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NON-AUDITORY EFFECTS OF NOISE AT WORK: A REVIEW OF THE LITERATURE

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ABSTRACT

This critical review consists of two main sections. The first is concerned with the effects of noise on performance efficiency, absenteeism and accidents, and the second with noise, physiological functioning and health. Both sections cover animal studies, laboratory studies with human volunteers, and field studies. The following noise parameters are considered: intensity, spectrum, duration, meaningfulness, intermittency and periodicity.

The section on noise and performance covers the following areas: sensory effects, motor tasks, noise and memory, selective attention, sustained monitoring, individual differences, combined effects of noise and other stressors, after-effects of working in noise, effects of irrelevant speech, and effects of noise on motivation. Most of these effects have been studied in the laboratory and it is argued that further research involving prospective field studies must be carried out to assess the significance of such effects in the workplace. Indeed, the section on accidents and absenteeism shows that there has been little research carried out on the effects of noise exposure during work.

The section on physiological effects of noise is concerned with vegetative responses (e.g. respiration, blood pressure, heart-rate, temperature, tremor and digestive function), biochemical effects (effects of noise on cholesterol levels, blood glucose, catecholamine excretion), and combined effects of noise and other occupational health hazards on physiological functioning.

The section on health covers surveys of the effects of noise on physical health, effects of noise exposure on hospital admissions and use of primary health care, birth abnormalities and noise, and noise and mental health.

The review assesses the reliability of studies which have reported non-auditory effects and evaluates whether reported effects might be due to agents or conditions other than noise. Areas where there are significant gaps in knowledge are identified and recommendations for future research are made.

The general conclusions drawn from the review are:

(1) Our knowledge of the auditory effects of noise has advanced to the stage where dose-response relationships are clearly defined but the non-auditory effects of noise are more complicated. Indeed, any study of noise in the workplace must consider the person’s perception of the noise, the extent to which it interferes with activities, whether it is also present outside the workplace, whether it interferes with sleep, and the reactions of the workers to protect themselves.

(2) There have been few sophisticated studies of the non-auditory effects of noise in the workplace. Those which have been carried out are often open to the criticism that effects attributed to noise could reflect other factors.

(3) However, previous research provides enough evidence of non-auditory effects of noise to warrant a large-scale industrial study.

(4) Laboratory studies of noise and performance show that moderate intensity noise, where there is no risk to hearing, can impair performance efficiency. These studies show that the nature of the noise and the type of task being performed are very important. We should, therefore, determine which activities are vulnerable in different types of noise.
(5) The effects of long-term noise exposure on performance and safety have largely concentrated on the relationship between noise and accidents. The results suggest that noise is at least a contributory factor, and future research, with better methodology, must clarify this area.

(6) With regard to the non-auditory effects of noise on health, there is considerable evidence that noise exposure influences cardiovascular function and catecholamine excretion.

(7) Epidemiological studies suggest that long-term exposure to noise is also a risk factor but at the moment it is difficult to give a more definite view because of the methodological weaknesses of much of the research.

(8) Noise influences sleep which may have important implications for performance the next day. However, it is unclear whether this effect of noise produces long-term health effects.

(9) Noise increases annoyance, and annoyance is associated with psychopathology. However, there is little support for the view that noise directly increases psychopathology.

(10) There have been suggestions that noise at work may be associated with abnormalities of reproductive function and birth defects. At the moment there is little concrete data on this topic, and yet it must clearly be considered in future studies.

The above points show that we need to carry out a multi-disciplinary, longitudinal prospective study of the effects of noise in the workplace. Such a study will answer many of the questions raised by this review and will move us towards the point where we have definite information about the real extent of the non-auditory effects of noise at work, and where we can make recommendations about methods of reducing such health and safety problems.
I NOISE AND ITS MEASUREMENT

1 The term noise has at least three meanings (1) a sound varying randomly and aperiodically in intensity and frequency, (2) a sound which interferes with the reception of another (i.e. masks it), and (3) a sound which we do not want to hear. A particular sound may be classified as noise on one or more of the above criteria, and the same sound may be classified as noise in one situation but not in another.

2 The part of the ear that is responsible for hearing is sensitive to variations in pressure. These variations are usually transmitted through the air and oscillations in pressure set up in an object are transmitted through the air by successive displacements of molecules. The greater these displacements the more pressure and power.

3 Intensity: The unit of measurement of intensity is the decibel. A logarithmic scale of magnitude is used because the dynamic range of power to which we are sensitive (between the absolute threshold - the level we can barely detect - and the terminal threshold - the level we can barely tolerate) is immense - in the region of $10^{14}$

$$dB = 10 \log \frac{E}{E_0}$$

where $E$ = the energy being measured
and $E_0$ = a reference standard.

The decibel scale, therefore, gives values which are logarithms of ratios.

Often reference levels are given in terms of pressure and levels expressed in this way are referred to as sound pressure levels (SPL).

$$\text{Number of decibels (SPL)} = 20 \log \frac{P}{P_0}$$

where $P$ = the pressure produced by a source
and $P_0$ = a standard reference value which corresponds roughly to the minimum pressure detectable by the human ear.

4 The reader is referred to Kohler (1984) for a further discussion of decibels. However, it is important to note the following facts:

(a) Subjective loudness increases less rapidly than energy or pressure. An increase in the region of 10 db is necessary to double the loudness as judged by the listener.

(b) Doubling of sound pressure increases SPL by 6 db and multiplication of sound pressure by a factor of 10 increases SPL by 20 db.

(c) Doubling sound energy, on the other hand, leads to an increase of only 3 db.

5 Frequency: Frequency is measured in terms of number of cycles per second (Hz). Human ears are sensitive to sounds between approximately 20 and 20,000 Hz.

6 Complexity: Most sounds are not pure or sinusoidal, but are made up of more than one frequency. Thus a sound might contain the frequencies 250, 500 and 750 Hz. The lowest frequency is termed the fundamental (and also the first harmonic) and the subsequent multiples the second and third harmonics.
7 Duration: Very short sounds (such as gun shots) are termed impulse noises. In contrast to this, longer ones with a thud-like quality (e.g. a metal hammer hitting a plate) are called impact noises.

8 When sounds are turned on there is a period of time called the rise time before they reach full intensity, and a period called the decay time when they are switched off.

9 Sounds may be switched on and off and are then referred to as intermittent. They may be switched on and off regularly (periodically) or irregularly (aperiodically). Both intermittency and regularity have been shown to be very important in determining the effects of noise.

10 Instead of being completely interrupted, the overall amplitude may be varied in a systematic way. This envelope variation is generally known as amplitude modulation.

Sound level meters

11 Several features are common to all sound level meters. First, a microphone is used to transform pressure variations into analog electrical signals. The voltages are then amplified and displayed on a meter or digital display. The meter also allows differential attenuation of the frequency range. This is important because the ear is not equally sensitive to all frequencies and three weighting networks can be used to simulate the action of the ear. The A-weighted network was chosen to simulate the sensitivity of the ear at low intensities, the B-weighted network was intended for medium intensities, and the C-weighted network for higher intensities. The A and C-weighted networks are most widely used. The C-weighted network essentially gives equal weight to all frequencies, whereas the A-weighting gives greater weight to the frequencies which contribute more to the effects on people.

12 Sound intensities usually vary over time. The Leq value for such a signal is the dB(A) level of a constant sound which, if continued over the same period, would represent the same total energy as the variable sound. Dose meters are small, simple sound level meters which can assess total cumulated noise exposure at the work place. The dose may be expressed as a proportion of the maximum permitted 8hr dose, or the Leq value may easily be derived from the reading. The dose meters can also signal when a specified maximum peak level has been exceeded.
II  NON-AUDITORY EFFECTS OF NOISE

13 The role of long term exposure to noise in causing hearing loss has long been recognised and research has progressed to where dose-response relationships have been derived. There is less agreement on the non-auditory effects of noise, and concern about such effects is a relatively recent phenomenon.

14 Non-auditory effects of noise can be defined as "all those effects on health and well-being which are caused by exposure to noise with the exclusion of effects on the hearing organ and effects which are due to the masking of auditory information (i.e. communication problems)". Such effects include performance effects, physiological responses and health outcomes, annoyance, and sleep disturbance.
III THE EFFECTS OF NOISE ON HUMAN PERFORMANCE: INTRODUCTION

Performance, annoyance and physiological response

15 The effects of noise on performance must be distinguished from subjective annoyance and from the effects of noise on physiological state. Indeed, it is quite common to find that these three types of measures do not agree. For example, a person may say that the level of noise is not annoying but objective measures of performance may show an impairment. Conversely, the person may express a violent dislike of the noise and yet be able to perform efficiently in it. Similarly, the noise may not influence performance even though physiological changes are apparent; or reduced efficiency may be observed with no detectable physiological changes.

The topic of "noise" arouses strong emotions

16 The above distinction between different effects needs to be made with special care in the case of noise. This topic arouses strong emotions both from those who assume that noise impairs every function and those who deny the existence of non-auditory effects of noise.

Noise research - a complicated area

17 Both of the extreme views mentioned in the previous section are wrong. The effects of noise on performance are definite, but complicated, because they require consideration of a large number of factors. Any claims about the effects of noise on performance, or the absence of such effects, should be carefully examined to see what kind of noise is being discussed and whether the study was adequately designed and the results not produced by agents or conditions other than noise.

Industrial studies

18 Many of the early studies of the effects of noise on performance examined real-life situations. The major disadvantage of such studies is the lack of control of other conditions. A second problem is that the mere fact that an investigator is studying noise may lead people to believe that they should work better in quiet. This may have an effect on efficiency which is not directly due to the difference in noise conditions.

19 Later research actually involved changing the noise level. A problem with this technique is that any change in working conditions may produce an improvement of morale, which in turn will lead to a temporary improvement in efficiency.

Laboratory studies

20 Following the criticisms of the early field studies there was a shift towards laboratory research. When evaluating these studies one must take careful note of the type of noise used (e.g. the level of noise in one study may be the same as that in the quiet condition in another). Similarly, one must see whether there are adequate precautions against any change being due to practice, fatigue, chance variation between individuals, transfer effects, and so on.

21 The present review is concerned with the effects of noise, especially moderate intensity noise (under 90 dB) on performance. Many of the older studies of this topic used levels which would now be discouraged because of the risk to
hearing. However, these results are still relevant to present problems and the theoretical developments from these studies will be briefly reviewed.

22 Important noise parameters, such as the meaning of the noise, the duration of the noise, and intermittent versus continuous noise will also be discussed. The review will largely focus on acute effects of noise but mention will also be made of some of the chronic effects of noise exposure.

23 Individual differences in response to noise will also be discussed, as will other factors which modify the effects of noise.

24 The review will emphasise the importance of the nature of the task being performed in the noise, and recent empirical results and theoretical approaches will be described. Many of these approaches will be shown to be inadequate, and current views emphasising the importance of strategy choice, effectiveness and selection will be discussed.

25 Finally, recommendations about the direction and methodology of future research will be made.

Auditory effects of noise

26 Any task involving auditory information is likely to be impaired by the presence of noise. Indeed, much of the research on the effects of noise has been concerned with its auditory effects and it is well-established that loud noise can produce deafness and interfere with communication. Mere listening in noise may also produce impairments in performance because of the additional effort involved. For example, Rabbitt (1966) showed that material previously learned in quiet may be more rapidly forgotten when, in the intervening period, the subject listens to speech in noise.

