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THE EFFECTS OF NOISE ON PERFORMANCE

Alice H. Suter
Gallaudet University

June 1989
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U. S. ARMY HUMAN ENGINEERING LABORATORY
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The effects of noise on task performance are quite complex, and not as predictable as other noise effects. They are often affected by non-acoustical factors, such as biological and psychological state, as well as external factors such as task complexity and the presence of other stressors. This report describes the rationale and some of the problems inherent in noise and performance research, as well as theories on the mechanisms of effects, and summarizes the various effects.

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Research on noise and vision suggests some effects from high noise levels on thresholds of sensitivity, critical flicker fusion, and visual field shifts. Small but reliable effects have been demonstrated on vestibular function, especially with asymmetric exposures. Motor performance usually adapts with repeated or prolonged exposure, but high noise levels can show persistent decrements. Some startle responses, notably the eye-blink response, do not habituate.

Probably the most important acoustical factor is noise level, with decrements tending to occur above approximately 95 dB. Intermittent noise, especially with aperiodic intermittencies, is more likely to disrupt performance than is continuous noise.

When noise is combined with other stressors it has been found to produce synergistic, antagonistic, additive, or no effects, depending on the nature and magnitude of stressors, and on other environmental conditions. Also, personality factors interact with noise and level of arousal to affect performance in complex ways.

With respect to task variables, noise has little effect on simple tasks, and can even improve performance on monotonous tasks. Tasks requiring continuous performance may be disrupted, especially by noise levels over 100 dB and if the job requires a high level of sustained performance. Intellectual function is not usually affected, but vigilance tasks are susceptible to noise, particularly under certain conditions. Complex tasks requiring more than one activity are much more likely to be disrupted than simple tasks.

Noise can sometimes produce significant aftereffects, one of the most common being a reduced tolerance for frustration. It also appears that noise can increase anxiety levels and the risk of hostile behavior, while decreasing the incidence of helpful behavior.

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Alice H. Suter
Gallaudet University
Washington, DC

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APPROVED: John D. Weisz
JOHN D. WEISZ
Director
Human Engineering Laboratory

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THE EFFECTS OF NOISE ON PERFORMANCE

I. INTRODUCTION

Noise is ubiquitous in military operations. Aircraft, armored vehicles, and most weapon systems routinely generate high levels of noise, and the personnel who work close to these noise sources must continue to perform their jobs effectively, despite the bang, whine, roar, or thunder nearby. Nowadays, there is considerable evidence that noise can disrupt task performance, even when communication is unnecessary or, at least, not problematical. Adverse effects can occur even when personnel are wearing hearing protectors. But there is also evidence that noise sometimes has little or no effect on job performance, and in some cases actually appears to enhance it. The primary purpose of this report is to review and analyze the literature in this area to obtain greater clarity with respect to the types of noise, jobs, and environments that produce specific effects. Special emphasis is given to noise conditions, jobs, and effects that are characteristic of U.S. Army operations. A secondary purpose is to make recommendations for further research in important areas where information gaps still exist.

The effect of noise on task performance is the subject of an enormous literature. Literally hundreds of studies have been conducted, examining the problem from a great variety of approaches. It is beyond the scope of this report to explore thoroughly each one of these approaches. Therefore, the report will provide a broad overview of the problem, citing examples of the relevant research. This process has been aided by a number of fine reviews (Broadbent, 1971, 1979 and 1983; A. Cohen, 1977; S. Cohen and Weinstein, 1981; Glass and Singer, 1972; Gulian, 1973; Jones, 1983; Loeb, 1980; and Loeb, 1986) to which the reader may turn for additional information.

The report will examine one particular area in somewhat greater depth. The effects of noise on sensory and motor function have been selected for a relatively more detailed review because of their obvious relevance to the success of military operations. Other effects, such as effects on cognitive processes and social interaction are also extremely important, and merit scrutiny in subsequent reports. But it appeared that sensory and motor effects would provide a good starting point because any decrements in the ability of military personnel to shoot accurately, drive vehicles, fly planes and helicopters, and exit effectively from noisy conveyances, theoretically could have serious consequences. Performance decrements could potentially result in minor inconveniences, combat disadvantages, mission failures, accidents, injuries, and even loss of life, depending on the nature and magnitude of the decrement and the context in which it occurred.

The effects of noise on performance have generated considerable controversy in the scientific community. Numerous studies have shown significant performance decrements, while many others have shown small effects that are not statistically significant. Other experiments show no effect at all, and quite a few indicate that noise can actually enhance performance. According to D.E. Broadbent, one of the most prolific researchers in this area:

> The topic arouses strong emotions, both from those who assume that any noise will impair any human function and from those who deny that it does anything beyond making it harder to hear. The first group sees any statement that a given function is as efficient in noise as in quiet as an argument for keeping noise levels high and therefore as objectionable; the second group tends to suppose that it is a waste of time to examine the accidents or errors of workers in a factory where there are no complaints. Both these extreme views are false. The effects of noise on performance are definite, but depend very much upon the task which is being performed. (Broadbent, 1979, p. 17-1)

Sometimes an author's approach betrays a bias. For example, Stevens (1972) discusses both noise and "glare" pollution, wondering "...why it is that the so-called disaster lobby, which propounds a message of environmental doom, agitates against noise but seldom against glare." He continues to express skepticism by saying: "...Although I do not like noise and glare, it seems to me that some of their alleged debilitating effects have been grossly exaggerated. Those leading the charge against noise pollution sometimes subject us to another kind of pollution, the pollution of intemperate protest, the pollution of imagined trauma." (Stevens, 1972, p. 36) When the author proceeds to discuss the results of a series of studies conducted by himself and his colleagues, showing little or no effects from high levels of noise, it would not be surprising if he elicited the same kind of skepticism in his readers.

Studies of the effects of noise on performance also seem to be particularly prone to more than one interpretation. The theoretical bases for these effects (or lack of effects) are very complex, subject to controversy, and have evolved considerably over recent years. In addition (or perhaps consequently), some researchers will consider effects that are not statistically significant nonetheless important, while others will cite the same study as showing no effects.

Broadbent (1979) discusses the various problems that characterize these kinds of studies. Industrial studies suffer from the lack of control of other conditions and the tendency for workers' performance to improve with any change in working conditions (the "Hawthorne Effect"). Problems occurring in laboratory studies include intersubject and intrasubject variability due to chance, and variability due to uncontrolled factors, such as fatigue. The control and specification of the noise stimulus differs widely (Broadbent, 1979). As an example of the disparity here, one study refers to a level of 50 dB, generated conveniently by experimental apparatus, as "noise" (Frith, 1967), while another refers to synthetic airplane noise at 90 dB as "quiet" (Stevens, 1972). In addition, descriptions of spectral and temporal characteristics are often omitted, especially in some of the older studies.

Other factors can also contribute to difficulties in interpreting the results of studies on noise and performance. First, there is a multiplicity of tasks, which will be discussed subsequently in greater detail, but also the subject's biological and psychological state can have an effect. Important biological variables include time of day, state of arousal, and perhaps gender (Loeb, et al., 1983; Broadbent, 1983). Psychological variables include motivation, attitude, "neuroticism" index, familiarity with the noise and the task, and coping strategies (Gulian, 1973; Broadbent, 1983).

One other area of complexity is the role of hearing protectors. Quite a few of the studies of high-level noise exposure have employed hearing protectors (e.g., investigations of the Aerospace Medical Research Laboratory). The investigators have assumed attenuations of about 25 to 40 dB (Nixon et al., 1966; Harris and von Gierke, 1971). In interpreting these studies, readers must first be aware that both the noise level and the spectrum will be considerably modified upon arrival at the cochlea. Also, the intersubject variability is likely to be increased because protectors will provide somewhat different amounts of attenuation among different wearers, especially if subjects insert their own earplugs.

Popular opinion holds that we need not be overly concerned about high levels of noise exposure, because nowadays all personnel who work in these environments wear hearing protection (Harris, 1973). This is a dangerous assumption. Simple observation, as well as methodical survey (Walden et al., 1975), reveals that soldiers and other personnel exposed to high noise levels very often do not wear hearing protection. When they do, the fitting and wearing procedures seldom match the effectiveness of those used in the laboratory (Berger, 1986), so that attenuation of 25 to 40 dB would be quite rare. Studies of the field attenuation of hearing protectors indicate that the mean attenuation is nearly one-third of that realized in the laboratory, and the standard deviation is three times larger (Berger, 1983). These facts must be considered when reviewing the research on the effects of noise on performance and attempting to apply it to real life conditions.

There are, therefore, many difficulties in interpreting the literature on noise and performance, and others in applying it to the real world. Despite these difficulties, the sheer quantity of the data, as well as the quality of many of these studies, allows us to draw certain conclusions. As Broadbent and many others have pointed out, there are definite effects of noise on task performance, but the situation is very complex, and the effects depend on a number of variables besides just the presence or absence of noise.

II. MECHANISMS

Some of the early investigations of the effects of high-level noise exposure took place under military auspices in the early 1950s. These studies were published together in what is known as the BENOX Report, short for Biological Effects of Noise Exploratory (Davis, 1953). One of these investigators, A.A. Ward (1953), concluded that high levels of noise stimulate, via the auditory nerve, the brain's reticular activating system, producing a state of wakefulness in the cerebral cortex and generally arousing the nervous system. He noted that "there are rich collaterals to this region [the reticular formation] from the acoustic pathways, and there is presumptive evidence that the labyrinthine component of the eighth nerve plays an even greater role in maintaining the normal activity of this region." (Ward, 1953, p. 74) Preliminary animal experimentation indicated a definite increase in electrical activity in the reticular formation in response to an 880 Hz tone at 137 dB, and in a human subject EEG alpha rhythms changed dramatically at that sound level, although the effects tended to decrease with repeated stimulation. Ward and his colleagues also found an increase in deep tendon reflexes at levels of about 134-136 dB, which Ward suggests could result in muscular weakness. He also suggests that since stimulation of the reticular activating system can precipitate epilepsy, individuals with this condition should avoid exposure to intense noise. (This caveat does not appear elsewhere in the literature cited in this report.)

In his review of the extra-auditory effects of noise, A. Cohen (1977) reaffirms the role of the eighth cranial nerve in stimulating the reticular activating system. Then, from this point, neural impulses "can spread diffusely into higher cortical areas that control alertness, cognition, and coordinated perceptual-motor behavior, i.e. task performance. At the same time the reticular formation can convey impulses to centers of the autonomic nervous system, thus triggering glandular, cardiovascular, gastrointestinal and musculoskeletal changes as part of a generalized somatic response to the excitation." (A. Cohen, 1977, p. 31) Figure 1 displays a suggested model of this mechanism adapted by Cohen (1977) from the work of Grandjean (1969) and Kryter (1970).

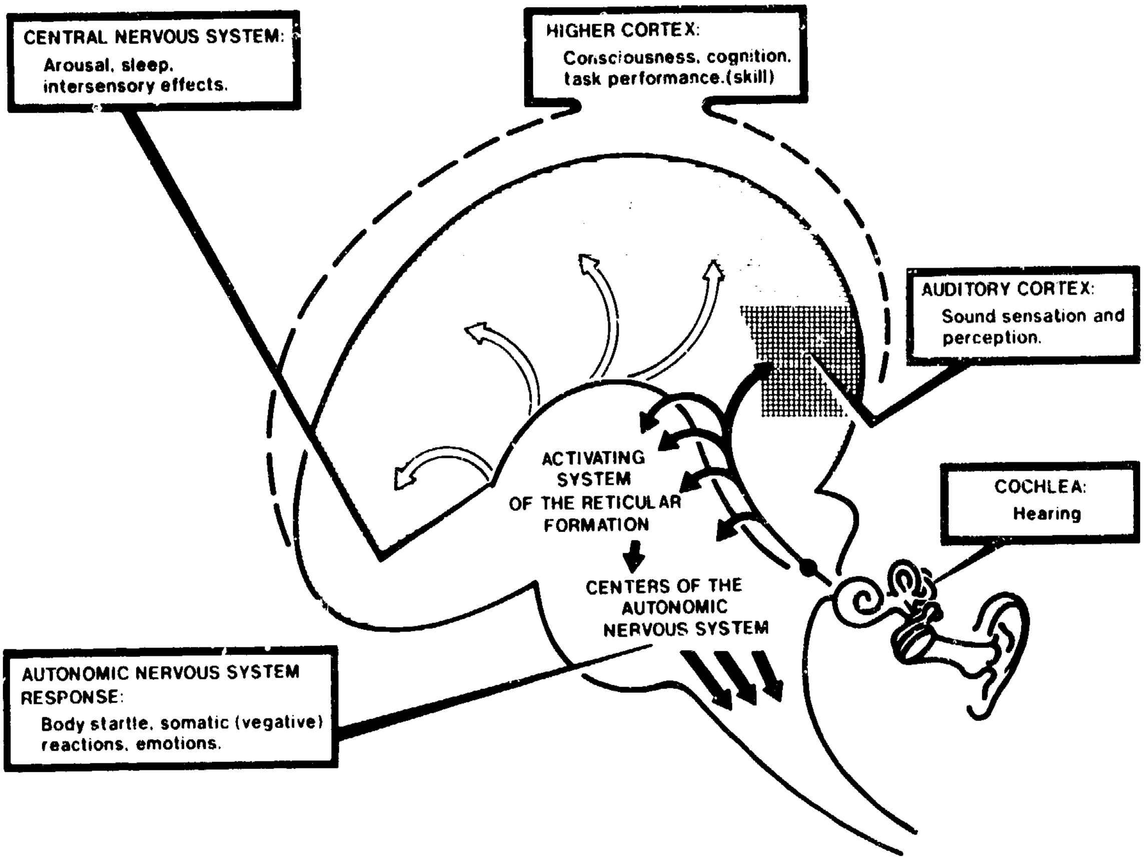

Figure 1. Hypothetical model of the extra-auditory effects of noise.

Note. From "Extraauditory Effects of Acoustic Stimulation" by A. Cohen in D. K. Lee, H. L. Falk, S. D. Murphy, and S. R. Geiger (Eds.) Handbook of Physiology: Reactions to Environmental Agents, Section 9, 1977, Baltimore: Williams and Wilkins. Reprinted by permission. Adapted from Grandjean, 1969 and Kryter, 1970.

