sleep disturbance becomes a chronic occurrence, health will be harmed. Community surveys further indicate that it is interference with rest and relaxation that is the underlying cause of people's complaints about noise (27, p.17).

Miller (43, p.748) concludes that a resulting health hazard is debatable since normal people will compensate for lost sleep by spending more time in deep sleep. However, noise definitely does cause a sleep disturbance and this will cause a decreased feeling of well-being and a chronic disturbance will become a hazard, particularly to those who are already sick and the elderly.

Conclusions on the Effects of Noise on Sleep

It is evident that noise levels above 35 dBA can cause sleep disturbance. This disturbance can be in the form of awakening from sleep, a shift from deep, stage IV sleep or difficulty in falling asleep.

Since sleep disturbance by noise will be affected by the individual differences and the type of noise, it is not surprising that people in the field have been unable to agree on a "safe level". In New Jersey, the nighttime noise limit for industrial and commercial sources was set at 50 dBA at the property line. With building attenuation, this probably leads to an interior level of around 35 dBA which will protect most people from being disturbed.

More research could be done in this area, particularly longitudinal studies that would look at the various factors including the individual's daytime noise exposure and whether the subject is ill or a poor sleeper. It would also be useful to examine the aftereffects of sleep disturbance such as decreased performance and decreased ability to recover from sickness.

EFFECTS OF NOISE ON SPEECH COMMUNICATION

How Speech Interference Occurs

We have all experienced the situation where the noise from a passing truck, lawnmower or airplane has interfered with a conversation. In fact, speech interference is the most common complaint about noise. It is a serious problem both in the performance of jobs and schoolwork, and in social interactions among people.

Speech interference occurs when noise or unwanted sound masks the reception of wanted speech signals. Speech can occur anywhere from 100 Hz to 8000 Hz, but most of it falls within 300 to 3000 Hz (43, p.740). Female voices are generally higher pitched than male voices and 2 to 3 dBA lower (39, p.60). Since speech often has redundant information in the form of cues such as context and body language, it often possible for it to be understood even when partially masked. Humans, in fact, have a great ability to "block out" unwanted sounds and concentrate on wanted signals. However, this ability is definitely limited-when noise gets loud enough, it will make the wanted signal inaudible.

There are various degrees of masking. If the speech signal is totally drowned out, it is considered below the threshold of detectability and inaudible. If the speech signal can be detected but not completely understandable, it is said to have poor intelligibility or discriminability. As noise levels increase, speakers will usually raise their voices to compensate until they are finally prevented from communicating. This, of course, can result in undue vocal strain. Distance between the speaker and the listener will also play an important role in communication. Figure 15 illustrates the relationships between noise level, distance, voice level and quality of communication.

The amount of communication achieved can be predicted or measured and many studies have been done in this area. Measurement is based on the distance between talker and receiver, the talker's characteristics, the type of speech, the noise source and level and the integrity of the listener's auditory system. The result is measured generally in the percentage of messages understood which is considered the measure of intelligibility (43, p.740). One way to predict the percentage of words that will be received is by using a signal-to-noise ratio. These ratios will depend on the type of speech being used, but can be very useful in predicting speech interference (39, p.68).

As already stated, many factors can influence the success of communication. One important factor is the concept of cultural influences. Distances between speaker and listener of less than 4 1/2 feet are generally used only for confidential or personal exchanges. Distances greater than 5 feet are usually not confidential and use a slightly raised voice. If the noise level

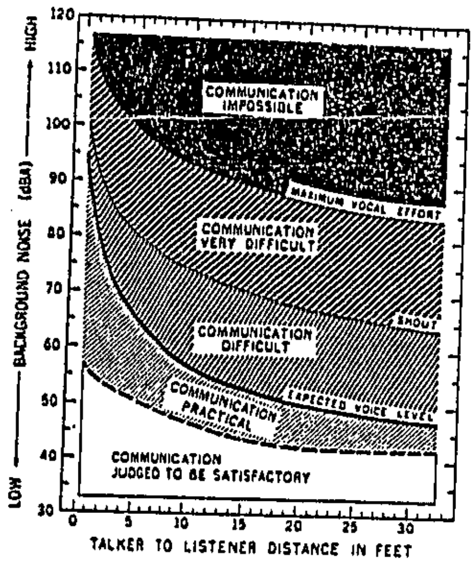

Figure 15 - Quality of Speech Communication in Relation to the A-Weighted Sound Level and the Distance between Talker and Listener (43, p.742)

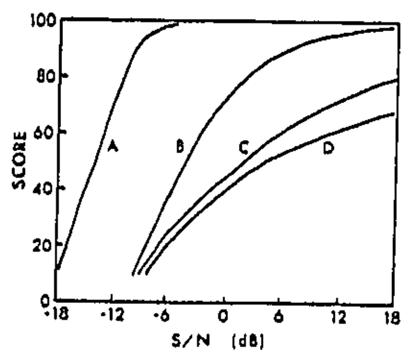

Figure 16 - Intelligibility of Spoken Digits (A), Words in Sentences (B), Isolated Words (C), and Nonsense Syllables (D) as a Function of Signal-to-Noise Ratio (67, p.76)

gets so high that people have to move closer together or raise their voices in a personal conversation, speech communication will be hampered. At a distance of 5 feet between conversants, a background level of 66 dBA or less would allow communication. This is the justification for the New Jersey state noise code having a daytime limit of 65 dBA. For conversations involving groups at distances of 5-12 feet, a background level of 60 dBA or less would be appropriate. If the distance goes above 12 feet, then background level must be below 55 dBA to have successful communication (43, p.742).