IV RESULTS FROM STUDIES USING LOUD NOISE (OVER 95dB):

A SUMMARY

27 Many of the older studies of noise and performance used very loud noise (often over 100 dB), and such levels should be eliminated because of the risk to hearing. However, the results from these studies are still useful because similar results may be obtained using longer exposures of moderate intensity noise (75 - 85 dB). For example, Smith and Miles (1985) had subjects carry out a serial choice reaction time task when they had been in 75 dBA noise for 2 hours and when they had been in the noise for 5 hours. The results showed that when the subjects had been in the noise for 5 hours there was an increase in the number of errors. This result is in agreement with those found in studies using louder noise (over 95 dB) for a shorter duration (e.g. Broadbent, 1953; Wilkinson, 1963). Some of the results from studies using loud noise have recently been obtained at lower levels. This is due to the development of more sensitive tests. For example, Smith (1985a) showed that even 85 dB noise may produce a bias in performance towards high probability sources at the expense of those with lower probabilities. This had previously only been found with louder noise but the task used by Smith was much more sensitive than those used in earlier studies (e.g. Hockey, 1970).

28 It is of some value, therefore, to list some of the general conclusions which have emerged from studies using noise of 95 dB or over. The reader is referred to Broadbent (1979) for detailed support for the general conclusions given here.
The first point that can be made is that the effects of noise on performance are very real but they depend on the task which is being performed. If the person has to react at certain definite times, receives clear warning signals, and has an easily visible stimulus, then there will be little effect of continuous loud noise on performance. Sensory functions such as visual acuity, contrast discrimination, dark vision, accommodation and speed of eye movements all show little effect of noise. Similarly, motor performance is rarely impaired by noise unless balance is involved. Simple reaction time is unimpaired provided the subjects have adequate warning about when to respond. Clerical tasks and mental arithmetic also show little impairment in noise and this leads to the general view that noise does not affect the basic functions out of which more complex tasks are assembled.

Broadbent (1979) has suggested that there are three main effects of continuous noise on performance. First, detrimental effects of noise may be found in monitoring tasks provided that (a) the noise level is over 95 dB, (b) the length of the watch is long, (c) the signals are hard to see, and (d) the situation is not one which encourages caution. Second, in continuous tasks the effect of noise appears to be one of increased momentary inefficiency interspersed by normal performance. For example, in the five-choice serial reaction time task noise increases the number of errors and gaps (occasional long reaction times) but has no effect on the average rate of responding. Again, this increased momentary inefficiency depends on the noise being over 95 dB and the subject having been in the noise for at least half an hour. In multiple tasks, or tasks with several sub-components, noise often leads to increased concentration upon the dominant or high probability component at the expense of other features. For example, Hockey (1970) showed that noise improved performance on a central tracking task but led to slower reactions to those lights which had a lower probability of occurrence. This result also appeared to depend on the presence of loud noise of fairly long duration.
The results of these older studies suggest that the noise level has to be above 95 dB to produce an impairment in performance. Yet people often complain that lower levels of noise interfere with their work. Recent studies have tried to explain this discrepancy between subjective report and objective measures of performance, and one possible reason for the discrepancy is the nature of the noise. In real life people are exposed to a wide variety of noises whereas most laboratory studies have used artificially generated continuous white noise. Certain researchers (e.g. Salamé and Baddeley, 1982) have suggested that one should move away from using white noise of varying intensities and use noise of greater importance in real life, such as speech. This approach has been adopted in recent studies.

Effects of irrelevant speech

Several studies have shown that performance is impaired if speech is played while a subject reads and remembers verbal material (e.g. Colle and Welsh, 1976). Salamé and Baddeley (1982) used a serial recall task to compare the effects of white noise and irrelevant speech, and found that memory performance was impaired by speech but not by the noise. Jones (1989) has reviewed studies of this topic and the main results are summarised below:

1. The effect of irrelevant speech is independent of its intensity. This is true in the range 55 dB(A) to 95 dB(A).

2. The meaning of the speech is unimportant in that effects may be obtained with foreign languages, with nonsense material and backward speech.

3. It is unclear whether the effect of speech is on memory or on perception. Loud music, over 100 dB, but not loud noise has been shown to impair visual acuity (Ayres and Hughes, 1986). Salamé and Baddeley (1982) found that the memory impairment produced by speech was a direct function of the phonological similarity of the irrelevant words, which suggests that irrelevant speech blocks the use of phonological information by impairing the efficiency of the articulatory loop. However, Broadbent (1983) suggested that this result could represent an effect of unattended speech on perception rather than on memory.

4. Vocal music has a greater disruptive effect than instrumental music. However, this is not found if the vocal component is hummed. This demonstrates that the words have to be properly articulated in order to disrupt performance.

Other types of task are also impaired by irrelevant speech but not by continuous white noise. For example, Baddeley and Thomson (cited by Baddeley, 1981) found that unattended speech, in the form of a radio broadcast, impaired the speed of semantic processing. In contrast to this, Eysenck and Eysenck (1979) and Wilding and Mohindra (1983) failed to demonstrate any effect of continuous white noise on semantic processing. Indeed, Smith (1985b) has shown that both semantic processing and syntactic reasoning are impaired by conglomerate, meaningful noise but not by continuous white noise.

Dornic, Larsson, Sarnelid, Svensson and Fernaeus (1982) examined the effects of type of noise and task duration on performance efficiency and perceived effort. When the task was of short-duration, perceived effort was significantly greater when irrelevant speech was played but continuous white noise had no effect. There was no difference between the effects of the two types of noise on performance. When the task was of longer duration, there was evidence of
adaptation to the white noise, although this was not true for the irrelevant speech (both for performance and effort).

36 The susceptibility of working memory tasks to disruption by irrelevant speech suggests that reading, with its reliance on memory and other processes, may also be impaired. Jones (1989) has reviewed a series of experiments on the effects of irrelevant speech on proof-reading. The results showed some similarities to the effects of noise on short-term memory (e.g. the effects appeared to be independent of intensity). However, there were also some differences. For example, the meaning of the speech was very important, with meaningful speech being more disruptive than meaningless speech. It was only the detection of non-contextual errors (e.g. typographical errors) that was impaired by speech, which possibly reflects the fact that speech makes analysis of meaning more difficult, which in turn means that analysis of graphemic features assumes a lower priority.

37 These recent studies of irrelevant speech have important practical implications. They suggest that one should avoid irrelevant speech when performing verbal tasks even when the level is below 95 dB. Indeed, attenuation by ten decibels will not remove the effects of irrelevant speech - a reduction of several tens of decibels will be necessary to achieve this.

Effects of intermittent noise

38 Other researchers have examined the effects of intermittent noise rather than continuous noise. These studies have been reviewed in detail by Broadbent (1979), and of major interest is the fact that they have isolated the stages of processing which are disrupted by the noise. Fisher (1972), using the five-choice serial reaction time task, found that intermittent noise only impaired performance when the noise burst arrived during the execution of the response. Differential effects of noise on certain stages of processing have also been reported by Woodhead (1986). She found that noise bursts were disruptive when they arrived during the intake of information in a mental arithmetic task but had no effect when they arrived during the actual calculation phase. Similarly, Salame and Wittersheim (1978) showed that noise bursts timed to coincide with a visually presented digit produced more subsequent recall errors than when the bursts arrived between digits. Smith (1985b) also reports results which can be interpreted as showing that intermittent noise interferes with the input and output stages of performance but has little effect on working memory.

39 Several studies have also demonstrated that the changes in performance produced by intermittent noise are confined to the short period following the onset and offset of the noise. Teichner, Arees and Reilly (1963) showed that the effect of this intermittent noise on performance depended on the change in the noise level, and both increases and decreases in the level of noise produced equivalent changes in performance.

40 Carter and Beh (1987) found that intermittent noise made subjects less sensitive, less accurate and more prone to response failure during a vigilance task. However, the subjects in noise responded more quickly. The variation in the predictability of the noise affected only the accuracy measure during the final quarter of the task, with the group with the least predictable noise showing the worst performance.

41 Other studies (e.g. Koelewa, Brinkman and Bergman, 1986) have found no effects of intermittent noise on vigilance, and further research is required to examine whether it is the nature of the task, or some other feature, which is
responsible for the conflicting results in this area (see Koelega and Brinkman, 1986).

Duration of the noise

42 The older studies of the effects of noise on performance also showed that the duration of the noise was important. Indeed, the nature of the noise effect often changes with time in the noise. Recent studies using moderate intensity noise have confirmed the importance of the duration of the noise. Smith and Broadbent (1985) have shown that subjects have to be exposed to the noise for at least 30 minutes before it influences the speed of naming colours and reading colour names. Smith (1983a) found that the effect of noise on ordered recall changes with time. Initially, the subjects were better at recall of order information in noise but there was a noise-induced impairment in the second half of the experiment.

Frequency

43 Broadbent (1957) examined the effects of low and high frequency noise on performance of the five-choice serial reaction task. The high frequency noise gave rise to more errors, although this difference was only significant in the highest intensity (100 dB) condition.

Predictability and perceived control

44 In other studies the predictability of the noise, and the subject's perceived control over the noise, have been shown to be important in determining the effects and after-effects of the noise (Glass, Singer and Friedman, 1969; Glass, Reim and Singer, 1971). Glass and Singer (1972) have reviewed this work on the effects and after-effects of random conglomerate noise, and the studies generally showed that the tasks performed during the noise exposure were unimpaired but tasks performed after the noise had been switched off were impaired. This impairment was reduced when subjects were given "perceived control" over the noise (they were told they could switch it off if they wanted although the experimenter would prefer them to leave it on - in fact, few subjects switched the noise off). Other means of reducing the after-effect included making the noise bursts more predictable (by making them more regular or by signalling their onset).

45 The noise did not have to be loud to produce after-effects (in one experiment 65 dB(A) was sufficient). Indeed, anticipation of a loud noise stressor may impair performance even when no noise is played, and expectation of control counters this effect (Cohen and Spacapan, 1984). Furthermore, Wohlwill, Nasar, DeJoy and Foruzani (1976) demonstrated that the after-effects of noise are not dependent on the power of the noise to disrupt task performance.

46 Willner and Neiva (1986) examined the effects of exposure to brief uncontrollable noise on recall of information from memory. They found that uncontrollable loud noise increased the recall of negative trait words, and suggest that noise induces a state which is similar to that found in clinically depressed patients.

47 Holding, Loeb and Baker (1983) examined the after-effects of continuous noise on risk and effort choices. They report that prior exposure to noise decreased the choice of high probability, high effort alternatives. This is similar to studies of physical fatigue and the authors conclude that exposure to noise does eventually produce real fatigue.
48 Other researchers (e.g. Jones, Auburn and Chapman, 1982; and DeJoy, 1985) have cast doubts about the generality of the perceived control phenomenon, and argued that the previous task situation is crucial in determining whether after-effects occur or not. Similarly, there are studies which report effects and after-effects of noise on mood but not on performance (e.g. Gawron, 1984).
VI LONG TERM EFFECTS OF NOISE

49 It is important to point out that all of the studies described so far have been concerned with the acute effects of noise (the longest noise duration was 7 hours - Smith and Miles, 1985). In order to get evidence about the effects of long term exposure to noise one has to turn to field studies rather than laboratory studies.