III. SENSORY AND MOTOR EFFECTS

Because of the interconnection of neural pathways in the central nervous system, the existence of intersensory and sensori-motor effects from sound stimulation would not be surprising. Studies of this area can be roughly categorized as visual, vestibular, and motor effects. Although many of these effects are small or even insignificant, some would be substantial enough to produce performance decrements in real life conditions.

A good example of some of the more dramatic effects is provided by a series of experiments at Wright-Patterson Air Force Base (Mohr et al., 1965) where subjects listened to very high levels of low-frequency noise and infrasound in the protected or unprotected modes. Two-minute durations as high as 140 to 155 dB produced a range of effects, from mild discomfort to severe pressure sensations, nausea, gagging, and giddiness. Effects also included blurred vision and visual field distortions in some exposure conditions. The nature and degree of all effects was dependent upon both sound level and frequency, with the most severe effects occurring in the audible frequency range (as opposed to infrasound), at levels above about 145 dB. The investigators found no temporary threshold shift (TTS) among their subjects, and the use of hearing protectors greatly alleviated the adverse effects (Mohr et al., 1965).

A. Effects on Vision

Some research has shown that minimum visibility thresholds for light are unaffected by noise levels as high as 140 dB (e.g., Coleman and Krauskopf, 1956 cited in Cohen, 1977). Jones et al. (1977) tested subjects in both impact noise at 135 dB (peak SPL) and continuous noise at 110 dB(A). Although pupil size increased with noise stimulation, visual acuity was not affected. In fact, the continuous noise exposure produced a slight improvement in acuity at first, which then adapted to pre-exposure levels. Pupil size also appeared to adapt with continued exposure.

In a review of some 500 Soviet studies on sensory interactions, London (1954) found a number of studies showing noise-induced decrements in peripheral visual sensitivity. Soviet research tended to show increases in central sensitivity to white light, but differential sensitivity to colored light, depending on the wavelength tested. The author admits that much of the Soviet work "adheres to standards of execution, reportage, and interpretation that would be quite unacceptable to the Western researcher...", but that Western work on sensory interaction has been "scattered and desultory, whereas in the Soviet Union the subject has been given systematic and sustained attention..." (London, 1954, p. 531)

Numerous other studies have supported differential sensitivity to colored light under noise stimulation. Kravkov (1936) found that a 2100-Hz tone at 100 dB improved sensitivity for green-blue light (528 μ) and decreased sensitivity for orange-red (610 μ). Letourneau and Zeidel (1971) replicated Kravkov's earlier work using more subjects and experimental conditions. They used a 1000-Hz tone at 0, 50, 70, and 90 dB (audiometric hearing threshold level), and found that acoustic stimulation lowered the threshold for green and white light, without regard to sound level, and that the threshold for red light was elevated significantly in high sound levels, but not in the lower levels. In a related experiment, Yakovlev (1938) found that in noise conditions, the limits of visual fields change according to color, with green and blue fields expanding, orange-red contracting, and red exhibiting no change. Those experiments may have implications for the perception of red or orange-red signals, and appear to be worthy of further exploration.

Noise exposure may also affect visual discrimination abilities. In his discussion of Soviet research, London (1954) noted two studies showing that noise causes a decrease in differential sensitivity to brightness on an already bright field. Broussard et al., (1952) also found thresholds for brightness discrimination slightly less acute in 90-dB noise levels, and greater response times for faint light differences (cited in Cohen, 1977). Harris (1968) exposed subjects to broadband noise levels of 70 dB (control), 120, 130, and 140 dB SPL. Subjects either wore earplugs in both ears (symmetrical exposure) or plugs in both ears plus a muff over the right ear (asymmetrical exposure). The results of a visual discrimination task showed decrements for asymmetrical exposure, especially at the 130 and 140 dB levels, but not for the symmetrical exposures. The decrements took the form of a greater number of errors, not slower response times.

Another interesting visual research area is the effect of noise on critical flicker fusion (CFF), the frequency at which flickering light appears to be in a steady state. Certain experiments have been cited as showing beneficial effects. For example, Frith (1967) found improvements with "noise" exposure, presumably due to increases in the subjects' state of arousal. Subjects categorized as extroverts showed more improvement than those classified as introverts. A closer look at the experimental procedures reveals that the "noise" was, in fact, an ambient room level of about 50 dB SPL, and "quiet" was produced by hearing protectors with an estimated attenuation of 30 dB. While the 50-dB level might be considered "sound", it could hardly be considered "noise".

Other studies indicate varying effects of noise on CFF. London (1954) reports Soviet research as showing that CFF for green light is reduced, while CFF for orange-red light is raised. Few details of experimental procedures are given. A study by Maier et al., (1961) gave almost opposite results, with noise reducing the CFF for orange-red stimuli, increasing the CFF for blue stimuli, and producing no change for green flashes. The effect was "small and complex" (changes of 2% to 4%). "Noise" stimuli consisted of pure tones at relatively low levels: 40 and 80 phons, which, once again, should be considered sound rather than noise.

The fact that some investigations of noise and vision have produced beneficial effects while others have produced decrements may not be so mysterious. London (1954) refers to the "Rule of Inversion" where stimuli of weak intensity produce one result, while the same stimuli when strong, produce the opposite result. He quotes Kravkov as saying that this effect does not always occur, but Letourneau (1972) also offers it as a possible explanation, noting many examples of it in the literature on sensory effects.

McCroskey (1957) studied CFFs of 10 to 62 Hz (presumably for white light) in 40 subjects during exposure to white noise at 94 dB SPL. Subjects showed significantly lower CFF during noise exposure, with no adaptation apparent. In a follow-up experiment, McCroskey (1958) examined the effects of several noise levels and longer exposures on CFF in 72 subjects, divided into groups of 9. White noise levels from 85 to 115 dB SPL produced significantly lower CFFs than during the quiet condition, regardless of the noise level. Longer durations (approximately 19 minutes) produced additional decrements at the 85 and 115-dB exposure levels, but not at the two interim levels of 95 and 105 dB. The author is unable to explain the differential effects. He suggests that these decrements may be problematical when individuals must make careful judgements among visual stimuli (McCroskey, 1957 and 1958).

Other effects of noise on vision have been cited in the literature. In their investigations, S.S. Stevens and his colleagues included the effects of high levels of noise on vision (Stevens, 1972). They found a slight, but not statistically significant decrement in visual accommodation (near to far and far to near). Because the same effects occurred when subjects used earplugs, they concluded that the mechanism was other than auditory. However, because subjects were exposed to continuous levels of noise at 115 dB, it is possible that the attenuation of hearing protectors was not sufficient to create a "non-noise" condition. The investigators found a decrement in speed of eye movement in one out of four subjects, but again the effect was not statistically significant. Also, the threshold for dark adaptation was slightly, but not significantly, higher in intense noise (Stevens, 1972). The fact that these investigators used a very small and select subject population (an N of only 4 or 5), and a "quiet" level of 90 dB, is likely to have had considerable influence on tests of statistical significance.

One of the most interesting and well researched areas is the effects of noise on visual field perception. According to Ades (1953), some of the early BENOX investigators found a slight, apparent shift of visual field usually toward, but in one instance away from, the exposed ear when the opposite ear was occluded with an earplug. This occurred for 1000- to 1500-Hz sound stimuli at a level of about 135 dB. Benko (1962) reported a concentric narrowing of the visual field resulting from exposures of 110 to 124 dB, and Chandler (1961) found that vertical lines were perceived to be tilted away from the primary source of sound stimulation when the sound level differed for the two ears (both studies cited in A. Cohen, 1977).

Parker and his colleagues performed a series of experiments on the effects of audible sound and infrasound on animals and humans (Parker et al., 1968, 1976, 1978, 1980). The investigators noted that other researchers had found shifts in visual field resulting from very high sound levels, namely 142 to 169 dB (Reschke et al., 1975, cited in Parker et al., 1976). Rapid-onset tone bursts had produced lateral shifts of visual field, and slow-onset bursts produced a tilting or rotation effect. Apparently, the 800- to 900-Hz range produced the maximum response (Reschke et al., 1975). Parker et al. (1976) found apparent shifts in visual field in approximately half of their subjects as a result of acoustic stimulation at much lower levels--120 to 125 dB. They found that the 500- to 800-Hz region resulted in the largest response, and that slow signal repetition rates (1/sec) produced the greatest perception of motion.

In a follow-up investigation, Parker and co-workers studied visual field shifts in 133 subjects as a function of stimulus frequency, repetition rate, and onset/offset time (Parker et al., 1978). Tone bursts at 100, 200, 500, 1000, 2000, and 5000 Hz were presented in six stimulus trains, ten bursts in each train, at a sound level held constant at 125 dB. The stimulus was varied according to repetition rate, 0.5/sec to 4.8/sec, and onset/offset time 0.2 to 25 ms. Subjects were asked to observe a black cross on a white background, and to report any changes. Those who reported target motion as a result of stimulation at more than one sound frequency were asked to estimate the amount of motion on subsequent trials. Of the 46 subjects that participated in experiment I (frequency varied and other factors held constant), 65% reported visual field shifts with one or more of the six stimulus trains. Subjects reported that..."the target appeared to jump a few millimeters laterally and then return to the initial position." (Parker et al., 1978, p. 1915) As expected, significantly more positive responses resulted from the 500 and 1000-Hz frequencies than from the other frequencies tested. Experiment II, where repetition rate was varied, showed the greatest effect at a relatively slow repetition rate (0.9/sec), but experiment III, where onset/offset time was varied, showed an erratic response pattern. No TTS in hearing level was observed. The authors concluded that visual field shifts from acoustical transients are real phenomena, and that people regularly exposed to high-intensity sound may suffer such dysfunctions with or without concomitant loss in hearing sensitivity.

In a subsequent study, Parker et al. (1980) investigated the contribution of other variables to visual field displacements. Among those variables studied were angular acceleration, exposure to an actual rotating visual field, head vibration, target illumination intensity, and alcohol consumption. From the results, the investigators concluded that manipulations that increase subjects' ability to maintain visual fixation will increase the apparent shift in visual field, while disruption of visual fixation (for example, by alcohol) will reduce the visual field shift. They also found that vibration tended to reduce the effect, which they presume to be due to the activation of the acoustic reflex.

B. Vestibular Effects

Since the early days of jet engine testing and maintenance, anecdotal evidence has appeared linking exposure to intense noise, with such complaints as dizziness, vertigo, nausea, and vomiting, among others (Ades, 1953). Dickson and Chadwick (1951) report that an engineer exposed to jet engine noise said he experienced "...a momentary sensation of imbalance accompanied by a lack of power to think..." (cited in Harris and von Gierke, 1971). Some of the early BENOX researchers reported equilibrium effects resulting from brief exposures to high noise levels when one ear was occluded with an earplug (Ades, 1953). As a result of siren noise at 140 dB, subjects consistently reported a feeling of being pushed sideways, usually away from the exposed ear, and one subject reported difficulty standing on one foot. These effects, however, were not as dramatic from jet engine (broadband) noise at 140 dB. Ades (1953) concludes that the threshold of labyrinthine dysfunction is about 135 to 140 dB and that these effects occur during, but not after, exposure. "We have not the faintest hint of any which could be classed as chronic." (Ades, 1953, p. 69)

Because the end organs for acoustic and vestibular perception are so closely related, it is not surprising that intense acoustic stimulation can result in vestibular effects. Parker et al. (1976) discuss the mechanism by which these effects might occur. They hypothesize that sound of normal intensity produces ac oscillations of endolymph and perilymph, compensated by oscillations of the round window. High intensity sound produces eddy currents, which are localized rotational fluid displacements (von Bekesy, 1935). High intensity sound can also produce nonlinear displacement of the stapes, causing a dc volume displacement, the result of which can be a fluid void in the labyrinth. To fill the void, fluid may be displaced along the endolymphatic duct and/or blood capillary pathways, which, in turn, could stimulate vestibular receptors. Figure 2 (from Parker et al., 1976, after von Bekesy, 1935) portrays a model of the labyrinth, indicating release points for fluid displacement resulting from the inward movement of the stapes. The authors conclude that both eddy currents and dc volume displacements serve to stimulate vestibular receptors in humans, when exposed to high levels of noise.

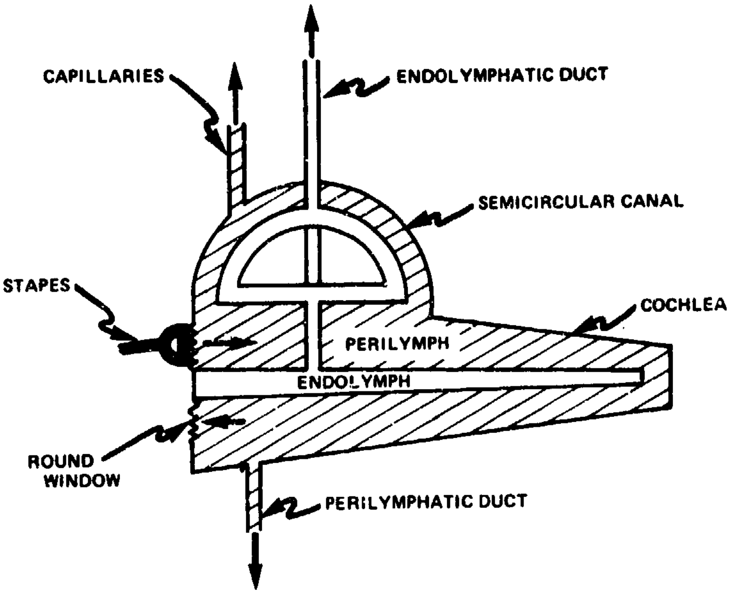

Figure 2. Model of the labyrinth, indicating release points for fluid displacement resulting from the inward movement of the stapes.

Note. From Effects of Sound on the Vestibular System (AMRL-TR-76-89), by D. E. Parker, L. A. Ritz, R. L. Tubbs, and D. L. Wood, 1976, U.S. Air Force. Reprinted by permission.