Another factor is the person's characteristics - speech articulation and age. If the speaker does not speak the language or dialect well or just has poor articulation, he will be much more easily masked by noise. If the listener is an older person, he will require a lower background noise level since the ability to understand partially masked speech decreases after age 30 (43, p.742).

Schindler and Vigone (61) confirmed this difference between young and old people. They exposed 10 young people (aged 19-21 years) and 4 adults (aged 40-50 years) to 72 dBA traffic noise and read them a series of two syllable words at various signal-to-noise ratios. The curves of percent intelligibility for the adults was much worse than for the young people. The adults could not achieve good comprehension until the speech signal reached at least 75 dBA (61, p.43).

In the workplace, earplugs may improve speech communication by lowering the level at the ear of both the speech and the noise so that the ear is not overloaded and can discriminate the speech. However, if earplugs are worn in a quieter situation, they may decrease intelligibility by lowering the level of speech below the threshold of detectability (39, p.83).

The speech itself will influence the quality of communication. Different sounds will be more intense at a given voice level than others. In general, vowels are louder and easier to understand than consonants. Figure 16 shows the signal-to-noise ratios for various types of messages. Spoken digits are the easiest to understand because they contain different vowels and can be distinguished even if barely understood. Nonsense syllable are the most difficult to understand because there is not context or knowledge of language to help you so both consonants and vowels must be identified (67, p.76).

It is obvious that the intensity and frequency of the noise will play a role in whether it causes masking. The type of noise - random, periodic, interrupted - will also play a role. The type of noise that will cause the most interference with speech, however, is speech itself (67, p.85).

Conclusions on Speech Interference from Noise

In the childhood effects section, it was clearly demonstrated how noise can interfere with speech communication in the classroom and at home with detrimental results on the child's speaking and learning abilities. It has also been mentioned in the performance section how noise can interfere with tasks by masking necessary auditory signals.

The masking of signals can be merely annoying as in the case of a masked doorbell sound, or it can be extremely dangerous as in the case of a masked warning signal or shout for help. It is believed that many accidents both in the workplace and on the roads are caused when people fail to hear warning signals. A study of industrial accident records has found that significantly higher numbers of accidents occur in noisier areas of the workplace. The Federal Railroad Administration found high noise levels to be a possible factor in 19 accidents over a 22-month period that resulted in the death of 25 employees (27, p.20).

Speech interference can also disrupt leisure activities and hinder development of social relationships. If it is too difficult to communicate, the amount of social interaction will decline. In particular, the enjoyment of retired life by older people who have a harder time discriminating sounds in noise can be significantly hindered.

Speech communication is a vital part of our lives from the time we are young and just learning language and reading skills, through our adult lives as workers and social people, to the time of our retirement when we want to enjoy leisure activities. It is very important that we do not allow noise to interfere with our lives, especially when it comes to life and death situations. Therefore, the levels of noise above 65 dBA must be avoided to insure that speech interference from noise does not occur.

RECREATIONAL HEARING LOSS

Although the possibility of hearing loss in the workplace is well known and well documented, people are often unaware that they can suffer hearing loss outside the workplace as well. Hearing loss from noise is a permanent condition that occurs gradually over a long period of exposure. Temporary hearing loss usually occurs first, with recovery after a few hours away from noise. But if the person continues to be exposed to high levels of noise, the temporary loss becomes permanent and may also be accompanied by tinnitus or ringing in the ears.

One of the prime offenders in the area of recreational hearing loss is the use of headset radios or "Walkmans". The New Jersey Noise Control Council devoted one of its health effects of noise press releases solely to these devices (48). They noted that there are no standards for recreational noise and studies have shown that these radios are capable of producing 120 dBA at the highest volume setting. A study by Dr. Phillip Lee showed that volunteers tended to set their radios at 90 to 104 dBA. After 3 hours of wearing their radios at these volumes, they had temporary hearing losses ranging from 10 to 30 dB HL and many of them had tinnitus.

The public should be aware that these radios can cause a hearing loss, may mask a warning signal if played loud enough and will probably interfere with concentration during the performance of tasks. Dr. Thomas Fay of the Department of Otolaryngology at Columbia University recommends that users of headset radios wear earplugs under their headphones to prevent hearing loss (54, p.49).