50 There are very few studies that have dealt with the effects of noise on safety and efficiency in the workplace, and these are reviewed in detail in a later section.

Noise and everyday errors

51 Smith and Stansfeld (1986) compared self-reports of everyday errors (failures of attention, memory and action) given by subjects who lived in an area with a high level of aircraft noise with those of a similar group who lived in an area with a low level of noise. In each group there were subjects who considered themselves to be highly sensitive to noise and others who had a lower level of noise sensitivity. The high aircraft noise group reported a greater frequency of occurrence of everyday errors and so did the noise sensitive subjects. However, there was no interaction between noise sensitivity and the level of aircraft noise.
VII INDIVIDUAL DIFFERENCES

Effects of noise on children

52 There is some evidence that the level of noise at home (Cohen, Glass and Singer, 1973) or at school (Crook and Langdon, 1974) can influence the development of reading. Cohen, Evans, Krantz and Stokols (1980) studied the effects of chronic exposure to aircraft noise on children's cognitive, motivational and physiological processes. Children in schools in the high aircraft noise area had higher blood pressure than those in the quiet area, were more likely to give up on a task, were more susceptible to distraction, and showed inferior performance on a cognitive task. They also examined the relationship between these effects and the length of time the child had lived in the high noise area. The results indicated some habituation of the physiological stress response to noise but there was no evidence of adaptation of the cognitive and motivational effects. Indeed, in many cases increased length of the noise exposure resulted in a greater negative impact of the noise.

Introversion-Extroversion

53 The personality dimension of introversion-extroversion has been related to individual differences in the effects of loud (over 95 dB) noise. It is a widely held view that extraverts are under-aroused compared to introverts, and since noise is often considered to increase arousal, this should mean that noise improves the performance of extraverts. Such results have been obtained. For example, Blake (1971) demonstrated that noise increased the speed of extraverts on a letter cancellation task, and Davies and Hockey (1966) found that the decrement in detection efficiency observed in extraverts tested in quiet was abolished by noise. Similarly, Baddeley (1968) showed that the logical reasoning performance of extraverts was improved by noise, whereas introverts were slower in noise than in quiet. Davies, Hockey and Taylor (1969) examined the effects of varied auditory stimulation on vigilance performance. Their 80 dB noise was associated with a lower false alarm rate in extraverts. Introverts preferred to work in silence whereas the extraverts preferred the varied auditory stimulation.

54 Geen, McCown and Broyles (1985) studied the effects of 65 and 85 dB noise on performance of a vigilance task by introverts and extraverts. When the noise level was low (65 dB) introverts detected more signals than extraverts, whereas in the 85 dB condition the two groups showed comparable performance. Geen (1984) found that extraverts preferred higher noise levels than did introverts. Introverts only showed decrements in paired associated learning when the intensity was above their preferred level, whereas the performance of extraverts declined if the intensity was either above or below the preferred intensity.

55 Discipio (1971) examined individual differences in the effects of noise and time on task on performance. Results for the group as a whole showed that performance was initially better in noise than in quiet but then showed the opposite pattern. This was entirely due to the extraverts, with the introverts showing an improvement during the exposure to noise.

Neuroticism and anxiety

56 Studies of the effects of noise on cognitive tasks suggest that neuroticism and anxiety levels are important in determining individual differences in response to noise. For instance, Nurmi and von Wright (1983) showed that when noise was played during learning it impaired the subsequent recall of neurotic and anxious subjects. Similarly, von Wright and Vauras (1980) showed that
intermittent noise impaired retrieval from semantic memory by neurotic subjects but had little effect on the performance of stable subjects.

57 Dornic (1980) and Dornic and Fernaeus (1981a) have examined the effects of noise and irrelevant speech on the performance and perceived effort measures of high and low arousal subjects (defining high arousal as neurotic introversion and low arousal as stable extraversion). The results showed that high arousal subjects had to exert more effort in order to resist the adverse effects of irrelevant speech. On working memory tasks, low arousal subjects made fewer errors than high arousal subjects and this difference was increased by distracting speech. However, results from a search task showed the opposite pattern of effects.

Psychoticism

58 In the only study which has examined the relationship between psychoticism and the effects of noise, Stelmack, Wieland, Wall and Plouffe (1984) found that psychoticism was inversely related to recognition memory performance in noise. This dimension requires further investigation.

Type A v Type B

59 Lovallo and Pishkin (1980) found that Type B's showed better initial coping with uncontrollable noise than did Type A's. However, Type B's showed reduced coping as the exposure length increased, whereas Type A's had a constant reaction to the noise. Other studies (e.g. Moch, 1988) have found no difference between the response of Type A's and B's to noise.

Age

60 Von Wright and Nurmi (1979) examined the effects of noise and irrelevant information on speeded classification tasks. The subjects were either adults, children aged six, or children aged nine. The noise slowed down the performance of adults in all conditions, slightly improved the performance of nine-year old children, and improved the performance of six-year old children when irrelevant information was present.

61 Hambrick-Dixon (1986) examined the effects of noise on different types of performance of five-year old children in quiet or noisy day care centres. Only psychomotor performance was impaired by noise in all children. Other types of performance (e.g. coding) showed an interaction between previous exposure to noise and noise test condition (i.e. children from noisy day care centres were better in the noise condition than the quiet condition, whereas those from the quieter centres showed the opposite pattern of results).

62 Davies and Davies (1975) examined the effects of noise upon age differences in two search tasks. In one of the tests noise significantly improved the rate of work for older subjects (65 - 72 years) but not the younger ones (18 - 31 years). Other studies, however, have shown that older subjects show greater impairments in noise than younger subjects. For example, Lahtela, Niemi, Kuusela and Hypén (1986) found that intermittent noise slowed down response speed of elderly subjects more than the young.

Sex differences

63 Gulian and Thomas (1986) found that noise reduced the pace at which female subjects worked, but had little effect on that of male subjects. However, some studies (e.g. Edmonds and Smith, 1985) have found no sex differences in the
effects of noise. Other research suggests that other factors (e.g. smoking - Knott, 1984; or time of testing - Loeb, Holding and Baker, 1982) may modify sex differences in the effects of noise on performance.

**Intelligence**

64 Johansson (1983) found that ten-year old children with high intelligence solved more items on a multiplication task in noise than they did in quiet. The reverse was found for children with low intelligence, who also showed worse reading performance in noise than in quiet. However, Edmonds and Smith (1985) report the opposite effect (i.e. high intelligence students were impaired by noise, whereas those with low intelligence improved) with twelve-year old children.

**Individual differences in the effects of moderate intensity noise**

65 If one returns to the discrepancy between the subjective response to moderate intensity noise (that it does often impair performance) and the older results regarding its effect on performance (that it has little effect), one can put forward another possible explanation of it, namely individual differences. The hypothesis that needs to be considered here is that some individuals are impaired by noise whereas others are actually improved by noise. This would result in little effect of noise on the group as a whole. It should immediately be pointed out that there is a great need for further studies of individual differences in the effects of moderate intensity noise on performance and the little evidence we have at the moment is contradictory. For example, Hörmann and Osterkamp (1966) showed that the effect of noise on organisation of memory was related to the individual's ability to resist distraction.

66 However, Smith, Jones and Broadbent (1981) failed to replicate this result. Indeed, Smith et al. (1981) could find little evidence for any individuals being particularly susceptible to the effects of noise. They tested subjects in noise and quiet on two separate occasions a week apart and examined the correlation between the two sets of quiet-noise differences. They found a zero correlation which shows that those individuals who were most impaired by noise in the first week were not those who showed the greatest impairment in the second week. One possible explanation of this result is that some individuals may be initially sensitive to noise but habituate rapidly whereas others may only become impaired after repeated exposure to the noise. Wilkinson (1974) also reports a marked lack of consistency in the individual performance patterns in 100 dBA noise.

67 Subjective responses show that there are individual differences in susceptibility to noise, and noise sensitivity has been postulated as an intervening factor which determines the annoyance level in the exposed individual. However, there is little evidence to support the 'noise vulnerability' hypothesis, which states that the effect of noise on behaviour depends on the sensitivity of the individual plus the presence of the noise. Smith and Stansfeld (1986) failed to find an interaction between noise exposure and noise sensitivity (with regard to frequency of report of everyday errors), and Stansfeld, Clark, Turpin, Jenkins and Tarnopolisky (1985a) found that noise exposure and noise sensitivity had different effects on psychophysiological indices. There is little evidence, therefore, to suggest that the absence of effects of moderate intensity noise on performance in many of the early studies is entirely due to individual differences in response to noise.
VIII NOISE AND TIME OF DAY

68 It has been suggested that the effects of noise vary as a function of other factors, and one which has received recent attention is time of day. Certain theoretical approaches suggest that the effects of noise will vary depending on what time of day testing occurs. It has been assumed that arousal increases over the day (see Colquhoun, 1971) and that noise may also increase arousal (see Broadbent, 1971). The Yerkes-Dodson law states that there is an optimum level of arousal for efficient performance, so this leads one to the prediction that noise should improve performance when circadian arousal is low (e.g. early in the morning) but have little effect, or even impair performance when arousal is higher. Blake (1971) found that noise improved performance on a letter cancellation task carried out at 8.00 a.m. but did not affect performance when it was carried out at 10.30 a.m. Similarly, Mullin and Corcoran (1977) found that detection rates on a vigilance task improved from morning to evening when the noise level was low but not when the noise level was higher.

69 Smith (1989,a) and Smith and Miles (1985) found little evidence to support the view that the effects of noise vary over the day. Indeed, the only reliable interaction between noise and time of day was the interaction between noise and the post-lunch dip. In this case noise reduced the impairment in performance on the Bakan vigilance task which was found following consumption of lunch (see Smith and Miles, 1986a). These results, and the vast differences between noise effects and time of day effects in performance (see Smith, 1987), support Broadbent’s (1971) view that noise and time of day have distinct effects and should, therefore, rarely interact.

Noise, time of day and gender

70 Recent research has demonstrated interactions between noise, time of day and gender. Frankenhaeuser and Lundberg (1977) showed that a certain type of mental arithmetic task (the Norinder task) was performed more slowly in noise than in quiet. However, Loeb, Holding and Baker (1982) found that this was only observed for male subjects tested in the morning. When male subjects were tested in noise in the late afternoon they completed more items than male subjects tested in quiet at that time. Female subjects did not even show the noise-induced impairment in the morning. Other studies suggest that the nature of the noise x time of day x gender interaction varies with the type of task. For example, Baker, Holding and Loeb (1984) used a computerised arithmetic task with a fast rate of presentation. The results showed that in the morning the males in noise were faster but less accurate than those tested in quiet, whereas in the afternoon noise produced slower but more accurate performance. Results for the females showed the opposite pattern. Smith (1989,a) failed to replicate the effects of Loeb et al. (1982), although he was using a lower intensity noise than in the original study. In one experiment he obtained interactions between noise, sex and time of day but these were unreliable and the exact pattern varied from task to task. Smith and Miles (1987b) examined this issue using long noise exposures (8 hours) and extreme times (day v night). Their results showed no evidence of noise, time of day and gender interactions.