One of the most salient vestibular effects is nystagmus, an involuntary turning or jerking motion of the eyeball, due to vestibular disease or stimulation. Some of the earlier experiments on the vestibular effects of noise used nystagmus as an indicator of vestibular involvement. Parker et al. (1968) found nystagmus in guinea pigs exposed to high levels of infrasound. The fact that eighth nerve section eliminated these responses whereas cochlear destruction did not, led the investigators to conclude that acoustical stimulation did indeed activate vestibular receptors. Harris (1972), however, was unable to produce nystagmus in human subjects at high exposure levels. His conditions included 5-sec and 10-sec exposures to a pure tone at 135 dB, broadband engine noise at 140 dB, and a 100-Hz tone at 120 dB, pulsed three times/sec for two minutes. Even subjects with a history of motion sickness produced no negative results (Harris, 1972).

Harris and others at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, performed a series of investigations into the vestibular effects of high levels of infrasound and audible sound. They had been particularly interested in the claims of certain British researchers that infrasound could cause serious performance decrements. According to Harris et al. (1976), studies by Evans et al. (1971), and Evans and Tempest (1972) found vertical nystagmus resulting from exposure to a 7-Hz stimulus at 130 to 142 dB. In reviewing these studies, Harris and his colleagues describe them as fraught with methodological and reporting deficiencies, faulty logic, and insufficient control for artifacts, etc. The authors were unable to elicit nystagmus at levels up to 155 dB in the laboratory at Wright-Patterson Air Force Base (Harris at al., 1976).

Parker and his team were also unable to replicate the effects found by the British researchers using infrasound levels of 112 to 150 dB in guinea pigs, monkeys, and humans (Parker et al., 1976). They suggested, however, that the results of Evans and Tempest might be due to audible components in the sound spectrum, and research with guinea pigs and monkeys confirmed this suspicion. Figure 3, from Parker et al. (1976) summarizes the thresholds found to evoke rotary nystagmus in guinea pigs and monkeys, with data for humans included for comparison. (The human data, from Ades et al., 1957 and 1958; and von Bekesy, 1935, include other vestibular effects in addition to nystagmus.)

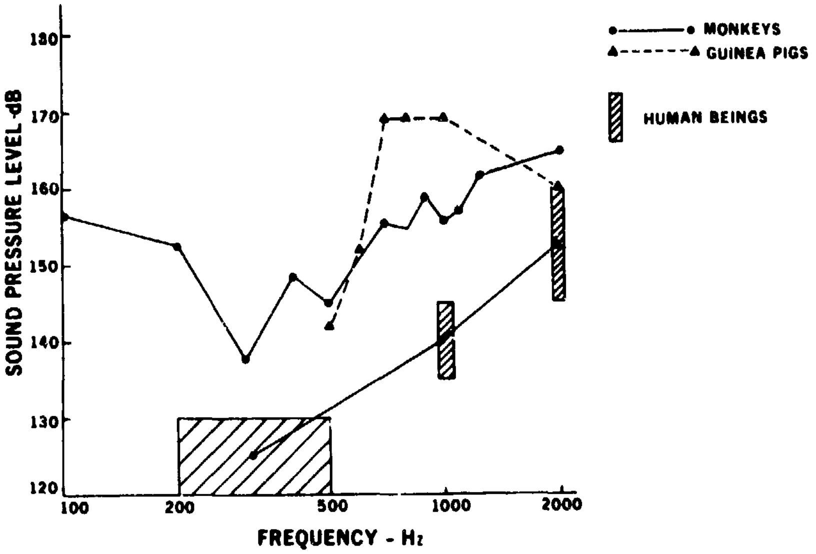

Figure 3. Thresholds evoking rotary nystagmus in guinea pigs and monkeys. Human data, including other vestibular effects, are shown for comparison.

Note. From Effects of Sound on the Vestibular System (AMRL-TR-76-89) by D. E. Parker, L. A. Ritz, R. L. Tubbs, and D. L. Wood, 1976, U.S. Air Force. Reprinted by permission.

In a somewhat different approach to the investigation of vestibular effects, Nixon et al. (1966) discovered a task that was sensitive to sound stimulation. This task was then used in a series of experiments in the laboratory at Wright-Patterson Air Force Base. First developed by Graybiel and Fregley (1963), the Rail Task had proved to be a good test for identifying labyrinthine disorders. Nixon, Harris, and their colleagues used 8-foot rails of differing widths and tested subjects' abilities to stand with eyes open, or closed, and to walk. They found that the only condition showing a significant effect from noise exposure was the standing, eyes-open position on the 1.5 inch rail, particularly when one ear received greater acoustic stimulation than the other (Nixon _et al_., 1966). Figure 4, from Harris (1973) shows a subject performing on the Rail Task.

Figure 4. Subject performing on the Rail Task.

Note. From "The Effects of Different Types of Acoustic Stimulation on Performance" by C. S. Harris in W. D. Ward (Ed.) _Proceedings of the International Congress on Noise as a Public Health Problem_ (EPA 550/9-73-008), 1973, U.S. Environmental Protection Agency. Reprinted by permission.

An asymmetrical condition, consisting of earplugs in both ears, with the addition of an ear muff over one ear, produced an estimated 80-dB sound level in one ear and a 100-dB level in the other beneath the protectors. This condition resulted in a mean change of 8% in the amount of time subjects could balance on the rail, with respect to the control condition. The symmetrical condition, where the estimated sound level was 80 dB in both ears, produced a slight decrement, but the change was not statistically significant. The authors point out that the estimated exposure levels are quite innocuous from the standpoint of audition (Nixon et al., 1966), but their attenuation estimates may have been somewhat optimistic.

In the next experiment, Harris and von Gierke (1971) tested the ability of 52 subjects to balance on various rail widths, eyes open and eyes closed, in sound field exposures to broadband noise at levels of 120, 130, and 140 dB. Sound levels under the protectors were assumed to be attenuated approximately 25 dB for plugs alone, and 39 dB for plugs and muffs. The results once again showed greater decrements in the eyes-open than in the eyes-closed condition, which the authors suggest may be indicative of interaction between the vestibular and visual systems. In the eyes-open position, significant differences were found between the 140-dB condition and all other conditions. Surprisingly, the 130 and 120-dB symmetrical conditions (plugs in both ears or plugs and muffs occluding both ears) showed systematic improvements over the control condition, although the differences were not statistically significant. In the asymmetrical condition (plugs in both ears plus a muff over one), subjects showed significant performance decrements in two of the three noise conditions. The investigators also measured performance on the rails after termination of noise exposure and found that, consistent with the simultaneous effects, noise exposure tended to improve subsequent performance when the exposure had been symmetrical, but to degrade it when the exposure had been asymmetrical (Harris and von Gierke, 1971).

A follow-up experiment was conducted by Harris and Sommer (1968) to determine the sound frequency most likely to produce decrements on the Rail Task. Also, to eliminate the uncertainty in sound exposure level caused by the use of ear protectors, the investigators presented the stimuli through earphones. Forty-eight subjects listened to pure tone stimuli of 100, 260, 590, 1500, and 2500 Hz at 95 dB in both ears or 75 dB in one ear and 95 dB in the other, while balancing on rails of various widths. The results showed a small but non-significant decrement at 590 Hz, and a significant decrement at 1500 Hz in the eyes-open, asymmetrical condition.

In another study of the effects of sound on equilibrium, Sommer and Harris (1970) used somewhat higher sound levels, again presented through earphones. This time they used broadband, predominantly low-frequency noise to simulate the spectrum imposed by hearing protectors. Overall sound pressure levels were approximately 115 dB to simulate plugs alone, and 100 dB to simulate plugs and muffs. Results on the Rail Task showed significant differences between both the symmetrical and the asymmetrical conditions and the control condition at both noise levels. However, the decrements were not as great as with actual plugs and muffs, worn in higher environmental sound levels (cf. Harris and von Gierke, 1971). Because of this, the authors conclude that extra-auditory stimulation, presumably through bone conduction, is the cause of the greater effects at higher sound levels. Moreover, they believe that stimulation through bone conduction is not a simple additive factor. If it had been additive, stimulation through earphones should have reduced the decrements proportionally for symmetrical and asymmetrical exposures, which did not occur. Another plausible explanation for the differences in the degree of effect would be that the actual attenuation of the hearing protectors was considerably less than that which was estimated.

C. Motor Effects

In an extensive study of the human startle pattern, Landis and Hunt (1939) describe the typical response to a sudden loud sound, such as a .22 caliber revolver: immediate closing of the eyes, followed by a forward motion of the head and neck, hunching of the shoulders, bending of the elbows and knees, contraction of the abdomen, and a forward motion of the trunk. The motion is symmetrical, uninfluenced by postural changes, and rapid, in that it may come and go within 1/2 second. Not all features of the response appear in all individuals, but the eyeblink invariably occurs. The eyeblink's mean latency is about 40 msec and duration about 15 msec. Landis and Hunt found that habituation occurred when the stimulus was repeated at intervals of about 1 to 2 minutes, that it was very rapid in some individuals, slow in others, and nonexistent in some. The eyeblink, however, never habituated, and head movement rarely did. They also found that knowledge of the stimulus can sometimes reduce the level of the response, and increasing the intensity of the stimulus will often increase response magnitude. When the authors studied trained marksmen (N.Y. police officers), they found responses that were only mild or moderate in magnitude, but all subjects exhibited eyeblink and head movements, and most showed mild facial distortion (Landis and Hunt, 1939).

In a more recent experiment, May and Rice (1971) studied the startle effects of a .22 caliber pistol fired through a silencer, resulting in a peak sound pressure level of 124 dB. The investigators found performance decrements in a pursuit rotor task for about two seconds after each shot, after which performance returned to control levels. Repeated exposures improved performance, but scores did not adapt completely over the 16 presentations (a total of 100 minutes).

Harris (1970a and 1970b) also investigated the effects of noise-induced startle on a pursuit rotor tracking task. He notes an observation by Thackray (1965) that some individuals recover cognitive-motor functioning rapidly, while others react sluggishly, even appearing to "freeze". Harris (1970a) exposed 20 subjects to B-duration impulses at a peak sound pressure level of 112 dB, while they were engaged in a pursuit rotor task. He found small decrements for the first few stimuli with respect to control trials, but subjects adapted both within and between sessions. To see if subjects would regain sensitivity after a considerable time interval, Harris (1970b) retested 6 of the original 10 subjects after intervals of 5 to 8 months. The results were not significantly different from the last day of the previous experiment, indicating no return of any noise-induced performance decrements.

Davis and Van Liere (1949) approached the issue of noise-induced startle by studying the effects on muscle tension. They suggested two response modes: the a-response, an initial response, which returns to normal within 1.5 second, and a b-response, a smaller tension increment with a latency of 1.0 to 1.8 sec, lasting at least 7.5 seconds. In response to .32 caliber blanks, subjects' muscle tension did indeed continue for about 7 seconds after stimulation, but adaptation occurred in that the b-response duration was shorter in later trials. A-response duration also decreased over repeated trials, but response magnitude did not.

With respect to continuous noise exposure, Stevens (1972) found no systematic relation between noise and degree of muscle tension, although he reports that some subjects did show more tension in broadband noise (115 dB) than in "quiet" (broadband noise at 90 dB).

In a slightly different measure of noise-induced muscular effects, Miles (1953) assessed four subjects' ability to squeeze hand dynamometers in a background of jet engine noise at 128 to 135 dB (although subjects wore earplugs). He found that right-hand performance increased by 2%, left-hand performance decreased by 10%, and total output (both hands) decreased by 2%.

Investigations of the effects of noise on manual dexterity have yielded what appear at first glance to be conflicting results, but these apparent conflicts may well be due to differences in noise exposure level. For example, Miles (1953) gives the results of high levels of jet noise as they affected a two-handed coordination task. Eight subjects, wearing hearing protectors, performed the task while exposed to jet noise of about 130 dB. Scores in noise were 6 to 8% lower than they were in quiet, indicating that subjects needed somewhat more time to perform the same task in noise, even though they showed a tendency to "make haste under the psychological stimulus of intense noise..." (Miles, 1953, p. 92)

In somewhat lower noise levels, on the other hand, Weinstein and MacKenzie (1966) found that white noise at 100 dB improved manual dexterity. Subjects were able to turn over a significantly greater number of blocks in the Minnesota Rate of Manipulation Test.

Harris (1968) included a test of manual dexterity along with visual discrimination in the experiment mentioned earlier. He found that the manual dexterity task was somewhat more sensitive to acoustic stimulation than was visual discrimination. Subjects needed significantly more time to manipulate nuts and bolts when they were exposed to the two higher noise levels (130 and 140 dB wearing ear protectors), than in levels of 120 dB and below. Surprisingly, there was no significant difference between responses in the symmetrical and asymmetrical conditions, which would have been expected, given the results on the visual discrimination and rail tests. The author suggests that the manual dexterity task was not sufficiently complex to bring out these differences (Harris, 1968).

Sommer and Harris (1970) included the same nuts-and-bolts manual dexterity task in their study of the effects on equilibrium of broadband noise at 100 and 115 dB, presented through earphones. Noise exposure produced small decrements (1% to 3% longer than in the control condition), but none of the differences approached statistical significance. Once again, however, the difference between this experiment and its predecessor might be explained by the likelihood that the actual sound level beneath the hearing protectors was somewhat higher than the investigator had estimated in the previous experiment by Harris (1968).

D. Summary of Sensory and Motor Effects

There do appear to be some effects of noise on vision, but these effects are too difficult to assess because vital information on the parameters of noise exposure are so often lacking. Some experiments show no effects, while others show differential effects, depending on such factors as the light wavelength, and the kind of visual effect studied. Noise exposure appears to increase sensitivity for green-blue light and decrease sensitivity for orange-red. Visual discrimination can be decreased by noise, especially with asymmetrical exposure. Studies of CFF suggest decrements for white light, but produce conflicting results for colored light. Perhaps the strongest evidence comes from studies of visual field effects, indicating shifts in visual field perception due to noise levels below those originally producing effects in the BENOX experiments. Sound levels of 120 to 125 dB can produce visual field shifts, and it appears that the greatest effect is for tones of 500 to 1000 Hz, with relatively slow repetition rates (0.9 to 1/second).