Personal radios are not the only music source with potential problems. A study in the British Medical Journal reported that stereos can reach 140 dBA, a level certain to cause permanent hearing loss (42, p.23). Car radios played loud enough to hear with the windows open can also reach dangerous levels. Terry (68) cites a study by the Environmental Health Administration that measured noise levels in 18 discos and found that half of them had levels that were an occupational hazard to the disc jockeys and bartenders based on Occupational Safety and Health Administration (OSHA) standards (90 dBA time-weighted average for 8 hours). Obviously, patrons of these discos are also being exposed to these dangerous levels and several of the discos had levels such that employees should only be there for 2 hours based on OSHA standards. In other words, the levels exceeded 100 dBA time-weighted average!

Dzelzkalns and Fay (26) warned the public about another potential site for hearing loss: the exercise studio. Levels of music played to exercise by are often unnecessarily loud, and again, hearing loss can occur from long exposure. Just because we enjoy the music in the exercise studio, disco or rock concert or the noise at a basketball game or social event, does not mean we cannot suffer hearing loss from it. We can! If you combine these recreational exposures with other community exposures from lawnmowers, power tools, hairdryers, dishwasher and other appliances, you increase even more the possibility of a permanent hearing loss. In addition, people living near some of the noise sources described earlier like airports, highways and railways, may be constantly exposed to damaging levels from those sources alone.

Recreational hearing loss can even begin at a very young age. Galton (30) cites a study that found noise levels from squeaky toys, model cars with lifelike horns and other noisy toys to be loud enough to cause hearing loss. An acceptable level for toys indoors according to this study is 85 dBA, but toys like cap guns can emit up to 152 dBA. Even the squeaky toys can have noise levels of up to 100 dBA!

What can be done about these non-industrial exposures? Obviously, noise is not going to disappear. However, there are many ways to quiet the environment. You can ask the instructors to turn down the music at the exercise studio. You can be careful to use the lowest settings on your personal radio. You can purchase quiet appliances and tools. You can wear personal hearing protection to protect your ears when the levels cannot otherwise be lowered. The public, however, needs to be made aware of these options and educated to the fact that their hearing is important and <u>they</u> are responsible for protecting it against noise, particularly levels above 85 dBA.

CONCLUSION

Community noise exposure can result in serious public health problems in addition to feelings of annoyance and frustration. The studies and evidence reviewed in this paper showed that noise can cause health effects in several areas. The noise levels at which these public health effects can begin to occur are summarized in Table X. These levels are based upon the results of the studies cited herein and will certainly be subject to change based on individual sensitivity and other factors previously stated.

Noise acts as a stressor and, as such, can lead to elevated blood pressure. Chronic noise exposure can lead to a permanent elevation in blood pressure which is a risk factor for serious cardiovascular diseases. Those with heredity or current risk for cardiovascular disease are especially prone to adverse stress effects from noise.

Noise can adversely affect the performance of certain tasks. Even if adequate performance is maintained, fatigue and irritation may be an aftereffect. The effects of noise on performance are particularly serious for young children because it hinders their ability to learn reading and language skills.

Noise can affect pregnant women as well who may give birth to babies with low birthweights or birth defects. Noise can also hinder social interactions, particularly people's tendency to help each other. In addition, the annoyance and frustration from constant noise exposure may be a factor in mental or emotional disorders.

Noise can disturb sleep resulting in ill health, decreased performance and possibly difficulty in recovering from sickness. This effect is particularly serious for the elderly and ill.

Important auditory signals can be masked by noise resulting in poor performance, hindered social interaction and enjoyment of leisure time, and accidental injury or death. Exposures to noise in the community, particularly during recreational activities, can also result in a permanent hearing loss.

Other effects were described in the paper as well, but the abovementioned effects are the best documented. These are serious public health problems and are certainly ample justification for the control of community noise. Not only should increased priority and funding be given to noise control programs, but the public should be made aware of the serious consequences of noise exposure in order to protect themselves.

Table X - Summary of the Public Health Effects of Community Noise and the Noise Levels at which They can Occur

Effect	Level
I. Noise as a Stressor	
Increased incidence of high blood pressure that leads to increased risk of cardiovascular disease	85 dBA (long term)
Vasoconstriction begins that can lead to high blood pressure	70 dBA
II. Adverse Effect on Task Performance	
Steady noise	90 dBA
Irregular noise	All levels
III. Prenatal and Childhood Effects	
Increased incidence of low birth weight	70 dBA
High frequency hearing loss in fetuses	85 dBA
Increased blood pressure in children	75 dBA
Decreased reading ability, auditory discrimination or language development	65 dBA (all long term)
IV. Social Behavior and Mental Health	
Decreased helpfulness and social interaction	80 dBA
Increased incidence of mental disorders	90 dBA
V. Sleep Disturbance	35 dBA
VI. Speech Interference	
Less than 5 feet between conversants	65 dBA
5 to 12 feet between conversants	60 dBA
Over 12 feet between conversants	55 dBA
VII. Recreational Hearing Loss	85 dBA (long term)

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