Noise and nightwork

72 Noise and nightwork are major occupational health problems and both have been shown to influence well-being, safety and efficiency. In recent years there has been a growing realisation that one must not consider occupational health hazards in isolation. Yet there have been few studies of the combined effects of noise and nightwork on performance.
Smith and Miles (1985, 1986a,b, 1987a,b) and Miles and Smith (1988) have reported results from a laboratory study of the acute effects of a combination of noise and nightwork on human function. The results may be summarised as follows:

(1) Both noise and nightwork influenced performance, but the effects varied according to the nature of the task being performed. For example, noise increased errors in detection tasks (e.g. cognitive vigilance tasks, memory-loaded search tasks), whereas perceptual-motor tasks (e.g. a test of manual dexterity, simple reaction time and a low memory load search task) were performed more slowly in the second half of the night shift.

(2) The effects of noise and nightwork were independent, and there was no evidence of the effects of noise being different in the day or night shifts.

(3) Post-meal impairments were observed in certain tasks and these were removed by noise, which suggests that noise and meals influence the same mechanism.

(4) There was little evidence of any personality sub-group being consistently most sensitive to a combination of noise and nightwork.

(5) Ratings of subjective mood showed a similar pattern to the performance data; both noise and nightwork influenced mood but the effects were selective and independent.
9 Importance of the Nature of the Task

74 One cannot deny the importance of the nature of the noise, individual differences and possible interactions between noise and other factors. However, none of these alone can account for the failure of the older studies to show effects of moderate intensity noise on performance. It is, of course, possible that everyday complaints about moderate intensity noise are mistaken. Before accepting this view researchers considered one other possibility that could account for the absence of effects in the older studies. Experiments using very loud noise (over 95 dB) have shown that the effects of noise on performance are very real but depend on the task being performed. It is possible that moderate intensity noise also produces task specific effects, and it will be seen from the review of the last ten years’ research on noise and performance that the recent studies have used very different tasks, and looked at performance in a very different way, from the studies which have already been discussed. The following section will describe various theoretical approaches which have been put forward to explain the effects of noise. Many of these will be shown to be inadequate but it should be emphasised that they have been of great importance in theoretical development.

The masking of internal speech

75 Poulton (1977) suggested that all the detrimental effects of noise could be explained either by the masking of acoustic cues, or in the case of cognitive tasks, by the masking of inner speech. The first part of this view has been strongly opposed (see Broadbent (1978)), and the second part has led to several experimental studies which will now be discussed.

Studies comparing the effects of noise with articulatory suppression

76 Wilding and Mohindra (1980) required subjects to memorise a list of letters and then produce ordered recall. They found that noise improved recall, but only if internal speech was allowed (in one condition sub-vocal articulation was suppressed by making the subject say ‘the’, ‘the’, ‘the’, over and over again). If noise masks inner speech one would have expected a harmful effect on memory, which should then disappear when articulatory suppression is added. Millar (1979) also studied the effects of noise and articulatory suppression and overall his results did not support the view that noise masks inner speech.

Cognitive vigilance tasks

77 Jones, Smith and Broadbent (1979) examined the effects of noise on the Bakan vigilance task. In this task single digits are presented on a screen and subjects have to detect a particular sequence, such as three successive odd digits. Post-experimental reports have demonstrated that subjects say the digits to themselves, so, if noise masks internal speech, this task should be impaired by noise. Jones et al. (1979) tried four slightly different versions of the task in levels of 80 or 85 dB. In each case there was some detrimental effect of noise, although the exact nature of the noise effect depended on specific features of the task. This, and the finding that noise had no differential effects on digits which were rehearsed together and those which were rehearsed separately, argue against noise producing effects solely by interfering with sub-vocal articulation. However, these results do show that vigilance tasks involving memory are susceptible to noise below 95 dB, and this is consistent with studies by Benignus, Otto and Knelson (1975), and has been confirmed by Miles, Auburn and Jones (1984), and Smith (1988a; in press, and in preparation).
Comprehension and semantic relationships

78 There is evidence that noise may impair comprehension, and Hockey (1979) found that subjects in loud noise had better recall of names from a passage but poorer comprehension than subjects in quiet. Similarly, Jones and Broadbent (1979) showed that subjects reading a message out loud in noise had difficulty in understanding the text. These two laboratory results are given some ecological validity by a result obtained by Smith and Stansfeld (1986), namely that people living in high aircraft noise areas reported that they "read something but fail to retain the meaning" much more frequently than subjects in low aircraft noise areas.

79 Studies of clustering in free recall have also shown that subjects in noise make less use of semantic relationships to aid recall than do subjects in quiet (Daee and Wilding, 1977; Smith et al., 1981).

Recall of order information

80 Hamilton, Hockey and Quinn (1972) examined the effects of noise on recall of paired associates and they found that 85 dBc noise produced a beneficial effect on recall of a single list with no intervening activity. However, this effect depended upon testing in the same order as the original presentation, for testing items in a new order removed the effect of noise. Daee and Wilding (1977) found that subjects in noise relied on order information to aid recall rather than semantic relationships. This result fits in with Dornic's (1975) suggestion that noise leads to increased use of a lower level storage mechanism that depends on order information. Wilding and Mohindra (1983) have put forward a sophisticated view of why noise influences recall of order. They claim that:

81 (a) Moderate intensity noise only affects memory if rehearsal occurs.
     (b) Noise slows rehearsal (see Mohindra and Wilding, 1983).
     (c) The effects of noise on rehearsal depend on task parameters.

Levels of processing

82 Schwartz (1975) showed that noise improved recall of phonemically related words but had no effects on recall of semantically related material. Similarly, Weinstein (1974) and Weinstein (1977) found that subjects checking visual text for spelling or grammatical errors were as good at detecting spelling errors when a radio broadcast or teletype noise was played but deteriorated on the grammatical errors.

83 Dornic and Fernaeus (1981a,b) found that noise produced better superficial but poorer semantic processing. This "levels of processing" view of the effects of noise fits the results just described which show that noise often impairs recall based on semantic relationships and leads to a reliance on order cues. However, it can be criticised from five points of view. First, a direct test involving manipulation of the encoding processes revealed no interaction between noise and the different encoding conditions (Smith and Broadbent, 1981). Second, there are several studies where there is no effect of continuous noise on semantic processing (Eysenck and Eysenck, 1979; Smith, 1985b; and Wilding and Mohindra, 1983). Third, there are experiments which show that recall of order information is not always better in noise (e.g. Smith, 1983a; and Wilding and Mohindra, 1983). Fourth, noise may have no effect on the organisation of recall and may even produce more organised recall (Smith et al., 1981). Finally, Dornic and Fernaeus (1982) examined the effects of noise on incidental learning. The
incidental material differed from the intentional in several ways (physical incongruence - incidental words in a different case; linguistic incongruence - incidental words in different languages). In quiet, incidental learning was improved by incongruence. However, the reverse was true in noise and Dornic and Fernaeus suggest that noise impairs the recall of heterogeneous material but enhances the recall of homogeneous material. Overall, these results show that verbal memory tasks are often susceptible to even moderate intensity noise but they cannot be explained in terms of a passive shift favouring one level of processing rather than others.

Verbal/spatial strategies

84 Hartley, Dunne, Schwartz and Brown (1986) examined the effects of noise on a sentence verification task (the subject had to verify whether a sentence and picture were compatible). Some subjects preferred to use a spatial strategy, converting words into a visual mental image, while others preferred to use a verbal strategy. The results showed that noise benefited the verbal and hindered the spatial strategy, which is consistent with noise reinforcing memory for verbal order. These effects were replicated in another study (Hartley, Boulton and Dunne, 1987) which examined the effects of noise on verbal and spatial solutions of Rubik's cube.

Selectivity in memory and attention

85 Broadbent (1971) suggested that noise increases the probability of sampling information from dominant or salient sources at the expense of non-dominant ones. This suggestion was well supported by results from experiments using noise levels over 95 dB. For example, Hockey (1970) showed that 100 dB noise improved performance on a central tracking task but produced less efficient reactions to lights from a visual display which were seen as presenting signals with a lower probability. A second line of evidence supporting Broadbent's view comes from studies of the effects of noise on the Stroop task, which show that noise reduces the amount of interference from irrelevant colour names (e.g. Houston and Jones, 1967). Similarly, Woodhead (1966) demonstrated that noise produced a greater shift to the dominant activity. When the non-dominant activity was emphasised there were no significant differences between noise and quiet.

86 Recent studies have also shown that Broadbent's view can be applied to the effects of moderate intensity noise. Hockey and Hamilton (1970) found that 80 dB noise impaired recall of task irrelevant, 'incidental information'. In their experiment the subjects were instructed to recall the order of eight words. Each word was presented in one of the four corners of the screen (two words per corner) and after the subjects had recalled the words in order they were then asked to recall the location in which the words had been presented. Noise improved recall of order (the intentional task) but impaired recall of location (the incidental task). Smith (1982) has replicated these results using priority instructions rather than the intentional/incidental manipulation. Furthermore, he demonstrated that the effects of noise vary with priority changes when either order or location was the high priority component.

87 Another example of noise influencing selectivity in memory is provided by the data of Eysenck (1975). In his task no material had to be especially learned for the experiment. Instead, retrieval from semantic memory was tested by asking the subject to produce, as quickly as possible, a word from a particular category and starting with a specified letter. This task is relatively easy if there is a common instance starting with the prescribed letter (e.g. an item of furniture - T - table). However, the task can be made harder by choosing a category-letter combination which leads to a rare member. Eysenck found that 80 dB noise slowed
down these non-dominant responses but had no deleterious effect on the easy ones. This result was also obtained in an experiment reported by Smith and Broadbent (1982).

88 Smith (1985a) has shown that noise may lead to faster responses to sources with a high probability of delivering a signal but will impair reactions to those with lower probabilities. He used a 3-choice serial reaction time task and after the subjects had been doing the task for some time he made one light more probable than the other two. Noise reduced reaction time to the more probable light but slowed responses to the other lights.

89 Unfortunately, there are other pieces of evidence which suggest that Broadbent’s statement is an oversimplification of what happens in noise. For example, if one considers the experiments involving recall of high and low probability information one finds that the effects of priority are easily modified and this in turn changes the effect of the noise (see Smith, 1982). Smith (1982) suggested that noise biases the allocation of effort towards the operation which appears to best repay the investment of more effort. This may take the form of a bias towards the high priority task but it is also likely to depend on other factors such as the difficulty of each part of the task, the subject’s prior experience and the salience of the stimuli.

90 Smith and Broadbent (1982) managed to replicate Eysenck’s (1975) findings in one study but in another they obtained the opposite effect (dominant instances were less favoured in noise and non-dominant instances were not impaired by noise). In the study which replicated Eysenck’s findings the subjects had previously been performing a task demanding recall of words from categories, whereas this was not the case in the second study. Presumably, therefore, the subjects in the two experiments approached the same objective task with different presuppositions and strategies of performance. Similarly, Smith and Broadbent (1982) found different effects of noise depending on whether the dominant and non-dominant instances were presented in blocks or mixed together.

91 Smith and Broadbent (1985) have shown that moderate intensity noise has no effect on the Stroop interference condition. Indeed, 30 minutes’ exposure to 85 dBC noise influenced the control conditions of the Stroop task, with the noise improving naming of colour patches but slowing the reading of colour names. Further evidence for the view that noise does not always increase selectivity when there are interfering cues comes from a study by Smith and Broadbent (1980), which showed that noise had no effect on the speed of finding a simple figure embedded in a more complex pattern.