Noise also produces reliable effects on vestibular function in certain circumstances. Nystagmus, which is a good indicator of vestibular involvement, has been induced by noise in experimental animals, but the evidence in humans is conflicting. The Rail Task does show reliable effects on vestibular function, but only in certain conditions: eyes-open, 1.5-inch rail, and most often under asymmetrical stimulation (plugs in one ear, plugs and muff in the other). Decrements occur consistently for broadband noise levels of 140 dB (with hearing protection), while decrements in the asymmetrical condition can occur at lower levels. Effects are not as great when noise levels of 100 to 115 dB are presented over earphones (simulating the higher levels experienced with ear protectors), but these differences may be due to overestimating the attenuation achieved by hearing protectors in the higher noise levels.

There is also evidence pointing toward noise-induced motor effects. Impulsive or other sudden, loud sounds can produce a startle response, consisting of a complex of motor responses. Most of these responses habituate, but it appears that the eye-blink never does, and some amount of head movement rarely habituates. Some research shows brief, but persistent decrements in motor performance after exposure to impulse noise, but other studies provide evidence that motor performance adapts with continued stimulation. Muscle tension, however, appears not to adapt completely. Investigations of the manner in which noise affects manual dexterity yield inconsistent findings, but these inconsistencies are probably due to differences in noise level. It appears that levels up to about 115 dB have little or no effect, with levels of around 100 dB actually improving performance on simple tasks. Levels of 130 and 140 dB, even with subjects wearing hearing protection, do show decrements in manual dexterity tasks.

IV. NOISE VARIABLES

Despite the tendency not to quantify or report parameters of noise exposure, such as spectrum, duration, and sometimes even level, certain trends have become evident. As one would expect, high-level exposures are more disruptive than low-level exposures, which can sometimes actually facilitate task performance. High-frequency stimuli tend to be more disruptive than low-frequency noise and infrasound. Intermittent and impulsive noise usually have greater adverse effects than continuous noise especially when the noise bursts are aperiodic and/or unfamiliar.

A. Sound Level

As we have seen from the discussion of sensory and motor effects above, high-level sound stimuli (above about 120 dB) almost invariably produce greater performance decrements than sounds of lower intensity. The BENOX experiments, using high levels of jet engine noise, provide some examples of these effects (Ades, 1953; Miles, 1953), as do the studies at Wright-Patterson Air Force Base which employed the highest noise levels (e.g., Mohr, et al., 1965; Harris and von Gierke, 1971; Parker et al., 1978). These effects occurred, in many instances, even though subjects wore hearing protection. Therefore, they could be expected to be more pronounced in the unprotected condition.

Performance decrements due to high sound levels are not, of course, limited to sensory and motor effects. For example, Miles (1953) found that jet noise of 130-135 dB for durations of about 6 minutes, caused slight decrements in a block assembly test, which involved memory and learning, as well as motor skills.

Broadbent (1957) conducted a study where various levels of noise, filtered in either a high-pass or low-pass condition, were presented to subjects as they performed a five-choice serial reaction task (cited in Broadbent, 1979). Decrements occurred at the highest sound level (100 dB), and were significant for the high-frequency band. In another experiment, Grimaldi (1958) studied the ability to perform a tracking task and to respond quickly to a visual stimulus. Subjects were tested in various frequency bands of intermittent noise with levels of 70 to 100 dB. Exposure periods consisted of 10 to 23 seconds of noise, interspersed with 2 to 13 seconds of quiet, totaling 30 minutes. Significant increases in errors and response times appeared in noise levels at 90 dB and above, and for the higher frequency bands, especially the 2400-4800 Hz band.

On the other hand, quite a few experiments have shown no effects or even improvements in noise levels above 90 to 100 dB (e.g., Allen et al., 1975; Stevens, 1972). For example, the series of studies previously cited by Stevens (1972) failed to find significant performance effects for broadband noise at levels as high as 115 dB, with durations as long as 7 hours. Another study by Poulton and Edwards (1974), found improvements in low-frequency noise at C-weighted sound levels of 102 dB (which, however, Broadbent estimates to be an A-weighted level of only 85 dB--see Broadbent, 1979, p. 17-14). The explanation for these differences appears to lie mainly with task difficulty, although many other factors enter in, such as spectral and temporal characteristics, and other variables that will be discussed further in subsequent sections. Despite these confounding variables, and as a result of many years of research and study, Broadbent (1971 and 1979) has concluded that 95 dB is the level, at and above which performance decrements are likely to occur as a result of exposure to continuous noise, and that levels below 95 dB are likely to produce no effect or even beneficial effects. In a more recent summary, Broadbent (1983) points to studies showing that levels as low as 80 to 90 dB may be disruptive of task performance if the task is sufficiently sensitive (c.f. Jones, 1983 cited in Broadbent, 1983).

B. Spectrum

Studies described above have indicated that high-frequency noise is more disruptive than low-frequency noise of comparable levels (Broadbent, 1957; Grimaldi, 1958). In fact, as mentioned, low-frequency sound can even have a beneficial effect (Poulton and Edwards, 1974). Evidently this is also true of infrasound, where levels of continuous noise as high as 150 dB have failed to produce significant sensory or motor effects (Mohr, et al., 1965). In another experiment, Harris and Johnson (1978) measured the effects of low-frequency noise and infrasound on cognitive performance, consisting of a serial search task and a complex counting task. The four noise conditions included broadband low-frequency noise at 110 dB, a 7-Hz infrasonic tone at several intensity levels from 125 to 142 dB, low-frequency noise combined with infrasound, and an ambient condition. Durations were 7.5 minutes per trial. The only significant effect that resulted was improvement due to a learning effect. The authors conclude that infrasonic levels above 150 dB may be necessary to produce decrements in cognitive performance (Harris and Johnson, 1978).

In a recent study, Landstrom (1988) assessed "wakefulness" based on EEG recordings, in response to exposure to infrasound. He found decreased levels of wakefulness from infrasound near perceptual threshold levels at 6 and 16 Hz but not at 12 Hz. In a follow-up field investigation he tested drivers exposed to greater or lesser amounts of infrasound in their trucks. Once again, he found lower wakefulness indices in the drivers exposed to higher levels of infrasound, especially after about 6 hours of driving. Landstrom suggests that moderate levels of infrasound may promote fatigue in working environments, and recommends further investigation of this potential problem.

C. Temporal Characteristics

1. Continuous Noise

Continuous noise appears to have little effect on simple tasks, even in relatively high sound levels. Stevens (1972) reports no significant effects on a reaction time task and a fast-speed pursuit rotor task administered during 7-hour durations of broadband noise at 115 dB. Allen et al. (1975) found that performance on a simulated pitch/roll tracking task improved 10 to 15% as a function of noise level, with broadband noise of 75, 95, and 115 dB presented through earphones. In a post-exposure assessment of subjective response, subjects reported that the noise seemed to focus their attention on the task, which, according to the authors, acted to reduce erratic behavior and facilitate performance (Allen et al., 1975).

For more complex tasks, however, such as Broadbent's five-choice serial reaction task (Broadbent, 1957), and a complex tracking task used by Eschenbrenner (1971), performance appears to deteriorate in high noise levels. Broadbent summarizes a number of studies showing that the effect of continuous noise on tasks involving a rapid sequence of actions is to produce greater numbers of errors and occasional slow responses, without decrements in overall response rate. These effects increase markedly in exposure levels above 95 dB, and often occur toward the end of a work period (Broadbent, 1979). Broadbent points out that simple memory tasks are not adversely effected by continuous noise, but some deterioration may occur if the demand on memory is continuous (Broadbent, 1979).

2. Intermittent Noise

Intermittent noise appears to be more disruptive than continuous noise, especially when the intermittencies are unpredictable. Gulian (1973) states that there is less adaptation with intermittent noise and a greater decline in performance over time. The study cited above by Eschenbrenner (1971) showed a significant effect for temporal pattern, with regularly intermittent noise somewhat more disruptive than continuous noise, and aperiodic intermittent noise significantly more disruptive than either of the other conditions. Broadbent (1979), however, cites studies by Teichner et al. (1963) and Warner and Heimstra (1971) as showing that intermittent noise with a 30% on-time, can actually improve performance on a search task, at least for familiar sounds and tasks. Jones (1983) notes that intermittent noise can act as a distractor early in an experiment, but later in the task the same noise can act as an arouser and improve performance.

Shoenberger and Harris (1965) note that other researchers have found that changes in the noise stimulus may be at least as important as absolute levels. They cite Teichner _et al_. (1963) as finding that shifts to lower noise levels produced decrements at least as large as shifts to higher levels on short-term memory and reaction time tasks. The results appeared as a deceleration in the rate of improvement due to learning. In their experiment, Shoenberger and Harris alternated noise levels of 65, 85, 95, and 110 dB for the first 30 minutes and final 15 minutes of trials, during which subjects performed a psychomotor task. The results gave moderate support for the findings of Teichner _et al_. (1963), particularly in the 85 dB to 110 dB condition, but the investigators concluded that the effect would probably be less important in well learned tasks (Shoenberger and Harris, 1965).

Broadbent (1979) also states that novel or unusual noise can cause a temporary decline in performance efficiency, but that these effects are minimized when individuals adapt, both to the noise and to the task. The theory is that a person reacting to an unfamiliar sequence of events is "heavily loaded", and performs additional tasks with difficulty. Practice at the task and familiarity with the noise will reduce the load and enable the individual to perform as before. Only if the sequence of events is truly random, would performance continue to be vulnerable. Broadbent believes that "...most industrial and military situations involve tasks which are, to some extent, practiced and noises which are to a large extent familiar. Thus the situation of the strange task and the strange noise is of only doubtful practical importance and little experimental interest..." (Broadbent, 1979).

3. Impulse Noise

The discussion of noise-induced startle response in previous paragraphs leads clearly to the conclusion that impulse noise can disrupt task performance, at least for a limited period of time. Once again, simple tasks, and self-paced performance may not be affected at all, especially after some amount of adaptation has occurred, but more complex tasks and tasks requiring continuous performance are likely to be more vulnerable. Gulian (1973) reports that the evidence on sonic boom effects is not so consistent, with some studies showing performance decrements, others showing non-significant effects, and still others indicating performance improvements.

D. Summary of Noise Variables

Noise level is, of course, an important variable, with performance decrements generally beginning to occur at levels above about 95 dB. Such decrements are dependent upon numerous other variables, particularly upon the complexity of the task. Simple tasks remain unaffected at noise levels as high as 115 dB or above, even for relatively long durations, while it appears that very sensitive tasks can be affected by noise levels as low as 80 to 90 dB. High-frequency sound is more disruptive than low-frequency sound. Infrasound apparently can be tolerated up to levels of about 150 dB without adverse effects, at least for short durations, but long-duration exposures may produce fatigue effects.

Temporal characteristics make a difference in the effects of noise on performance. Continuous noise has little effect on simple tasks, even at levels exceeding 115 dB (as stated above), and with more complex tasks, generally shows its effects toward the end of the work period. Intermittent noise can be considerably more disruptive, especially if the task or noise is unfamiliar. Aperiodic intermittencies are more likely to produce adverse effects than regular ones, and changes in the noise stimulus may be as important as absolute level. Again the effects are variable, depending on task complexity and other factors. It also appears that adverse effects here are mitigated by familiarity and practice. Impulse noise can be additionally disruptive because it produces a startle response, but these adverse effects can also be expected to habituate, to a large extent.

V. NOISE AND OTHER AGENTS

Different stressors affect performance differently. According to Broadbent (1971), heat generally produces performance decrements at temperatures above about 80-85 degrees F (26.7 degrees to 29.4 degrees C). Heat stress interacts with an individual's existing state of arousal, and may produce performance increments or decrements, depending on an individual's existing state. Sleep loss can also have differential effects, depending upon the type of sleep lost, i.e., whether it is REM or non-REM sleep (Broadbent, 1971). Broadbent (1971) states that sleep loss generally affects vigilance and serial reaction tasks by causing an increase in slow reactions or pauses during which there is no reaction. He maintains that the effect of heat stress is to cause a greater number of errors, mainly at the beginning of the session, and noise causes a greater number of errors primarily late in the session. When stressors are experienced in combination, the resulting situation can be quite complex. The effects may be additive, antagonistic, synergistic, or there may be no effects at all. The outcome will depend on the nature and magnitude of the stressors, the type and degree of difficulty of the task, the individual's state of arousal, and the mechanism through which the stressors act to degrade performance.

A. Sleep Loss

Broadbent (1979) reports that the five-choice serial reaction test is adversely affected by sleep loss. Although the same task is also degraded by noise (Broadbent, 1957), noise reduces the adverse effects of sleep loss when the two are combined (Wilkinson, 1963). Similarly, Loeb (1980) describes a study by Hartley and Shirley (1977) showing that sleep loss reduces adverse effects caused by noise. It appears that sleep loss lowers the subjects' level of arousal, but noise acts to raise it again.

B. Gender and Circadian Rhytnm

In an investigation of the effects of noise on mental arithmetic, Loeb et al. (1982) found no effect from broadband noise at 95 dB(A). When the data were analyzed according to time of day and gender, however, men showed significant noise-related decrements in the morning, and women did slightly (but not significantly) more poorly in the afternoon. Loeb (1986) cites information from Quinkert and Baker (1984) supporting differences in circadian cycles between men and women. Loeb also refers to research by Baker et al. (1984), exploring these interactions further, who found that in quiet, women performed better in the morning, and men did better in the afternoon. The introduction of noise reversed this pattern, enhancing men's performance in the morning and degrading it in the afternoon, while enhancing women's performance in the afternoon and degrading it slightly in the morning. The results of these two studies (Loeb et al., 1982 and Baker et al., 1984) are not consistent in the direction of effect, although they both show significant interactions between noise, time of day, and gender. The differences may be related to differences between tasks or between measures of performance. The findings of Baker et al. (1984) for male subjects are consistent with those of Sommer and Harris (1972) for noise plus vibration (see following section on vibration).