Confidence of judgments in noise

92 Broadbent and Gregory (1963, 1965) found that very loud noise (over 90 dB) produced more confident assertions and denials in the second half of a vigilance task, but reduced the number of reports of intermediate confidence. Poulton (1978, 1979) suggested that the confidence changes in noise are due to noise blurring the distinctions between rating categories.

93 Jones, Thomas and Harding (1982) and Smith (1989b) have demonstrated that even moderate intensity noise may change the use of confidence categories. However, both studies showed that the nature of the noise effect depended on the material that had to be recalled. Jones et al. (1982) tested memory in the quiet (for material presented in noise or in quiet) and this meant that their effect could not be explained by a single mechanism based on confusion between categories of confidence.
The inadequacy of early explanations of the effects of moderate intensity noise

94 Although these recent studies have shown that moderate intensity noise does influence performance they also reveal the inadequacy of most theories which suggest that performance is shifted by noise in an invariant or mechanical fashion. Changes in the difficulty of the task, subject's prior experience, and changes in other task parameters may abolish or even reverse certain effects. Many of the tasks affected by this level of noise have used verbal materials and this made it initially attractive to think in terms of an effect of noise on internal speech. However, verbal tasks often present subjects with several ways of doing a task and noise may change the relative efficiency of performing in one way rather than another.

The 'hidden defect' view of noise effects

95 Hamilton, Hockey and Rejman (1977) suggested that in noise there is a faster throughput of information but reduced short-term storage. This was supported by two results. First, a study of letter transformation speed showed that there was a slight benefit to be had in noise when there was no storage load, but performance was impaired by noise when there was a high storage load. Second, in a running memory task noise improved recall of the most recent items but impaired recall of items earlier in the list. 96If noise alters the relative efficiency of different stages or processes then certain results will be obtained when these processes are used a great deal and other results when they are used to a lesser extent. This type of theory of why noise effects are variable will be referred to as the "hidden defect theory". The noise-induced defect in the running memory task is the reduced storage capacity. This suggests that the effect of noise on running memory will depend on whether the memory load is high or low, and, indeed, Smith (1983b) has shown that Hamilton et al.'s results are only obtained in high memory load conditions.

Strategies of performance in noise

Appropriate strategies can eliminate the effects of noise

97 Pollock and Bartlett (1932) carried out an experiment in which subjects were given groups of letters and told to form as many words as possible from these letters. At first the subjects were impaired by noise but later they were able to perform as well as in the quiet condition. The subjects reported that as time went on they discovered rules and mechanical techniques of solving these problems, and once they had developed these strategies the noise ceased to have an effect. This shows that choice of an appropriate strategy can act as a buffer against the effects of noise.

Noise influences the choice of strategy

98 Smith (1983c) has reviewed evidence which demonstrates that when subjects carry out a task which can be performed in different ways, noise may lead to the adoption of certain strategies in preference to others. This view will be referred to as "strategy choice theory". Some examples of noise influencing the choice of strategy will now be given. First, there is evidence that subjects in noise may use a maintenance rehearsal strategy rather than an elaboration strategy (Daee and Wilding, 1977). Second, subjects in noise may adopt different recall strategies from subjects in quiet (Miles and Smith, 1988; Smith et al., 1981). Third, Smith (1985c) carried out an experiment on the effects of noise on the recall of global features and local detail, and he found that in
quiet subjects showed a bias in favour of recalling global features whereas subjects in noise showed a preference for local detail.

99 If task parameters are changed then the method of doing the task often changes. This plausibly explains why noise effects vary when task parameters are altered. This point can be illustrated by considering the results of Smith et al. (1981) in more detail. They found that noise reduced the amount of clustering in free recall, and this was due to recall in noise consisting of fewer words in the initial clusters and greater subsequent recall of individual words. This strategy was not used when the word lists contained weak instances of categories (initial clustering was greatly reduced in this condition), nor if exhaustive categories (e.g. units of time) were used (in this case, all the words from one category tended to be recalled in one cluster, hence there was little recall of individual words). In these last two conditions there was no reduction of clustering in noise.

Noise reinforces the use of the dominant strategy

100 In many tasks it is obvious that one strategy should be used in preference to others. This may be because of instructions, previous experience, or some other feature of the task. Studies by Smith (1982) and Wilding, Mohindra and Breen-Lewis (1982) have shown that noise may reinforce the use of the dominant strategy. Verbal tasks are particularly sensitive to noise and this may be because they offer a variety of strategies, and shifts of dominance or preference can occur more easily than in tasks with sensory input.

101 Dornic (1981) showed that loud noise changed bi-lingual language systems in favour of the dominant one. In another experiment (Dornic, 1982) he had subjects carry out a Stroop task in which the interfering stimuli came either from the dominant language or from the non-dominant language. When interference came from the non-dominant language noise reduced the effect. However, when the interfering words were from the dominant language noise increased the Stroop effect.

Resource allocation in noise

102 Smith (1988a; in press; and in preparation) has examined resource allocation in noise by studying dual task performance. The difficulty of each task was varied, so was the probability of having to do the task, and in other conditions one of the tasks had a higher priority than the other. The results showed that:

103 (1) The effects of noise depended on the nature of the task, e.g. when subjects carried out a cognitive vigilance task involving detection of repeated numbers (DORN) and a proportion perception task (PROP), DORN was impaired by noise whereas PROP showed little effect.

(2) Changing the task parameters only influenced the noise effect if the two tasks competed for common resources, e.g. the effect of noise on DORN and PROP was not altered by changes in difficulty, probability or priority. This was because PROP was performed in a passive, automatic way and was not influenced by the active allocation of processing resources. However, when DORN was paired with a task which was also influenced by the active allocation of processing resources (a running memory task), then the effect of noise was modified by changes in the task parameters. For example, when there were no priority instructions, DORN was impaired in noise but this effect was removed when DORN was made the high priority task.
(3) The effects of noise depended on whether the task parameters were constant or were rapidly changing. This will be discussed in more detail in the section on noise and flexibility of changing strategy.

**Noise alters the efficiency of the control processes**

104 Rabbitt (1979) has suggested that the effects of noise on the five-choice serial reaction time task (an increase in errors and/or gaps) can be explained in terms of noise producing inefficient control of the speed-error trade-off function. The effect of noise on the control processes may reflect initial coping with the task and may disappear when practice shows which is the most suitable method for doing the task. However, the effects may also be longer lasting and transfer from one experimental condition to another. This can be illustrated by the results from an experiment by Smith (1985d) on the effects of noise on recall of strong and weak associates. The rationale behind the study was that noise should increase associative recall when this was the obvious strategy to use (when the list contained strong associates) but not when recall association was less obvious (when the lists consisted of weak associates). The subjects were shown two lists of words, the first consisting of strong associates and the second weak associates. As predicted noise increased associative recall in the first list but associative recall was also better in noise for the second list. This reflects the transfer of strategy from one condition to another.

105 Smith (1985a) showed that noise reduced reaction times to lights with a high probability of occurrence. Following this condition the probabilities of the lights were equated and it was found that the effect obtained in the biased probability condition continued even when the equal probabilities were restored (i.e. the light which had been the high probability one was still responded to more quickly in noise and the others more slowly even though they now occurred with the same probability).

**Asymmetric transfer**

106 The effect of noise may also transfer to the quiet condition. Asymmetric transfer effects are well documented in the literature (see Poulton, 1982), as are the after-effects of noise (see Cohen, 1980).

**Inflexibility in noise**

107 Poulton (1982) considers asymmetric transfer to represent transfer of the strategy used in one condition to another condition. This suggests that subjects in noise may be considered rather inflexible and this view is supported by some recent results. Dornic and Fernaeus (1982) have reported a study which shows that noise increases processing rigidity by impairing switching between cognitive strategies. Smith (in press) had subjects carry out a dual-task involving PROP and a running memory task. The difficulty, probability and priority of the tasks was changed quite frequently, and in this experiment noise produced an overall impairment of the running memory task. This is probably due to the subjects being unable to develop a satisfactory coping strategy in noise (see Pollock and Bartlett, 1932) because of the changing demands of the task. Pons and Baudet (1978, 1979) examined the effects of noise on word associations. They found that the originality of associations was reduced in noise (or if variety of response persisted in noise then the latency was higher) and that associations tended to be repetitions or alternations.
Motivational changes in noise

108 This review has, up to now, been concerned with providing a detailed profile or description of the effects of noise. This description would not be complete without some discussion of the motivational changes found in noise. Indeed, this will also allow us to consider some of the possible explanations for the effects of noise which have been described.

109 It has been shown that noise reduces subjects’ tolerance for frustration (Glass and Singer, 1972), reduces their level of aspiration (Krenauer and Schönfliog, 1980), changes the amount of effort put into the task (Schulz and Schönfliog, 1982), and influences their perception of competence (Jones, 1984). Schönfliog (1983) provides an excellent account of the relationship between cognition, motivation, task demands and performance in noise.

Effort and noise

110 It has been suggested that voluntary effort may be used to compensate for the potentially deleterious effects of noise on human performance. If this is the case, then some of the negative effects of noise on performance may be masked by compensatory effort. However, this extra effort may occur at some physiological cost. Tafla, Evans and Chen (1988) tested this view in a study of the effects of noise on a complex mental arithmetic task. Reaction time increased on the task under noise, but only in low effort conditions. As predicted, noise had no effects on performance under high effort conditions. However, systolic and diastolic blood pressure increased during the high effort conditions in noise.

Psychological set and noise

111 Fisher (1983) examined the effects of noise on choice reaction time tasks and on subjective judgments of the speed of response. Reaction times were faster in noise but subjects used more "slow" categories to describe them. The effect was not observed when the same reaction times were re-rated under instructions, which indicated that they were "random time intervals", nor when a new group of subjects rated the original reaction time data. A further study demonstrated that subjects believe that noise will slow reaction times. These results suggest that pessimistic expectancies about the effects of noise may play an important role in determining what effect noise has on performance.

112 Other studies have manipulated the attitudinal set of the subjects. For example, Mech (1953) told one group that noise facilitates performance, another that noise interferes with performance, and a third that noise sometimes facilitates and sometimes interferes with performance. The control group was given no information concerning the effect of noise. Mech found that set did influence the effect noise had on performance and that the change was in the suggested direction.

113 However, other studies have suggested that the effects of set can easily be modified by other factors. For example, Gawron (1982) found that the effect of noise was modified by the type of set that was induced, but that this was only observed in the group told that noise would facilitate performance and for performance on certain tasks. Gulian and Thomas (1986) found complex interactions between gender and cognitive set, which they suggest supports the idea that the effects of noise are mediated by a constellation of factors. Indeed, Jones (1984) has argued that noise changes the individual’s perception of what is competent performance. He has suggested that the effect of noise on performance reflects the interaction between the subject’s beliefs about the
aversiveness of the noise, the level of performance the subject considers appropriate, the demand characteristics of the experiment and the instructions of the experimenter. A threat to competence by noise may give rise to the selection of certain types of strategy aimed at maintaining the integrity of performance.

**Noise and knowledge of results**

114 Woodhead (1958) found that verbal encouragement and knowledge of results eliminated the deleterious effects of noise in about one-third of the subjects. However, Wilkinson (1963) found that a combination of noise and knowledge of results led to even worse performance than noise alone.