C. Incentives

The use of incentives, such as rewards, knowledge of one's performance results, or even punishment, usually acts to improve task performance, presumably by raising the level of arousal. Broadbent (1971) reports that incentive serves to improve performance that has been degraded by heat stress. He also points out that high levels of incentive can actually produce greater errors on a serial reaction task, just as noise does. He believes that noise and incentive reinforce each other, and that they seem to operate under the same mechanism. For example, an experiment by Wilkinson (1963) showed that noise slightly improved performance in a situation where no incentive was present. When incentive was introduced, in the form of knowledge of performance results, scores improved considerably, but the addition of noise reduced the otherwise strong improvement. Figure 5, from Broadbent (1971) (after Wilkinson (1963)), displays these results. Here, noise alone acts to raise the level of arousal and improve performance. In the motivated state, noise raises the arousal level still further, resulting in overarousal, and consequently degrades performance.

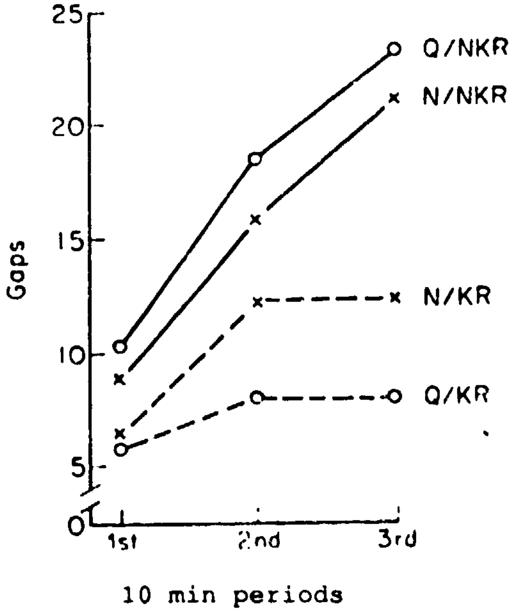

Figure 5. Gaps in performance as a function of task duration, noise condition, and incentive. Parameters are noise (N) or quiet (Q), and knowledge of results (KR) or no knowledge of results (NKR).

Note. From Decision and Stress by D. E. Broadbent, 1971, London and New York: Academic Press. Reprinted by permission.

The noise and incentives interaction, however, does not always produce such clear-cut results. In an experiment by Manninen (1985), noise degraded a choice reaction-time task, but incentive served to improve it beyond the scores produced in the control condition. In this experiment the two agents appear to have an opposing effect.

Tafalla _et al_. (1988) hypothesized that incentive serves to override the negative effects of noise on performance, but does so at a physiological cost. Subjects were exposed to a composite of traffic, office, and unintelligible speech noise at 90 dB(A) in a randomly intermittent pattern, and a control condition of ambient noise at 45 dB(A). During exposure they were engaged in a mental arithmetic task that was scored both on the basis of speed and accuracy. Subjects were instructed to use maximum effort (for which they could also win $50 for the best performance), or "one-half effort". Results showed, as predicted, that noise had no effect on performance during maximum effort. In the low-effort mode noise adversely affected speed but enhanced accuracy. While this enhancement was not expected by Tafalla _et al_., it is consistent with the enhancement effects noted by other investigators, especially at low levels of arousal (see discussion of Task Variables, Section IV). Interestingly, Tafalla and his colleagues found that both systolic and diastolic blood pressure increased significantly in the high-noise, high-effort condition, supporting their notion that noise interacts with incentive to produce unimpaired performance but at a physiological cost.

These kinds of results point out the difficulties inherent in interpreting a multitude of other studies, where the degree to which incentives influence the results may be impossible to judge.

D. Heat

Hancock and Pierce (1985), in their extensive review of the combined effects of noise and heat on task performance, comment that investigators have found synergistic, additive, antagonistic, and negligible effects. The nature of the effect depends on the type of task, the time of exposure, and the onset order and severity of the stressors. Table I, from Hancock and Pierce (1985), summarizes most of the research on the combined effects of noise and heat. The authors conclude from this information that the majority of the evidence points toward a relative insensitivity resulting from the combination, and that the two stressors appear to act independently. They point out that many of the studies suffer from methodological errors, in that they lack precise specification of the stressors (a familiar complaint), and they tend to examine only acute effects. According to Hancock and Pierce, decrements are more likely when deep body temperature is affected, which would occur only during relatively long exposures. This is in contrast to Broadbent's opinion that decrements from heat stress occur early in the session (Broadbent, 1971). The authors believe that a "conservative course of action would be to regard these stressors as slightly synergistic in combined effect and to act accordingly." (Hancock and Pierce, 1985)

In one experiment not cited by Hancock and Pierce, Manninen (1985) tested the effects of noise, vibration, heat, and incentive, both singly and in various combinations. Reaction time on a choice reaction task showed decrements for both heat and noise alone, and somewhat greater decrements for the combination, but the effect was not completely additive. Interestingly, heat had a significantly beneficial effect when it was added to vibration.

TABLE I
Summary of Studies on Combined Heat and Noise Effects

Study	Heat Level (°C)	Noise Level (dB)	Exposure Time (min)	Specific Tasks	Combined Effect
Viteles and Smith	22.8[B] 26.7 30.6	72[C] 80 90	240	Mental multiplication Number checking Lathe test Type coding Discrimeter Location test Pursuit test	No consistent interactions. Suggested interaction only for the lathe test. Potential example of synergy.
Pepler	20.3[A] 37.8	Barely[C] intelligible voice	20	Pursuit tracking task	No interaction or addition effects observed.
Bell, Provins and Hioms	29.5[A] 63.0	85-95[C] Simulated	Varied by subject	Visual monitoring	Lack of a noise control precludes precise interaction assessment.
Arees	11.9[B] 19.2 31.7	One-minute[C] bursts at 100dB at 30/45 min into task.	60	Visual monitoring	No effect for either heat, noise or combination on mean detection efficiency.
Dean and McGlothen	21.1[A] 26.7 32.2 37.8 43.3	70[C] 110	30	Radar/meter monitoring ten other performance tasks.	No main effects. No interactive effects.
Bell	22[A] 29 35	Random bursts[D] of 1-9s duration at 1-9s intervals 55 95	33	Primary task-pursuit tracking Secondary task-response time	No main or interactional effects for primary task. Suggestion of addivity for secondary task decrement.
Renshaw	22.2[B] 25.6 28.9 32.2	41[D] 80 90 100	90	Five-choice serial reaction task	Indication of synergy for measure of response gaps.
Grether *et al.*	20[B] 31	80[C] 105	60 35	Tracking Choice reaction time Voice communication Mental arithmetic Visual acuity	Presence of vibration prevented discrete effects of heat and noise being distinguished.
Grether *et al.*	21[B] 31	80[C] 105	60 35	As above with a telephone test substituted for voice communication	Combined heat and noise effects not distinguished separately.
Bowman and von Beckh	24[A] 51	66[D] 85	60	Tracking Response time	Presence of acceleration buffett and low light obscured heat and noise effects.
Loeb and Jeantheau	52[A]	125[C]	225	Visual monitoring	Heat, noise and vibration in combination, no distinguishable effect of heat and noise alone.
Poulton and Edwards	19.0[B] 34.4	80[E] 102	90	Tracking Visual monitoring	Some statistical indications of both synergy and antagonism. Possible artifact of methodological approach.
Wyon *et al.*	22[A] 30	50[D] 65	30	Serial choice response Visual vigilance task	Some indications of synergy and antagonism in selected groups but small number of subjects per cell in study.

[A] Dry bulb temperature
[B] Effective temperature
[C] Noise scale not reported
[D] dB (A)
[E] dB (C)

<u>Note</u>. From "Combined Effects of Heat and Noise on Human Performance: A Review" by P. A. Hancock and J. O. Pierce, 1985, <u>American Industrial Hygiene Association Journal</u>, <u>46</u>, pp. 555-566. Reprinted with permission by American Industrial Hygiene Association Journal.

E. Vibration

In a series of experiments at Wright-Patterson Air Force Base, Harris and his colleagues investigated the combined effects of noise and vibration on task performance. Harris and Shoenberger (1970) found, not unexpectedly, that vibration alone (0.25 g at 5 Hz) produced decrements in both the horizontal and vertical dimensions of a tracking task, and also in a reaction time task. Noise alone (broadband at 110 dB) caused decrements on only the vertical dimension of the tracking task, and a small, statistically insignificant effect on the reaction time task. The effect of noise plus vibration on the tracking task was additive, with no effect for the combination on the reaction time task. To avoid the mechanical effects of vibration, Harris and Sommer (1971) tested essentially the same conditions on a mental arithmetic task. Neither noise nor vibration produced adverse effects alone, nor did vibration plus noise at 80 or 90 dB. However, vibration combined with noise at 110 dB produced significant decrements.

Grether *et al*. (1971) used broadband noise at 105 dB, and vibration of 0.3 g at 5 Hz, along with heat at 120 degrees F to test subjects' responses on the two-dimensional tracking task and the mental arithmetic tasks, as well as a choice reaction task. Noise alone showed no significant effects except on the reaction time task. Combined stressors showed no significant effects over any of the individual stressors. In fact, the tracking task was less affected by the combinations than by the single stressors.

Because of the evidence that circadian rhythm affects task performance, Sommer and Harris (1972) tested the effects of the original vibration and noise combination (0.25 g at 5 Hz and 110 dB) on mental arithmetic at 6 a.m. and 3 p.m. They found the expected improvements at 3 p.m. (over 6 a.m.) in the no-stress condition, and a slight decrement for the noise plus vibration condition, relative to the no-stress condition at 3 p.m. The interaction between time of day and stress (noise plus vibration) led these authors (like Loeb and his colleagues) to conclude that circadian rhythm may affect these kinds of experiments.

In an attempt to investigate the effects of slightly lower levels of noise and vibration, Sommer and Harris (1973) used the same two-dimensional tracking task, with vibration of 0.10 g at 6 Hz, and broadband noise at 100 dB in somewhat longer sessions. Noise alone produced no significant effects, while vibration produced adverse effects in both dimensions. In combination, noise actually reduced the adverse effects of vibration. When Harris and Sommer (1973) raised the noise level back to 110 dB, the combined effect was additive once again.

Finally, Harris and Shoenberger (1980) changed the parameters to noise at 100 dB(A), vibration to 0.36 RMS g (complex rather than sinusoidal vibration, which is more typical of actual operations), and an experimenter paced cognitive task (the Complex Counting Task). The results showed significant decrements each by noise and vibration alone. The combination produced performance that was slightly poorer than the control condition, but the differences did not reach statistical significance. Surprisingly, the combined stressors produced less effect than either stressor alone. An experiment by Manninen (1986) also found no significant effect from noise plus complex vibration, but did show some increase in effect (body sway) from noise in combination with sinusoidal vibration.

F. Psychological Factors

There are certain psychological variables that interact with noise exposure to affect job performance. Like incentives, they are usually uncontrolled, and their effects will not be readily apparent.

Some investigators have categorized their subjects as introverts and extroverts to investigate personality variables in combination with noise. Broadbent (1971) mentions research in which noise improved performance of extroverts early in the morning but not later in the day, while introverts showed no effects. He also cites an experiment by Davies and Hockey (1966), showing that noise improves vigilance performance of subjects classified as extroverts under certain conditions. These experiments support the theory that extroverts operate at chronically lower arousal levels than introverts, and noise raises their arousal levels (especially in the morning), enhancing task performance. Broadbent's (1971) own research, however, indicated that the correlation between noise effects and introversion/extroversion was unstable, and complicated by another personality dimension, neuroticism.

Another confounding variable, whose effects are often unknown or overlooked, is the psychological "set" created by the instructions given to the subjects. Mech (1953) investigated this problem by presenting four groups of subjects with four slightly different sets of instructions. Group A, the control group, was told that the experiment concerned the effects of noise on work. Group B was told the same, along with the suggestion that previous subjects had performed better in noise. To Group C it was suggested that previous subjects had done better in quiet, and to Group D it was suggested that previous subjects had performed more poorly in noise at first, after which they had adapted and performed better in noise. Subjects performed mental arithmetic while listening to "verbal" noise (competing message) at a level of 70 dB, over an eight-day period. The results, displayed in Figure 6, showed a statistically significant difference in performance among the four groups, with each group performing according to its pre-experimental set.

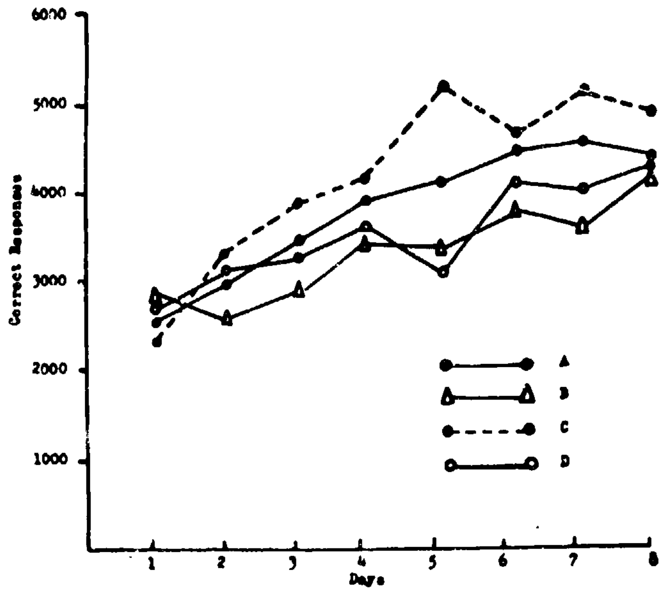

Figure 6. Performance on a mental arithmetic task while listening to "verbal" noise, as a function of days over which the task was presented. Parameter is pre-experimental "set."

Group A:	Control
Group B:	Instructed that previous subjects performed better in noise
Group C:	Instructed that previous subjects performed worse in noise
Group D:	Instructed that previous subjects had performed worse in noise at first, then adapted and performed better

<u>Note</u>. Adapted from "Performance in a Verbal Addition Task Related to Pre-Experimental 'Set' and Verbal Noise" by E. V. Mech, 1953, <u>Journal of Experimental Education</u>, <u>22</u>, pp. 1-17. Reprinted by permission.