115 Thomas and Jones (1979) examined the interaction between loud noise and knowledge of results during and after performing a line drawing task. Subjects were given either no feedback, success feedback, failure feedback, or a mixture of success and failure feedback. When the line drawing task was performed in quiet both success and failure feedback improved performance. In contrast to this, subjects in noise performed the task more quickly when there was no feedback or when a mixture of success and failure was given. When the task was performed in noise subjects produced lower ratings of success in all conditions except the failure condition. After the line drawing task the subjects carried out a problem solving task (in quiet). Subjects who had been in noise took more time to solve the problems, except for those subjects who had been given failure feedback. The valence of the feedback is, therefore, an important factor in determining the precise direction of the noise effect.

**Noise and social behaviour**

116 This is a very important area because many activities involve social interaction and may be impaired if there are problems within the group. Many of the effects of noise on social life reflect direct effects of noise on communication. However, there is evidence that noise may reduce helping behaviour (see Page, 1977), increase aggression (Donnerstein and Wilson, 1976), influence the judgment of others (Siegel and Steele, 1980), and reduce the processing of social cues seen as irrelevant to task performance (Cohen and Lezak, 1977).

117 Other studies have examined the effects of noise in different social settings. Auburn, Jones and Chapman (1987) carried out an experiment on the effects of noise on the Bakan vigilance task, with the subjects being tested either alone or with another. Noise and social setting influenced performance but the effects of the two factors were independent. Nagar and Pandey (1987) found that crowding and noise led to a deterioration on cognitively complex tasks but not on simple tasks.
XI COMBINED EFFECTS OF NOISE AND OTHER OCCUPATIONAL HAZARDS

118 Experimental studies of noise are usually rather artificial in that they examine the effects in isolation. In real-life the worker is often exposed to a complex combination of stressors and it is important to determine whether these have additive, interactive or independent effects. Work on combined effects of occupational health hazards has greatly increased in recent years (see Manninen, 1988b), although the number of performance studies is still small.

Noise and nightwork

119 These studies have already been described (paragraphs 72 - 73) and are reviewed in detail by Smith (1988b; 1989c).

Heat and noise

120 These experiments have been reviewed by Hancock and Pierce (1985) and Wyon (1984). Hancock and Pierce (1985) argue that the effects of these factors are largely independent. Wyon claims that 85 dB noise counteracts both the positive and negative effects of moderate heat stress on mental performance, but increases the negative effects of extreme heat stress. In a very recent study Hygge (1988) showed that heat and noise produced both independent and interactive effects, depending on the activity being carried out.

Noise and vibration

121 This has been widely studied (e.g. Harris and Shoenberger, 1980; Seidel, Meister, Metz, Rothe, Ullsperger, Blüthner, Bräuer, Menzel and Stroka, 1988). Generally, the results have shown that mental performance is not significantly altered by varying the combinations of noise and vibration.

Noise and illumination

122 Pepler (1960) examined the effects of heat, glare and irrelevant speech on tracking performance. He concluded that heat influences the control of movement, whereas speech and background glare impaired perception.

123 Nakai, Hosokowa and Saito (1987) examined the effects of noise and illumination on search from a VDU. The noise reduced the speed of search and was associated with a slowing of the brain waves. The most conspicuous slowing of the brain waves was observed when the noise was paired with the lowest illumination intensity (300 lx).

Noise, sleep loss, alcohol and other drugs

124 All of these variables have been assumed to alter arousal. For example, sleep loss decreases arousal whereas noise is thought to increase it. Noise should, therefore, remove the performance impairments associated with sleep loss, and such results have, in fact, been obtained (e.g. Corcoran, 1962). However, Broadbent (1971) has suggested that a uni-dimensional model of arousal is inadequate and that the variables should be classified into at least two subgroups. In the first he put noise, sleep loss and amphetamine, and he argued that these should interact in a reliable way. In the other group he placed time of day, alcohol and barbiturates. Variables from this second group were thought not to interact with those in the first, and detailed studies of noise and time of day show that this is the case (see Smith, 1987).
Hartley and Shirley (1977) found that sleep loss made performance more risky and that noise caused a rise in the risky criterion. There was evidence that in combination noise and sleep loss had mutually antagonistic effects on discriminability. In contrast to this, Hartley, Couper-Smartt and Henry, (1977) found that noise and chlorpromazine applied separately caused impairments in similar ways. When applied in combination the two agents cancelled each other out.

Hamilton and Copeman (1970) found that both noise and alcohol impaired detection of peripheral lights. However, the two agents did not interact and analysis of another part of the task showed that alcohol impaired tracking, whereas noise had no significant effect on it.

Cox, Simpson and Rothschild (1973) found that pre-loading with glucose impaired performance on a tracking task. Noise also impaired performance, although pre-loading with glucose attenuated this effect.

Broadbent's classification is too simplistic and recent accounts (e.g. Hockey and Hamilton, 1983) have tried to produce detailed profiles of the performance effects associated with each factor, rather than comparing them on a single task. This approach must now be supplemented with more studies of the combined effects of the different stressors.
XII AN EVALUATION OF THE EFFECTS OF NOISE ON PERFORMANCE

Are the experimental techniques adequate?

129 As in any area of research there are certain studies which it is difficult to evaluate because of the lack of detail in the report. Other studies can be disregarded because of things such as small subject numbers, although it should be noted that these are mainly studies which have shown no effect. Indeed, inadequate sampling of subjects, poor experimental design, etc., are more likely to give null results than positive.

Could all the detrimental effects of noise on performance be due to auditory effects (e.g. masking)?

130 This is unlikely for three main reasons:

(a) First, the same equipment, etc., gives rise to detrimental effects in some conditions, or experiments, but not others.

(b) Mackay, Cox and Freeman (1978) found that noise impaired tracking performance both in the presence and absence of task-related auditory feedback. In other words, one can get the same noise effect from equipment differing in the amount of auditory feedback given.

(c) After-effects of noise exposure have been observed and here the subjects are being tested in the quiet.

Are the effects negligible?

131 Some people may suggest that even if there are detrimental effects of noise on performance efficiency they are too small to be worth considering. For example, in some experiments noise produces very small increases in reaction time or in error rate (which is often already low), and these are often associated with improvements in other parts of the task. However, the consequences of an error may be great (e.g. driving a car), and in modern situations accidents and scrappage rates due to error are of major economic importance. Whether a performance impairment matters or not depends on a particular situation, and until we have further information about the size of noise effects in real-life situations, it is difficult to be more precise about the importance of the effects. At the moment, the little information we have from the field suggests strong relationships between noise levels, errors and accidents.

Are the findings mutually consistent?

132 By taking into account the nature of the task, the way it is performed, the nature of the noise, the characteristics of the person doing it, details of the experimental setting, etc., it is possible to construct a profile of the effects of noise. This is more complicated than earlier views (e.g. Broadbent, 1979) but is an elaboration rather than rejection of accounts based on much smaller databases. A summary of the profile of the effects of noise on performance will now be given.

A summary of the major conclusions that can be drawn from recent studies of the effects of noise on performance

133 Previous reviews of the effects of noise on performance fall into three categories. Some reviews (e.g. Kryter, 1970) have concluded that apart from its direct acoustic effect noise will not interfere with performance. Such a view
arises partly from a proper emphasis on the absence of any noise induced impairments on routine and predictable tasks. However, a more detailed examination of the literature shows that there are studies which report detrimental effects. These have either been ignored in certain reviews or have been carried out after the reviews were written.

134 More recent reviews (e.g. Gulian, 1973; Loeb, 1983) have concluded that the effects of noise are complicated, influenced by many different factors and still only partially known. The effects of noise reviewed here are certainly complicated and a major part of recent research has involved identification of factors which modify the effects of noise. Nevertheless, certain general conclusions can be drawn about the effects of moderate intensity noise on performance. In this respect, the present review is similar to those which are more definite about the effects of noise on performance (e.g. Broadbent, 1979; Jones, 1989). Indeed, the two main conclusions are very similar to those made by Broadbent (1979), and they are that noise has a definite effect on performance but that the precise nature of the effect depends on the type of noise and the task being performed.

135 Broadbent’s conclusion about the importance of the nature of the noise was largely based on the comparison of continuous and intermittent noise. Recent studies have confirmed that performance will be temporarily disrupted by sudden bursts of noise, and that activities involving the continuous intake of new information are most at risk from this type of effect. A major development in recent years has been the interest in the effects of irrelevant speech, and we now have strong evidence that even very low intensity speech will impair ordered recall of verbal materials (even when they are presented in written form). Further research is required in this area, particularly on the effects of the phonological similarity between visual and auditory information. This research will be important in helping us understand why some sounds are more intrusive or annoying than others, and it will enable us to obtain a more precise view of the mechanisms underlying the effects of irrelevant speech on memory and reading. Furthermore, field studies should now assess the educational, economic and social impact of irrelevant speech in the work environment.

136 Broadbent (1979) concluded that some types of activity were more susceptible to the effects of noise than others. Recent results have enabled us to produce a more detailed profile of the effects of noise on performance and the main conclusions are summarised below:

137 (1) There are effects of noise related to the use of internal speech but these are complex and cannot be accounted for by a simple masking theory, or any other mechanistic model which assumes that noise alters performance in a passive, mechanistic way.

138 (2) The effects of noise on performance depend not only on the type of task, but on task parameters and other features of the experimental situation. However, there is evidence that noise may produce the following type of change in performance:

(a) Noise leads to the choice of certain strategies in preference to others.

(b) Noise often reinforces the use of the dominant strategy.

(c) Noise impairs the control processes which track and change performance. This may lead to biases in the allocation of processing resources, and it may make the subjects rather inflexible and less adaptive to change.
We have information on all of the above points but further research is now required to address the following topics:

1. Strategies in non-verbal tasks: little is known about the way noise disrupts tasks which do not employ verbal materials.

2. Noise and strategy selection: further research is required on the factors which influence strategy selection in noise. In particular, there must be studies of individual differences in strategies of performance in noise.

The other type of study which must now be undertaken will involve detailed consideration of the long term effects of noise exposure, and of the combined effects of noise and other factors. Ideally, this will involve prospective studies and assessment of appropriate interventions which change the noise levels and other parameters. Until this is done we will not know whether our elaborate studies of the acute effects of noise in the laboratory are of relevance to real-life effects. Preliminary indications suggest that they are. For example, Lévy-Leboyer and Moser (1988) examined the effects of noise on tasks involving assembly of a carburettor and an air conditioner. Noise improved the speed of assembling the air-conditioner but reduced the speed for carburettor assembly. These conflicting results can be explained by the different content of the two tasks and the different abilities required to do them.
XIII NOISE, ACCIDENTS AND PRODUCTIVITY.

141 The previous section described the effects of noise on the efficiency of human performance. All of these studies have been concerned with the acute effects of noise, and in order to get evidence about long-term effects one has to turn to field studies rather than laboratory experiments.

Noise and accidents

142 There are very few studies which have dealt with safety and efficiency in the workplace, and yet several strong statements have been made about this topic. For example, King (1947), addressing the National Safety Congress, stated that ".....in certain circumstances, noise may actually be one of the direct causes of an accident." Similarly, Heald (1955) drew attention to the relationship between aircraft noise and accidents on the flight decks of aircraft carriers. However, no evidence was presented to support these assertions.