A more recent experiment by Gawron (1982) failed to replicate Mech's results. Subjects who were told that noise facilitated performance did indeed have their best performance on a digit canceling task in the highest noise levels, but subjects who were told that noise hinders performance showed no significant decrements. Also, there was no significant facilitation in this group for the two other tasks evaluated. The author mentions that psychological set did interact with task complexity as well as noise level, but gives no details about this interaction. Probably the most salient reason for the differences between these two experiments lies in the duration: Gawron's experiment consisted of a series of six 4-minute trials, presumably over a single day while Mech's subjects worked a total of four hours, spread over an 8-day period. Only after the first day did the differences in Mech's groups become apparent.

In these experiments the suggestions were quite overt, and the influence was intentional. In most investigations of noise and performance, one would assume that the instructions are standardized, and carefully constructed so as to avoid this kind of bias. However, to the extent that the experimenter's prejudice might be intuited by eager subjects (who are usually students or young military volunteers), the experimental results will be influenced to an unknown degree.

G. Summary of Combined Stressors

One thing is quite clear from the above discussion, and that is that the combined effects of noise and other stressors are extremely complex. The direction and degree of effect depend on many factors: an individual's state of arousal, including gender; circadian rhythm; the nature of the task; the magnitude and duration of the stressors; and personality and other psychological factors. They also depend on whether the stressors operate under similar or antagonistic mechanisms, although it is not always clear what the various mechanisms are.

Noise and sleep deprivation appear to act in opposite directions, although it is conceivable that certain conditions of sleep deprivation (e.g., loss of REM sleep) can result in overarousal. Both noise and incentive appear to act as arousers. Incentive usually improves performance, but the addition of noise reduces these gains. Because incentive (or the lack thereof) is present to some extent in virtually every experiment, it is very difficult to know the extent to which it influences the effects of noise alone. The evidence on noise combined with heat is mixed: some synergisms, some antagonisms, and sometimes no effects. Most of the exposures are acute, however, so longer exposures deserve some caution. The series of experiments at Wright-Patterson studying the combination of noise and vibration showed no effects or even subtractive effects in moderately high levels, up to 105 dB. Above that level the effects appear to be additive, at least when noise is combined with sinusoidal vibration, which produces greater decrements (in combination with noise) than complex vibration.

Personality factors may also combine with noise exposure to affect noise in complex ways. These factors appear to interact with level of arousal, or at least with changes in level of arousal. Psychological "set" may influence an individual's expectations of noise effects, thereby either enhancing or degrading performance.

VI. TASK VARIABLES

A. Simple Tasks

As we have pointed out above, simple tasks are not adversely affected by noise, even at relatively high sound levels. Broadbent (1971) suggests that the reason why many of the early experiments on noise and performance showed no effects was because they used tasks in which information was handled at fairly low rates; crucial information was predictable and interspersed with periods of no information. In other words, these tasks were not sensitive to momentary disruptions of information intake, as vigilance or serial reaction tasks would be (Broadbent, 1971). Simple clerical and intellectual operations rarely show impairments from noise at sound levels between 80 and 100 dB, and sometimes as high as 140 dB (Broadbent, 1979). Reaction time remains unimpaired so long as the signal is predictable (Broadbent, 1979), and as we have demonstrated, most sensory and motor performance is unaffected up to fairly high levels of noise.

B. Tasks Requiring Continuous Performance

On the other hand, tasks involving continuous performance appear to be more vulnerable. Broadbent (1979) observes that noise produces a focusing of behavior, with greater concentration on the task. When attention is diverted, especially by intermittent (or impulsive) noise, momentary inefficiencies will occur. The end result is increased variability in performance, even though average performance may not change. In other words, noise will produce momentary lapses, for which subjects will compensate later in the task by improved or more rapid performance. Broadbent (1979) gives several examples of such cases: In a clerical task involving the cancellation of digits, intermittent noise up to about 90 dB caused variations in performance at different times in the test, with no overall performance decrement (Sanders, 1961). In a serial reaction experiment, subjects showed no difference in average performance, but reaction times were considerably slower after bursts of intermittent noise (Fisher, 1972). Another continuous task involving decisions about a series of visual stimuli was disrupted by bursts of noise at 95 dB (but not at 85 dB), causing performance decrements for 20 to 30 seconds after the noise burst (Woodhead, 1959 and 1964).

Broadbent (1979) points out that some tasks of continuous performance may be more vulnerable than others. For instance, a tracking task such as driving on a straight road will be relatively insensitive to intermittent disruptions. Rapid driving on a difficult course, however, where every lapse could have serious consequences, would be a different matter. In some tracking experiments, subjects have actually shown improved performance during noise exposure. A good example is the tracking experiment mentioned previously by Allen _et al_. (1975), where subjects reported that noise had enabled them to focus their attention on the task. Other, more complex, tracking tasks, however, have shown decrements (e.g., Eschenbrenner, 1971).

Harris and Filson (1971) tested subjects with a cognitive test of continuous performance, a serial search task. They noted that Broadbent had emphasized certain conditions as necessary to produce adverse effects: The test durations should be a minimum of 30 to 60 minutes; the task should be experimenter paced, requiring the subjects' continual attention; and the noise level should be 100 dB or above. To test these parameters, Harris and Filson exposed subjects to broadband noise at 105 dB for 36-min. durations daily over a period of 5 days. One group's exposure was interrupted with 3 rest periods, while the other group's exposure was continuous. The results showed significant performance decrements for the no-rest group, especially toward the end of the experimental period, indicating that the subjects did not adapt to the noise stress. These findings show that continuous performance can be disrupted by noise, if certain conditions are present.

C. Intellectual Function

As mentioned earlier, simple intellectual and clerical tasks are not usually degraded by noise, even up to very high noise levels. In his review of the effects of noise on intellectual function, Loeb (1980) cites some studies showing differential effects of noise on memory and mental arithmetic. It appears that sound levels of 80 to 90 dB can actually improve primary memory, for example, of stimulus content or order of items, while impairing incidental memory, such as stimulus location (Hockey and Hamilton, 1970; Davies and Jones, 1975). Noise at 85 dB was found to improve visual memory of recent items, but degraded memory for less recent ones (Hamilton, et al. 1977). Loeb also cites studies showing that noise can impair auditory memory (Rabbitt, 1966; Murdock, 1967), but one has to consider the possible effects of masking, especially spread-of-masking effects at high sound levels. One experiment avoided potential stimulus masking by presenting the stimuli visually and attempting to restrict subjects' internal auditory or proprioceptive feedback by presenting white noise at 100 dB through earphones and by clamping the subject's tongue or requiring him to hold his breath. Such feedback restrictions appeared to impair short-term memory, and the combined effects of internal auditory and proprioceptive restrictions were additive (Adams et al., 1969, cited in Loeb, 1980). Although there are obvious discomforts (and possibly distractions) inherent in holding one's breath and having one's tongue clamped, there is additional evidence that noise may adversely affect the internal speech necessary for short-term memory (Wilding and Mohindra, 1983).

With respect to mental arithmetic, Loeb (1980) reports that short-term memory can be affected, but the results are complex. For example, in one experiment (Park and Payne, 1963), noise produced no overall decrement, but increased performance variability (as in tasks requiring continuous performance, described above). In another, noise degraded performance only during the presentation of a number to be memorized, but actually improved performance when it was presented during the calculation period (Woodhead, 1964).

There is evidence that noise is disruptive to complex intellectual functioning. For example, Harris and Shoenberger (1980) showed that noise at 100 dB(A) could disrupt a short-term memory task which was sufficiently difficult. This experimenter-paced task required subjects to keep simultaneous count of the number of flashes of lights located in three positions.

D. Vigilance

There is good agreement that noise can adversely affect vigilance, which requires in individuals "...a readiness to respond to infrequent, low-intensity signals occurring at unpredictable temporal intervals." (Buckner and McGrath, 1963, p. vii) McGrath (1963) points out that many vital military missions require vigilant observers, and that our national security is dependent upon the efficiency of missile detection and early-warning systems.

Broadbent (1971) states that the chances of detecting a stimulus during a vigilance task depend on the probability of the stimulus, an individual subject's state of arousal, and any change in responsiveness when the watch continues for a long period of time. If for some reason an individual's internal criteria for reporting a signal should change, the outcome in terms of performance efficiency can also change (Broadbent, 1971). Noise can effect such changes.

Hockey (1970a) summarized the evidence to date on the effects of noise on vigilance. These findings are reprinted in Table II. In general, Hockey concluded that the most important variable was task complexity: that multi-source tasks or tasks with high signal rates resulted in decrements, and that single-source tasks or tasks with low signal rates showed improvements or no effects from noise exposure. Hockey's experiments (1970a and b) demonstrated the complexity of the manner in which noise affects vigilance performance. The primary task was a pursuit-tracking task in the center of the visual field, and subjects were instructed of this fact. The secondary task consisted of monitoring 6 lights spaced around the window housing the tracking exercise. Broadband noise at 70 dB ("quiet") and at 100 dB was presented in two 10-min. segments for each condition, and again after a one-week interval. Subjects' performance on the primary (tracking) task improved slightly over time in the noise condition, although it did not improve in the quiet condition. Performance on the secondary (vigilance) task improved for the centrally located lights, but was significantly degraded for those coming from the peripheral sources. The author concluded that noise produces a shift in the distribution of efficiency over various components of the task (Hockey, 1970a). In a subsequent experiment, Hockey found that the difference in ability to detect central and peripheral signals was not so much a question of location, as it was the subjects' perception of the probability of stimulus occurrence (Hockey, 1970b).

Broadbent (1979) discusses many of the important parameters concerning noise and vigilance. He points out that moderate levels of noise and music can improve the performance of vigilance tasks, citing McGrath (1963) and Davies et al. (1973). Subjects categorized as introverts show no improvement in noise levels of 95 dB, whereas those categorized as extroverts do (Davies and Hockey, 1966). Noise tends to reduce the number of responses when subjects are unsure (Broadbent and Gregory, 1963 and 1965), and increases the number of "confident" detections (Hockey, 1973). Broadbent (1979) also points out that the effects of noise depend on task complexity. For example, there was no effect on vigilance in white noise at 100 dB when the dials to be observed were easy to see. When they were more difficult to see, however, noise at 100 dB caused decrements (Broadbent, 1954). Broadbent summarizes by stating that noise will adversely affect vigilance if (1) the level is above 95 dB, (2) the length of the watch is long, (3) the signal may come from a number of sources, (4) the situation does not encourage caution, and (5) the signal is difficult to see (Broadbent, 1979).

E. Complex Tasks

By now it should be evident that complex tasks are considerably more vulnerable to noise exposure than simple ones. Gulian (1973) points out several ways in which tasks can be made more complex. Investigators can multiply the sources of stimuli, such as dials or lights to be monitored; increase the intrinsic difficulty of the task; make the temporal requirements more stringent; or give the subject simultaneous tasks.

TABLE II

Effects of noise in vigilance tasks: the importance of signal rate and number of sources on the direction of the effect

	Author(s)	No. of sources	Signal rate (per hour)	Noise conditions	Effect on performance
(1)	Broadbent (1951)	20	10	100 vs. 70 dB	decrement
(2)	Broadbent (1954)	20	10	100 vs. 70 dB	decrement
(3)	Broadbent and Gregory (1963)	3	72	100 vs. 75 dB	decrement
(4)	Jerison (1959)	3	82	112 vs. 79 dB	decrement
(5)	Broadbent and Gregory (1965)	3	200	100 vs. 75 dB	decrement
(6)	McGrath (1963)	1	72†	72 dB (varied vs. steady)	decrement
(7)	Broadbent and Gregory (1965)	1	200	100 vs. 75 dB	decrement
(8)	Kirk and Hecht (1963)	1	30	65 dB (varied vs. steady)	increment
(9)	Jerison (1957)	1	30	114 vs. 83 dB	none
(10)	McGrath (1960)	1	24†	72 dB (varied vs. steady)	increment
(11)	Broadbent and Gregory (1965)	1	70	100 vs. 75 dB	none
(12)	Davies and Hockey (1966)	1	24	95 vs. 65 dB	increment
(13)	Davies and Hockey (1966)	1	48	95 vs. 65 dB	none
(14)	Tarrière and Wisner (1962)	1	16	90 vs. 35 dB	increment

All tasks using more than one source (nos. 1 to 5) are impaired by noise. In the two single-source tasks which show impairment (6 and 7) the signal rate was manipulated within the experiment. A higher rate gives impaired performance and the lower rate either no effect (11) or improvement (10). This trend is also evident in 12 and 13, where increasing the signal rate cancels out the facilitatory effect of noise.

†Event rate was varied in these experiments, from one stimulus every 0-66 sec. to one every 2 sec.

Note. From "Effect of loud noise on attentional selectivity" by G. R. J. Hockey, 1970, *Quarterly Journal of Experimental Psychology*, *22*, pp. 28-36. Reprinted by permission.

An example of an intrinsically difficult task is the tracking task used by Eschenbrenner (1971). Subjects viewed simulated earth movements as if they were orbiting over the earth's surface, and used a hand control to compensate for perceived motion. White noise at 50, 70, and 90 dB was administered during each 40-sec. trial for 20 trials in each session. Temporal patterns were continuous, and intermittent with a 2-sec. on-time, in which they were presented in both periodic and aperiodic patterns. Somewhat surprisingly, all noise patterns produced significant performance decrements, although the aperiodic pattern produced significantly poorer performance than the continuous or periodically intermittent noise. The author concludes that "...Manual image motion compensation is a complex psychomotor task that requires continuous processing of sensory information and is, therefore, extremely susceptible to the distracting effects of noise." (Eschenbrenner, 1971, p. 62)

Most of the complex tasks used to assess the effects of noise have been dual or combined tasks. For example, Broadbent (1979) describes experiments involving intentional and incidental memory. When subjects are instructed to remember words, their performance improves in noise, but when asked unexpectedly to recall the location of the words, their performance deteriorates (Hockey and Hamilton, 1970; Davies and Jones, 1975).

As explained above, experiments by Hockey (1970a and b) used as a primary task a pursuit-tracking task, and a vigilance secondary task, with the result that performance on the secondary task was degraded by noise when subjects perceived signals in the periphery as being less probable. In another experiment involving dual tasks, Finkleman and Glass (1970) presented subjects with broadband noise at 80 dB(A) in predictable and unpredictable intermittency patterns. They found performance on a primary tracking task to be unaffected for either noise pattern, and that significant decrements for a secondary digit recall task occurred only in the unpredictable condition. Glass and Singer (1972) interpret these results as showing that noise must be especially aversive to degrade task performance.

Loeb and Jones (1948) extended Hockey's (1970a and b) studies by performing two experiments with tracking as the primary task and vigilance as the secondary task, and two with vigilance primary and tracking secondary. Each task had either a "bias", with the probability of the vigilance stimulus toward the location of the high priority task, or "no bias", meaning equal probability of the stimuli. The investigators state that there were no "appreciable" effects of noise on the vigilance task, regardless of task priority, but they present no data to support this finding. The authors state that their results were not in agreement with those of Hockey. However, noise did significantly degrade the tracking task in both the bias and no-bias conditions. According to Loeb (1980), this task was more difficult than the tracking task employed by Hockey, which may help explain the differences on tracking performance.

Loeb (1980) reports other experiments that were stimulated by Hockey's original studies (1970a and b). One by Forster and Grierson (1978), which found no effects, used conditions similar to Hockey's, except that the noise level was 91 dB instead of 100 dB, and the tracking task was more difficult. Another by Finkleman <u>et al</u>. (1977) showed decrements on both a primary tracking task and a secondary digit recall task, resulting from noise at 93 dB(A).

F. Summary of Task Variables

Noise exposure usually has no adverse effects on simple routine tasks, where information is handled at low rates, crucial information is predictable, and constant attention is not required. In fact, noise can even improve the performance of monotonous tasks, presumably by elevating one's level of arousal. Tasks requiring continuous performance, such as tracking tasks, may be momentarily disrupted by noise, but subjects usually can compensate by improved or more rapid performance, leaving average performance unchanged. If the task is sufficiently demanding, these momentary lapses can adversely affect overall performance, especially if noise levels exceed 100 dB, and performance continues for more than 30 minutes.

Intellectual function, such as short-term memory and mathematical calculation, can also be momentarily disrupted without decrements in overall performance. When these tasks become more complex, noise is more likely to affect them. For example, incidental memory is likely to be impaired while primary memory is unaffected. The mechanism may involve the interference by noise with internal auditory and proprioceptive feedback.

Vigilance performance appears to be more easily disrupted by noise exposure. Although moderate levels of noise once again may improve performance, especially if the signal originates from a single source, higher exposure levels are likely to degrade performance. Performance is more readily degraded by noise when the signal emanates from numerous sources, cautious behavior is not encouraged (i.e., signal probability is high), and the duration of the watch or experiment is long.

Task complexity has been identified in numerous instances as being a crucial determinant of the effects of noise on performance. Decrements occur either because the task is inherently demanding or because an individual must perform two or more tasks simultaneously. Performance on the primary task usually remains unaffected, or even improves, while performance on the subsidiary task deteriorates. As above, the nature and degree of effect depend on noise level, the inherent difficulty of the task, and the subject's perception of signal probability. Also, the temporal pattern of the noise appears to be important, with unpredictable noise bursts being more disruptive than predictable ones.

VII. AFTEREFFECTS

While most researchers have looked at noise and its concomitant effects on task performance, a few have examined the aftereffects, with some interesting results. Probably the classic study in this area was conducted by Glass and Singer (1972). The noise stimulus was a sound-on-sound recording of two people speaking Spanish and another speaking Armenian, mixed with the sounds of various office machines. The result was broadband noise of approximately 150 to 7000 Hz, with the mode at 700 Hz. Presentation levels were "loud" at 108 dB(A) and "soft" at 56 dB, presented in a fixed intermittent pattern of 9-second bursts, once per minute for 23-25 minutes, and in a pattern where burst and interval durations varied randomly (while maintaining equivalent sound energy). Exposure conditions were, therefore, loud periodic, loud aperiodic, soft periodic, soft aperiodic, and no noise. Subjects performed simple cognitive tasks during the noise exposure periods, and afterward were given four puzzles, two of which were insoluble (a measure of tolerance for frustration), and subsequently a proofreading task. The authors considered these tasks relatively simple.

Resulting performance on the insoluble puzzles showed significant decrements for the average number of trials for the 108 dB(A) vs. the 56 dB(A) noise conditions. Subjects also showed poorer performance after the aperiodic noise than after the periodic noise, and, in fact, the deficits following the soft aperiodic condition were greater than those following the loud periodic condition. The proofreading task showed no differences in the number of lines read for either the periodic or aperiodic noise conditions, but there were significantly more errors following the aperiodic noise condition. Errors also increased following the loud noise as opposed to the soft noise conditions, but the difference did not reach statistical significance.

Glass and Singer (1972) performed another experiment to explore the predictability concept further. This time they preceded the 108 dB(A) aperiodic noise burst with a signal light in one condition, presented noise and an uncorrelated light in another, and noise without light in a third condition. The results showed that predictability made a significant difference in frustration tolerance, but not in proofreading accuracy. Although the authors were unable to explain the lack of effect on the proofreading task, they concluded that in general, the principal effect of noise on task performance is caused by the absence of predictability, and that this effect is greater after than during the noise exposure, in the absence of "task overload". They hypothesize that individuals may manage to control their "affective reactions" until the noise ceases, at which time it is no longer necessary to maintain maximum performance. They also conclude that perceived control over the noise is the crucial factor, determining the difference in effect between predictable and unpredictable noise bursts.

Loeb (1980) reports that the research by Glass and Singer (1972) has stimulated other similar investigations. For example, Percival and Loeb (1980) replicated the Glass and Singer experiment with the same tasks and general design, using a tape of the earlier investigators' complex noise stimulus with the same intermittency schedules. This time the peak A-weighted sound levels were 95 dB in the fixed and random schedule noise conditions, with a continuous level of 46 dB(A) in the control condition. Percival and Loeb found no significant effects during the simple tasks performed during exposure. Once again, subjects made significantly fewer attempts to solve insoluble puzzles after noise exposure, and the effect was greater after the unpredictable than after the predictable noise bursts. No effect was evident for the proofreading task. According to Loeb (1980), other researchers also have been unable to replicate the proofreading effect (Wohlwill et al., 1976; Moran and Loeb, 1977), but studies by Wohlwill et al. (1976) and Rotton et al. (1978) did replicate the effect on insoluble puzzles. Loeb notes that when the noise stimulus was meaningful speech, the effect was greater than when it consisted of noise without speech. Consequently, he suggests that the meaning of the noise (speech sounds vs. non-speech sounds) may be responsible for the difference (Loeb, 1980).

In an attempt to probe the particular characteristics of noise that produce behavioral aftereffects, Percival and Loeb (1980) repeated their experiment using four types of intermittent noise: (1) normal aircraft flyovers, (2) combinations of aircraft flyovers that had been acoustically modified to produce sudden onsets and offsets as well as randomly fluctuating peaks, (3) white nose with sudden and unpredictable onset and offset, and (4) original Glass and Singer noise. The investigators found that the Glass and Singer noise and the modified aircraft noise produced significantly lower levels of tolerance for frustration on the puzzles than the other types of noises. They note that the only physical characteristics these two noises have in common are multiple and unpredictable changes in sound level within randomly scheduled intervals. They also suggest that cognitive aspects may play a role in that both of these noise stimuli were unusual combinations of real world sounds. Another possible explanation could be differences among stimuli in total sound energy, because the authors do not mention controlling for this aspect.

The results of these investigations show that high levels of noise can produce adverse effects on performance after the exposure is discontinued, mainly on tasks that are sensitive to frustration intolerance. The effects are greatest when the noise stimuli contain speech sounds, and when they are characterized by unpredictable changes in sound level.

VIII. EFFECTS ON SOCIAL BEHAVIOR

There is an extensive literature concerning the effects of noise on social behavior, and a complete review of this topic is beyond the scope of this report. However, it would be useful to summarize some of the findings at this time.

The following studies are discussed in greater detail by Cohen and Weinstein (1981) in their review of the nonauditory effects of noise: Mathews and Cannon (1975) found in a laboratory experiment that fewer subjects were willing to help someone who had "accidentally" dropped materials when background noise levels were 85 dB than when they were 65 dB. In a subsequent field study, the same results were demonstrated in a background of lawn mower noise. This time the addition of a cast on the "victim's" arm, enhanced helping behavior under quiet conditions, but failed to do so during noise exposure. In another such experiment, Sauser et al. (1978) found that subjects recommended lower salaries for fictitious employees when exposed to office noise at 70 to 80 dB(A), than in quiet.

Sherrod and Downs (1974) exposed subjects to three noise conditions: soothing (seashore), distracting (containing speech), and distracting with perceived control. After the noise exposure had terminated, helpful behavior was assessed, with the result that subjects were most helpful after the soothing noise, and least helpful after the distracting noise with no perceived control. In another study of noise aftereffects, Donnerstein and Wilson (1966) found that subjects without perceived control over their noise exposures gave more shock to their fellow subjects than those with perceived control. Finally, Siegel and Steel (1979) found that subjects were less able to discriminate between behaviors and make attributions of responsibility when they were exposed to broadband intermittent noise at 92 dB than in quiet. (Above studies cited in Cohen and Weinstein, 1981.)

Jones (1983) cites studies by Boles and Hayward (1978) and Korte et al. (1975) showing that increases in noise level reduce the number of subjects willing to grant interviews on the street. He also cites Korte and Grant (1980) as finding that aversion to noise may speed a subject's passage through a noisy setting. He points out that some of these experiments may have been influenced by the presence of a verbal response requirement, and mentions that Korte et al. (1975) did not find an increased number of people ignoring the request for an interview (Jones, 1983).

Broadbent (1979 and 1983) notes the increased risk of hostile behavior associated with noise exposure and cites additional evidence suggesting that subjects will give each other increased amounts of shock and noise when they themselves are exposed to noise (Broadbent, 1979). He also cites evidence that noise increases anxiety levels (Broadbent, 1983), which may, at least in part, account for the increases in antisocial behavior.

IX. THEORY

The preceding discussion on sensory and motor effects has provided considerable evidence that quite high levels of noise exposure can produce adverse effects on performance by acting directly on vestibular receptors and other sensory processes (as shown in experiments by Mohr et al., 1965; Reschke et al., 1975; and Parker et al., 1968, 1976, 1978; etc.). The probable mechanisms have been outlined earlier. But what is the mechanism for effects from more moderate levels of noise exposure?

There is widespread agreement that noise causes increases in an organism's level of arousal through stimulating or "toning up" the reticular formation. The resulting increase in arousal level has provided one of the original explanations for the effects of noise on performance, both positive and negative. As mentioned above, a certain amount of stress (by noise or similar stressors) can enhance task performance, especially when the task is routine and monotonous. If, however, an individual is already optimally aroused for a certain job, the addition of noise exposure can bring on a state of overarousal, and performance suffers. These concepts are displayed graphically in Figure 7, from Broadbent (1971). Broadbent (1983) points out that the adverse effects of overarousal can be mitigated by factors that generally reduce arousal (such as sleep loss) and increased by factors that generally increase arousal (such as incentives and neuroticism).

Of course the picture is more complex than Figure 7 would indicate. As we have seen, performance in noise may be affected by other factors, such as circadian rhythm, personality, and psychological set. There is even some evidence that gender may be an additional determinant (Loeb et al., 1983). Consequently, Broadbent (1983) theorizes that there are actually two systems involved in arousal. The first system is the traditional concept, displayed in Figure 7, and the second takes the form of a monitoring system that attempts to compensate whenever arousal departs from an optimal level. If this second system operates properly, performance will not be adversely affected (Broadbent, 1983).

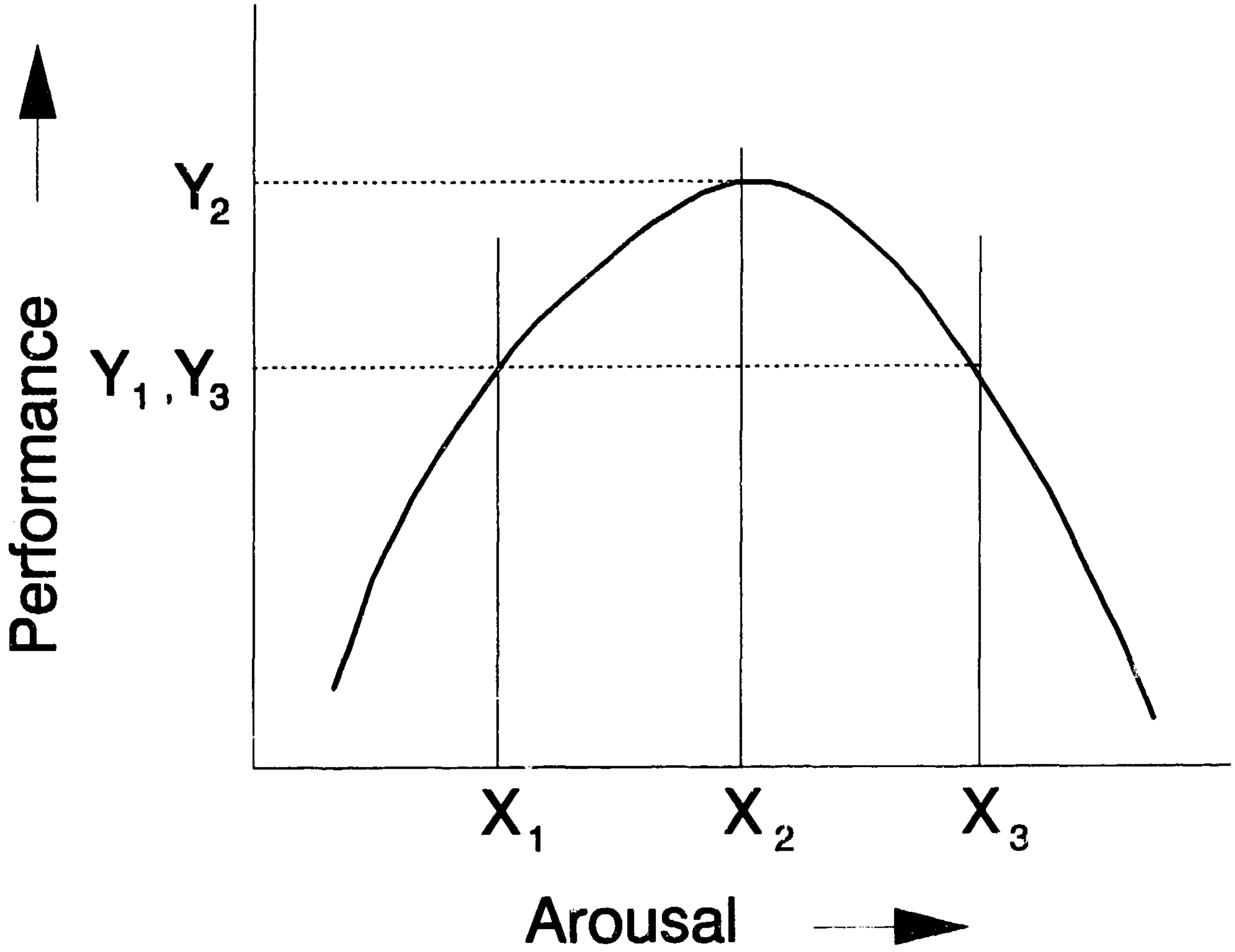

Figure 7. Changes in performance as a function of changes in arousal. A rise in arousal may give a rise in performance if it corresponds to a movement from X_1 to X_2; performance will rise from Y_1 to Y_2. But the same rise in arousal will give a fall in performance if arousal is already at X_2; a further rise to X_3 will give a drop from Y_2 to Y_3.