143 Other reports have suggested that there is little evidence of a relationship between noise exposure and accidents. For example, the Committee on the Problem of Noise (Wilson Committee Report, 1963) concluded that "We have been able to obtain little evidence on the effects of noise upon the incidence of industrial accidents." Similarly, Atherley and Purnell (1969) stated that "We are aware of no studies which show a consistent effect of noise on accident rate." However, there have been studies of this topic and these will briefly be reviewed.

Noise and accidents: Between group studies

144 Kerr (1950) reported a significant correlation (0.42) between the frequency of accidents and the noise levels of 53 departments in an electronics factory. Forty other factors were examined and noise produced the second highest correlation (after job mobility).

145 Cohen (1974) showed that people who worked in high noise areas of a factory manufacturing boilers had more accidents than those in low noise areas in the same plant. The high noise group consisted of those exposed to levels of 95 dB(A) or more, and 35% of this group had 15 or more injuries over the five-year period investigated. In contrast to this, only 5% of the low noise group (exposed to less than 80 dB(A)) had a comparable injury rate. The number of accidents per worker was greatest for the younger persons in noisy jobs and for those who had the least experience at such jobs. The accident rate diminished with increasing age and job experience for workers in noisy workplaces, with similar, though less obvious, changes noted for those located in quieter areas.

146 A similar result was obtained in a French study by Jessel (1977), with accidents being three or four times more frequent in noisy situations than in quiet ones. Lees, Romeril and Wetherall (1980) found no significant effect of noise on accidents. However, they only studied 140 workers and the effect of noise would have had to be very large for them to detect it.

147 Noweir (1984) studied a sample of 2458 workers exposed to average noise levels ranging from 80 to 99 dBA in different operations of three textile mills. The frequency and severity of accidents in the high noise departments were greater than in the low noise departments although the difference was not statistically significant. Further analyses examined the extent to which the noise effects reflected personal, socioeconomic or occupational history factors. The results showed that none of these factors modified the extent of the difference between high and low noise departments.
Wojtczak-Jaroszowa and Jarosz (1987) found that accidents peaked at 11.00 a.m., which was the time of highest noise level. However, it was also the time of highest productivity, largest number of workers, a time when there was a need for fast co-operation, and both administrative and medical offices were open then.

Indeed, all of the above studies suffer from the problem that noise exposure is confounded with other uncontrolled variables. Kerr (1950) made the following comment which applies to most studies of noise and accidents—"Whether the noise level is causal of accidents or mostly an incidental correlate of hazardous factory operations is not entirely clear." Most of the studies described above roughly matched the high and low noise groups for factors such as age, work experience, etc., but it was not possible to match the work tasks or working environments.

In order to counter this fundamental criticism intervention studies involving noise reduction have been carried out and these are summarised in the next section.

Effects of noise reduction on accident rates

Cohen (1976) reports data on the frequencies of job injuries for 400 workers in high noise job areas for two year periods before and after introduction of a hearing conservation programme involving use of personal ear protection. There was a significant reduction in the number of injuries after the introduction of the programme (median number of injuries before = 3.8, median number after = 2.3). In contrast, there was no corresponding reduction in the injury rate of workers in low noise areas.

Cohen argues that the above results cannot be attributed to plant-wide changes in general morale or awareness of safety. However, it is possible that such factors were responsible because the hearing conservation programme was applied differently to the high and low noise groups. The injury rate was lower both for workers who regularly wore their hearing protectors and those who did not, which also suggests that factors other than noise reductions may have been involved.

Schmidt, Royster and Pearson (1980) found a similar reduction in accident rates after the introduction of a hearing conservation programme. However, this study did not include a control group and neither was information on the actual use of hearing protection collected.

Noise and accidents: possible mechanisms

Noise could increase accidents by its auditory effects. Indeed, the 1972 Code of Practice states that noise may lead to accidents by "hindering communications and by masking warning signals." Another possibility is that noise may impair attention either by a direct distraction effect or in a similar way to that seen in laboratory studies of serial responding.

It is impossible to tell whether the results reported in the literature reflect auditory or non-auditory effects of noise. The results of Cohen (1976) suggest that the higher accident rate in noise may be produced by non-auditory effects. This is because the use of hearing protection does not impair the effectiveness of selecting warning signals. The protectors reduce the level of both the signal and noise by the same amount, and it is the signal/noise ratio which is important in determining audibility. However, problems may arise when
they are worn by people who already have an existing noise induced hearing loss (see Wilkins and Acton, 1982).

**Noise and accidents: conclusions**

156 There have been very few studies of this topic and the results suggest that noise is at least a contributory factor in the occurrence of some accidents. It is unclear whether these results reflect auditory or non-auditory effects of noise. Further studies must involve more detailed analysis of individual accidents, and this should enable us to determine the specific noise effects involved. Prospective studies are needed, as are intervention studies which do not change the working environment (apart from reducing the noise level). Most of the previous research has also been concerned with very loud noise levels, and comparisons of moderate intensities with low levels are now required.

**Noise and productivity**

157 Weston and Adams (1932) examined the performance efficiency of weavers who wore ear defenders on alternate weeks for six months. The results showed that efficiency was 12% greater when wearing ear plugs, and this was observed in all ten workers, even though some of them thought that the ear plugs made no difference or actually led to a deterioration of their performance.

158 Broadbent and Little (1960) examined the effects of noise reduction in the workplace. The results agreed with those of laboratory experiments described in the previous section, in that the relative rate of work in noise and quiet was not improved by noise reduction, whereas human error was less frequent when noise was less. This is a very important result because it confirms that noise does produce human error, even in people who are used to it.

159 Noweir (1984) also reports that production efficiency was lower in noise and that workers in noise were more likely to be disciplined for damaging material.

160 Overall, these results do seem to confirm the view that noise may influence the quality of work, which may, in some circumstances, have a large economic impact.
XIV RECOMMENDATIONS FOR FUTURE RESEARCH ON THE EFFECTS OF NOISE ON PERFORMANCE EFFICIENCY AND SAFETY

161 The effect of noise on performance has been studied in great detail in the laboratory for over 40 years. These studies have been carried out with many differing aims and it is not surprising, therefore, that previous reviewers have reported a rather confusing picture of the effects of noise. Indeed, many experimental studies have been carried out to aid theoretical development, or elucidate which mechanisms are affected by noise, rather than having been concerned with the practical consequences of noise exposure.

162 In general, one may conclude that there is not sufficient evidence from the laboratory studies to predict the effects of noise in the workplace. This is mainly because most laboratory studies have examined the effects of very short noise exposures, and we have little information on the changes in performance associated with longer exposures. The first need, therefore, is for some longitudinal research in this area.

163 Two of the main conclusions from the laboratory are that the effects of noise depend on the type of noise and the nature of the task being performed. This makes it difficult to select any level below which we can say with confidence that there will never be any detrimental effects of noise. Rather, we should aim to detect which activities are vulnerable in a particular noise environment. The fact that the effects of noise depend on its precise form and on the activities performed in the noise is similar to conclusions drawn about other occupational hazards. For example, the effects of shiftwork have been shown to depend on the nature of the shift system and on the task being performed. Future longitudinal studies of the effects of noise in the workplace must, therefore, pay close attention to task characteristics and the specific parameters of the noise. Indeed, noise intervention procedures should ideally be used rather than relying on cross-sectional comparisons.

164 Present research has also shown that it is a mistake to consider the effects of noise in isolation. The longitudinal studies in the workplace must not only consider the noise characteristics and features of the tasks being performed but the role of other factors found in that working environment must also be examined. These factors may be other forms of physical stress or stressful characteristics of the job. It is also necessary to consider characteristics of the worker which are not directly related to the job but which may be important in coping with occupational stress (e.g. social support).

165 One must conclude by stating that it is highly desirable to carry out a prospective, longitudinal study of the effects of noise in the workplace on different aspects of performance efficiency. After-effects of noise exposure must also be examined for there is little evidence on whether noise at work influences the efficiency of activities carried out in leisure time.

166 The next section reviews research on the effects of noise on health. It is of major interest to examine whether a longitudinal study in the workplace would also benefit this area, for, if this is the case, a multidisciplinary study could then be mounted. This would not only provide information on the effects of noise per se, but would clarify the relationship between changes in performance efficiency and effects on health.
The basic non-auditory physiological effects

It is thought that noise produces its primary physiological effects by changing the reticular activating system (RAS). The RAS activates the higher cerebral centres, the sympathetic autonomic nervous system, the adrenal medulla (which may lead to an increase in catecholamines), the adrenal cortex (which may increase the level of cortisol), and the limbic system (which produces changes in emotion and mood).

Davis, Buchwald and Frankman (1955) measured the effects of repetitive exposure to 1000 Hz tones of various intensities on blood pressure, pulse, peripheral vasodilation, GSR amplitude and latency, breathing amplitude and depth, and temporal pattern of breathing. When a series of tones were given the early ones produced an initial rise in pressure pulse amplitude. There was a decrease, followed by a sustained rise. Volume pulse increased briefly and then fell. Finger volume decreased, which indicates peripheral vasoconstriction. GSR amplitude and latency decreased and pulse rate slowed. Breathing rate amplitude increased, although the rate itself decreased. Generally, there were few changes in the reactions when the noise was below 70 dB, and the effects observed between 70 and 90 dB were less pronounced than changes between 90 and 120 dB. Generally, all of the effects tended to adapt or extinguish with stimulus repetition, except for the increase in deep breathing, which increased with repetition.

Davis (1948) examined the effects of noise on muscle action potentials, and the results showed that noise increased the EMG levels. Davis and Berry (1964) and Stern (1964) also found that gastrointestinal mobility was increased by high levels of noise.

It is important to know whether these laboratory effects are also observed in real-life, and, if so, whether such effects also habituate rapidly. Bättig, Buzzi, Zeier and Müller (1979) investigated the effects of aircraft noise on physiological responding. They found that under field conditions the effects did not habituate completely. However, the authors argue that extreme caution is required when interpreting the present results in terms of effects of noise on health. They also point out that the physiological effects of noise vary enormously from individual to individual.

A major research problem is that the physiological effects of noise are agent non-specific, and other factors in the workplace may produce similar changes. The time of measurement of the physiological changes is also important for some reactions present immediately after noise exposure may have disappeared or even reversed at a later time. Indeed, a major issue is whether such effects do result, after prolonged exposure, in a cumulative pathology.

The importance of the nature of the noise

Just as in the study of the behavioural effects of noise, the parameters of the noise can be crucial. The intensity of the noise has already been shown to be very important, and this has been confirmed in a study by Horio, Sakamoto and Matsui (1972). They found that moderate levels of noise increased corticosteroids in rats but that this increase was short-lived. In contrast to this, higher noise intensities led to the corticosteroids being elevated over a longer time period.
The meaning of the noise is also very important. For example, Atherley, Gibbons and Powell (1970) found that meaningful, but not meaningless noise, led to an increase in 17 ketosteroid excretion in urine. Other studies have shown that control over the noise can influence physiological responding. Breier, Albus, Pickar, Zahn, Wolkowitz and Paul (1987) exposed 10 healthy volunteers to 100 dB under controllable and uncontrollable conditions. Subjects in the uncontrollable noise condition had greater hypothalamic-pituitary-adrenal axis function (as measured by elevations in plasma ACTH), and had higher levels of sympathetic nervous system and electrodermal activity.
XVI  METHODS OF STUDYING NON-AUDITORY PHYSIOLOGICAL AND HEALTH EFFECTS OF NOISE

(a) Epidemiological studies

174 There have been many epidemiological studies of the non-auditory effects of noise (see Welch, 1979, and Thompson, 1981, for reviews). The overall quality of these studies is poor with failure to give detailed descriptions of the methodology. Furthermore, the noise exposures are often inadequately specified, criteria for conditions such as hypertension vary, and often there are no quantitative data. However, the biggest problem with these studies is the lack of consideration of other workplace variables.