Note. From Decision and Stress by D. E. Broadbent, 1971, London and New York: Academic Press. Reprinted by permission.

Another popular theory used to explain the effects of noise on performance is Broadbent's "filter" theory (Broadbent, 1958 and 1971). Broadbent (1971) describes the nervous system as a single channel, having a limited capacity for transmitting information. This limited capacity channel is preceded by a selective device or filter, which selects only certain stimuli for processing or storage. Noise causes the filtering of some stimuli in favor of others, usually those proceeding from dominant sources (as, for example, in the experiments of Hockey, 1970a and b; and Finkleman and Glass, 1970). This mechanism appears to be operating primarily in tasks involving perceptual selection, reaction time, and memory (Broadbent, 1971). Noise increases the tendency to select information from probable sources at the expense of information from improbable sources, and in the extreme, evidence from only one source will be considered (Broadbent, 1971).

McGrath (1963) points out that Broadbent's filter has a bias in favor of novel stimuli and also those of greater physical intensity, which theory is borne out by much of the evidence presented in this report. McGrath also refers to the arousal theory as an explanation for noise-induced performance decrements, and he conducted an experiment to test these two hypotheses. Subjects performed a perceptual selection task in which they detected increments in brightness of an intermittent light while listening to continuous, broadband noise at 72 dB, or a variety of auditory stimuli (music, TV, traffic noise, etc.). The results showed that the varied auditory stimuli enhanced performance more than the continuous noise. When the task was made more difficult by increasing the stimulus rate and shortening the interstimulus interval, performance was significantly better with the continuous, broadband noise. McGrath concludes that these results support a combined arousal-filter theory. The novel stimulus produced a beneficial effect at relatively low arousal levels, but a distracting effect at higher levels of arousal, once the task had been made more difficult. McGrath mentions that Broadbent (1958) also favors both theories in that the overall level of performance is determined by arousal, but the decline that often occurs as performance continues is caused by "increasing filter deviations".

In more recent years, Broadbent (1983) has developed another explanation for the effects of noise on performance, which involves a shift in the choice of strategies for task performance. He notes that noise will have a differential effect on two groups of people performing the same tasks in the same conditions, according to the way they choose to approach the task. Changes in strategy are particularly common to verbal tasks (such as verbal memory), but characterize non-verbal tasks as well. Noise appears to solidify a pre-existing strategy, so that once it has been adopted, it is more difficult to change (Broadbent, 1983).

Certain investigators, most notably Poulton (1976, 1977, 1978) disagree with Broadbent's theories. Loeb (1980) presents a succinct explanation of the controversy as follows: Poulton claims that many of the adverse effects attributed to noise exposure are not replicable. Increasing arousal can only benefit task performance, and any apparent degradations are due to the masking by noise of acoustic cues produced by the subject, which ordinarily provide feedback on the quality of performance (such as tapping sounds), or the masking of inner speech used for purposes of auditory memory or rehearsal. According to Loeb, Broadbent (1978) has replied that some of the studies cited by Poulton as failing to show adverse effects when feedback was eliminated, did not use comparable noise levels. In addition, he believes that Poulton disqualified numerous studies for insufficient reason, and ignored other relevant studies, such as those concerning aftereffects. Loeb's opinion is:

> I think that Poulton has been of service in affirming the role that interference with acoustic feedback and various kinds of influence on short-term memory may play in influencing performance in noise, but I am not convinced that they play the role that he suggests in a great many of the cases cited. (Loeb, 1980, p. 316)

Finally, it is important to note the contribution of psychological factors. Glass and Singer (1972) have demonstrated the importance of the predictability of the aversive stimulus, which they have determined is dependent upon the presence or absence of perceived control. Gulian (1973) stresses the role of noise-induced annoyance, which is related to aversion, anxiety, and muscle tension, etc., all of which can affect task performance.

Any theory of noise-induced performance effects would be incomplete without taking these effects into account.

X. SUMMARY AND CONCLUSIONS

The preceding discussions provide confirmation for a variety of averse effects of noise on task performance, although the picture is rather complex. The effects on performance are not nearly as easily discerned and predictable as other noise effects, such as those on hearing or speech communication. As we have seen, the extent to which noise affects performance depends on numerous non-acoustical factors, such as the subject's biological and psychological state, as well as external factors such as task complexity and the presence of other stressors. Comparison of research results is made more difficult by differences in approach and experimental design. These problems are then exacerbated by lack of control over possibly contaminating variables and lack of precise specification of the stimulus and other experimental conditions. Nevertheless, enough research has been conducted, presumably of sufficient quality, to enable us to make a number of useful generalizations.

A. Summary of Effects

Research on noise and vision suggests adverse effects on thresholds of sensitivity and CFF, but more research is needed with more explicit control of experimental conditions before positive statements can be made. There is fairly strong evidence for noise-induced shifts in perceived visual field resulting from noise bursts at 120-125 dB. Small but reliable effects of noise on vestibular function have been shown by a series of experiments using the Rail Task at Wright-Patterson Air Force Base. These effects are especially evident at an exposure level of 140 dB with hearing protectors (resulting in actual exposures substantially lower than this level), and are greater for asymmetric exposures. Motor performance usually adapts with repeated or prolonged exposure, but levels as high as 130-140 dB can show persistent decrements, even when hearing protectors are used. Most startle responses brought on by impulsive noise habituate with repeated exposure, but the eye-blink response never habituates, and some amount of head movement rarely does.

Noise exposure level is, of course, one of the most important variables. Performance decrements generally begin to appear at levels around 95 dB, although noise below this level may cause adverse effects on particularly sensitive tasks. Continuous noise is less likely to be disruptive than intermittent noise. Aperiodic noise, probably because it is perceived as uncontrollable, is considerably more disruptive than periodically intermittent noise.

The effects of noise in combination with other stressors can be quite complex: synergistic, antagonistic, additive, or no effect. Noise usually has a beneficial effect when combined with sleep deprivation. Gender and circadian rhythm appear to interact with noise, but the direction of effects is unclear. Noise and incentive are both arousers, and noise may reduce the beneficial effects of incentive if overarousal should occur. Noise plus heat have produced mixed results: sometimes noise has a beneficial effect on performance that has been degraded by heat, sometimes the effect is additive, and at times, synergistic. Personality factors interact with noise and level of arousal to affect performance in complex ways.

With respect to task variables, noise usually has little effect on simple tasks, and can even improve performance on monotonous tasks. Tasks requiring continuous performance, such as driving vehicles and flying planes, may be momentarily disrupted, especially in noise levels over 100 dB. These disruptions need not affect overall performance unless the task is quite demanding, but they may have serious effects if a high level of sustained performance is necessary to the job. Intellectual function is not usually affected unless the task is complex or unless a task must be performed continuously for long durations. Vigilance tasks are susceptible to noise exposure, especially when the signal to be watched for may originate from a large number of sources, one's internal criteria may not be cautious, or if the watch is long. Complex tasks, especially those involving more than one activity, are much more likely to be disrupted than simple tasks, with lower priority task components usually incurring the decrements.

It seems that noise can have even greater effects after exposure than during exposure and the most common effect appearing in the experimental literature is a reduced tolerance for frustration. Finally, even fairly moderate noise levels (80 to 90 dB) indicate that noise raises anxiety and increases the risk of hostile behavior, while decreasing the incidence of helpful behavior.

B. Discussion

Having looked at the various effects of noise on task performance found in the laboratory, the question remains as to how to generalize these results to real-life conditions. In fact, one might expect real-life effects to be either greater or less severe than those found in the laboratory. The chances are that they would be greater because most laboratory studies use acute exposures of fairly short duration. Consequently, adverse effects that tend to occur only with prolonged exposure, such as those characteristic of vigilance or continuous performance tasks, may not have time to show up, especially in more moderate levels of noise exposure. On the other hand, performance decrements in real-life conditions may be somewhat less than those found in laboratory experiments because noise exposed workers and soldiers become familiar with both task and noise, thereby enhancing the process of habituation. The benefits of habituation, however, would disappear in emergency situations involving sudden changes in the task, especially if it should become unfamiliar, or the introduction of novel noise stimuli. Field studies should be helpful in elucidating this issue.

Another question that arises from studying the noise and performance literature is how to explain the apparently conflicting evidence. A good example would be the widely divergent results when noise is combined with heat. Most likely, these apparent conflicts are due to differences in experimental conditions, such as the relative magnitudes of the stressors, and the type and difficulty of the task. Throughout the discussions we have seen considerable support for the "rule of inversion", with low and moderate stimulus levels enhancing performance and high levels causing degradations. But even when explanations are not readily apparent, it would be inappropriate to assume that the positive and negative results "cancel" each other. Although many investigations have failed to show significant adverse effects, the fact that many others have shown such effects indicates that these effects may very well be expected to occur in real life, but only in certain circumstances.

If indeed these adverse effects are most likely to occur in relatively high noise levels (above 95 dB, and especially above about 115 dB), perhaps we need not be overly concerned because hearing protectors are usually required at these levels in industrial and military settings. Again, the assumption of safety is unwarranted. First, we have seen that performance decrements have occurred from high levels of noise exposure even though subjects wore hearing protection. Also, as explained above, real-life fitting and wearing practices greatly reduce the effectiveness of hearing protectors, especially ear plugs, and, unfortunately, many soldiers and industrial workers are unwilling to wear hearing protectors despite official requirements.

One might also say that the asymmetric exposure condition, which appears to be considerably more disruptive to task performance than the symmetric condition, is esoteric and not reflective of real life. It is true that individuals do not usually wear just one hearing protector. However, when one considers the uncertainty inherent in the field use of hearing protectors, it is quite conceivable that one plug could be fitted well and the other poorly. It is also conceivable that a noise-induced hearing loss could be greater in one ear than in the other, or that one ear canal is occluded by cerumen and the other not. Thus, some degree of asymmetry could be relatively common.

Finally, assuming that adverse effects on performance are likely to occur, what are the consequences of these effects? Broadbent (1979) points out that in the typical laboratory study, the increase in errors is only about 1% of the correct responses, but that this represents an increase of 50% over the number of errors made in quiet. The importance of this increment depends entirely upon the context. If errors are not expensive, then there is no problem. But if accuracy is more important than speed, changes of this magnitude must be taken seriously (Broadbent, 1979). If both accuracy and speed are important, and if the consequences of errors are severe, then noise represents a serious hazard to task performance.

C. Research Recommendations

1. Because this report has presented a broad overview of the effects of noise on performance, it was not possible to evaluate all of the relevant studies in each area and to scrutinize each one. Although relatively more effort was devoted to sensory and motor effects, a more thorough perusal of the research in this area could be helpful. Perhaps the next step would be to select the particular area of greatest interest to the U.S. Army, extend the effort to cover studies omitted in this report, and examine the experimental procedures of all of the relevant studies in some detail. This would enable the Army to determine the most beneficial approach to any desired research efforts.

2. Most research on the effects of noise on performance has taken place under laboratory conditions. Subject populations have generally consisted of college students with normal hearing, who are, presumably, highly motivated, interested in the experiment, and eager to please. To the extent that these qualities do not reflect noise exposed military personnel, it would be useful to employ subjects similar to those who regularly perform in noisy military operations. In addition, experiments should be conducted in the field, whenever possible, using tasks that are representative of real jobs, such as driving armored vehicles, manipulating helicopter controls, monitoring gauges, sighting targets, etc. Such tasks should be examined singly and in the combinations in which they actually occur, with and without the additional

environmental stressors that often accompany the task, such as heat and vibration. Noise and task durations should reflect actual durations encountered in military exercises.

3. The effects of noise on vision would appear to degrade activities involving sighting and firing at targets, and others involving the detection of signal lights, particularly red and green ones. Studies should be designed to simulate the visual requirements of combat and training exercises, to assess possible decrements from high levels of noise. Conditions should include impulsive noise as well as other types of noise typical of military environments.

4. It would be useful to examine the effect of noise on performance, with and without hearing protectors, and when hearing protectors are partially inserted, symmetrically and asymmetrically. Noise levels and spectra should reflect those regularly encountered in tanks and helicopters.

5. Because cooperation and adherence to commands are particularly critical in the military environment, it would be useful to explore the effects of high levels of noise on social behavior in the military context. While designing realistic yet controlled conditions might be difficult, the results could be of great interest.

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