175 Most of the research has been cross-sectional although a few have used prospective designs and some have employed noise-related interventions. The findings have usually been qualitative and there is little basis on which to derive dose-response functions or infer causality. While most areas have led to both positive and negative results some effects of noise have been observed quite regularly. For example, 80% of the studies reviewed by Thompson show some relationship between noise exposure and increased blood pressure.

(b) Experimental studies

176 These have usually involved introducing some form of hearing protection or have involved studying the same individual under high and low noise conditions. For example, Ising, Gunther, Haverstadt, Kraune, Markert, Melchert, Schokreckt, Thefeld and Tietze (1979) studied brewery workers on days when they were wearing hearing protection and days when they did not. The results showed small intra-worker elevations in blood pressure and noradrenalin when the workers did not wear protections. Similarly, Ising, Diene, Gunther and Markert (1980) found that high traffic noise increased blood pressure and several biochemical measures.

(c) Animal studies

177 Studies of rats have shown that noise sometimes increases blood pressure and sometimes does not. However, the rat model is not very appropriate because of the difference from humans in the structure and functions of its auditory system.

178 Peterson, Augenstein, Tanis and Augenstein (1981) examined the effects of noise on the blood pressure of primates. They observed elevations in blood pressure which did not drop after a full month of post-exposure in quiet. The monkeys showed no appreciable hearing loss which suggests that the non-auditory effects may occur at levels below those which cause damage to hearing. Of major interest is the finding that providing the animal with partial control over the noise resulted in smaller blood pressure changes.

Which physiological effects have been studied?

179 Rehm (1983) has summarised results from studies which have looked at a range of functions. These may be split into two categories - those which have examined vegetative responses - e.g. the effects of noise on respiration, heart-rate, cutaneous blood flow, constriction of the peripheral blood vessels, skin temperature, tremor, secretory function of the stomach, bowel transit, and bioelectrical activity of the brain - and those which have considered the biochemical effects of noise and examined blood lipid functions, blood glucose, cortisol, adrenalin, noradrenalin, dopamine, growth hormone, and magnesium and calcium levels.
There has been little study of the effects of noise on immune system functioning and resistance to infection. However, in one study (Jensen and Rasmussen, 1970) those mice inoculated with a virus just before noise exposure were more susceptible to infection, and those inoculated after the noise were less likely to become infected.

Research needs

Even before one considers these topics in detail it is apparent that there are many gaps in our knowledge. The role played by the various physical parameters (level, frequency spectrum, temporal pattern, and duration) of the noise is unclear. Similarly, the role of the context in which the noise occurs requires further study. Attention should be given to individual differences so that we know the relationship between the person’s annoyance and physiological response, and so we can determine which are the susceptible sub-populations.

Problems due to communicating in noise

Laryngopathies, laryngitis, vocal chord polyps and nodules are all found in people who work in a noisy environment. Communicating in noise often leads to increased annoyance, and if the noise prevents communication the worker may become isolated, interaction with others may be less cohesive, which in turn may result in lower job satisfaction.

Noise annoyance

While there is concern over the effect of the nature of the environment on health, it has been demonstrated that psychological factors, such as how the environment is perceived, are clearly important. For example, if one considers noise annoyance one finds that intensity alone only accounts for about 25% of the variance. The major determinants (often explaining 50% of the variance) are psychological factors - the person’s attitudes and beliefs about noise and the noise source.

Borsky (1969) suggests that annoyance is heightened when:

1. The noise is perceived as unnecessary.
2. Those responsible for the noise are perceived as unconcerned about the exposed population’s welfare.
3. The exposed person dislikes other aspects of the environment.
4. The person believes that noise is harmful to health.
5. The noise is associated with fear.

Noise and physical illness

The cardiovascular effects of noise have already been mentioned. Other studies suggest that noise increases the probability of many illnesses (e.g. Cameron, Robertson and Zaks, 1972) and leads to an increase in visits to the doctor and increased use of drugs (Grandjean, Graf, Cauber, Meier and Muller, 1973). However, these studies lack appropriate controls for income, housing levels and education (see Cohen, Glass and Phillips, 1979).
Other research has examined the effects of noise on mortality rates (e.g. Meecham and Shaw, 1979). These studies suggest that those exposed to noise are likely to show an increase in deaths due to stroke or cirrhosis. However, the comparability of the noise exposed individuals and the control group used in the study is questionable (Frerichs, Beeman and Coulson, 1980).

Noise and mental health

Various studies (e.g. Jenkins, Tarnopolsky, Hand and Barker, 1979; Meecham and Smith, 1977; Tarnopolsky, Watkins and Hand, 1980) have been concerned with the relationship between mental health and noise exposure. Workers in noise often show increased incidence of nervous complaints, nausea, headaches, instability, argumentativeness, and changes in mood and anxiety (see Cohen, 1969; Miller, 1974). Jansen (1961) has also shown that noise at work leads to an increase in social conflicts at home. However, all of these effects may reflect other work stressors as well as noise. Community studies have also presented slight evidence of increased mental hospital admissions in high noise areas near airports, although some of these effects have been attributed to other factors.

Effects of noise on susceptible sub-groups

In some laboratory studies subjects suffering from essential hypertension have been exposed to noise (e.g. André, Hansson and Björkman, 1981). They did not differ from healthy subjects in their blood pressure response to noise but did show greater changes in peripheral vasoconstriction. Other studies have compared coronary-prone (Type A) or non-coronary prone (Type B) people (e.g. Lovallo, 1980). While the Type A subjects showed differences in vasoconstriction and biochemical parameters when they were exposed to noise, there were no differences in the effects of noise on the heart rate or blood pressure of the two groups.

Pregnancy and birth defects

Ando and Hattori (1973, 1977) found that babies born near Osaka airport were of low birth weight. Jones and Tauscher (1978) found a greater number of abnormal births to mothers living in the noisiest areas around Los Angeles airport than would be expected by chance. However, it is unclear whether these results reflect the socio-economic status of the groups studied, and whether they could be due to other factors associated with airports, such as pollutants (carbon monoxide, unburnt fuel in the atmosphere, or airborne metal particles).

Rehm and Jansen (1978) and Knipschild, Meijer and Sallé (1981) examined the effects of noise on birth weights and birth defects. Both studies indicated a positive relationship between noise exposure and a reduced birth weight or an increase in the percentage of premature births. However, the effects were slight and not statistically significant in the Rehm and Jansen study. The Committee on Hearing, Bioacoustics and Biomechanics (1982) reviewed the human and animal data on the pre-natal effects of exposure to high-level noise. The Committee concluded that neither in human studies nor in animal experiments was there clear evidence of an effect of noise on pregnancy. This issue will be covered in more detail in a later section (paragraph 297) and more recent information from a study concerned with many occupational health hazards will be described there.
Noise and sleep disturbance

There is ample evidence to show that

(1) Noise may prolong the time needed to fall asleep

(2) Noise may cause awakening once asleep

(3) Noise may interfere with returning to sleep once awake

(4) Noise may cause shifting from deeper sleep to shallower sleep.

191 It has been estimated (Lukas, 1977) that the probability of being awakened is 5% at 50 dBA and 30% at 70 dBA. Similarly, the probability of changing sleep stage is 15% at 50 dBA and 45% at 70 dBA. Again, other factors (e.g. familiarity of the noise, duration, intensity, intrusiveness, abruptness of onset, predictability, and the age and sex of the person sleeping) may easily modify the effects of noise on sleep.

192 The short-term consequences of noise during sleep are well documented. Noise during sleep increases heart rate and this effect does not appear to habituate. Some studies have shown that subsequent performance is disrupted following noise during sleep, although others have not obtained such effects. In contrast to the acute effects of noise during sleep, there is, at present, little evidence of adverse health-effects associated with noise disturbed sleep.

193 The previous sections have given an overview of the non-auditory effects of noise on physiological functioning and health. The next sections treat the various topics in more detail and show that there has been a growing realisation that we should not consider noise in isolation but that the combined effects of occupational health problems must be studied.
XVII RECENT RESEARCH ON THE EFFECTS OF NOISE ON CARDIOVASCULAR FUNCTION

(a) Surveys

194 Knipschild (1977a) examined the relationship between aircraft noise exposure and data from a community cardiovascular survey. About 6,000 people (men and women, aged 35 - 64 years) were screened. The following relevant data were recorded for each participant:

1. age, sex, residence.
2. angina pectoris, medical treatment for heart trouble and hypertension, taking of cardiovascular drugs, smoking habits.
3. high blood pressure (systolic >175 and/or diastolic >100 mmHg), pathological heart shape (x-ray), ECG, and height/weight.

Afterwards the subjects were divided into two groups: those living in areas with high aircraft noise (NNI>37) and those with lower aircraft noise exposure (NNI=20-37).

195 The results showed that in the areas with high aircraft noise, more people were under medical treatment for heart trouble and hypertension and took more cardiovascular drugs (especially true for the women). Furthermore, in areas with higher levels of aircraft noise there were more people with high blood pressure and pathological heart shape. In the areas with the higher aircraft noise roughly 50% more people had cardiovascular impairment.

196 The differences between the two noise areas could not be explained by age, sex, smoking habits, height/weight, or by socio-economic differences. The fact that each individual was screened in an identical manner is a great methodological improvement. However, it should be noted that only 58% of those approached took part in the study, which means that the results could reflect a sampling bias. However, it is unclear how exposure to noise could produce such a bias.

197 Knipschild and Sallé (1979) investigated whether people living in a street with high levels of traffic noise ran an increased risk of contracting cardiovascular diseases. The subjects were housewives aged 40 - 49 years, and 1342 lived in quiet streets (Ldn<62.5 dBA) and 399 in noisy streets (Ldn>62.5 dBA). The frequency of consultation with a cardiologist, hypertension, angina pectoris, ischaemia on ECG and heart shape pathology were examined. No differences were found between the two groups, which may reflect the fact that the differences in exposure were too small. Alternatively, this type of noise may have a much smaller effect than, say, aircraft noise (see Knipschild, 1977c). Indeed, while the medical effects of aircraft noise exposure are relatively clear, other types of noise still require further study. If aircraft noise is rather unique it may also be difficult to generalise from research on it to the effects of noise in the workplace. The following sections are concerned with workplace noise and cardiovascular function.

198 Verbeek, van Dijk and de Vries (1987) carried out a cross-sectional study of the relationships between blood pressure, noise exposure and noise-induced hearing loss. Male workers from the production departments of 6 factories were examined. The assessments included:
(1) Duration of exposure to industrial noise (from work records)
(2) Otological anomesis
(3) Otoscopic examination
(4) Audiometry
(5) Measurement of blood pressure.

199 When the data was corrected for age it was found that those who had been
exposed to noise for 20 years had a systolic pressure 16 mm higher and a
diastolic pressure 7 mm higher than in workers exposed for less than 10 years.
The percentage of workers with hypertension (again after correction for age)
increased from 9% in the group exposed for less than 10 years to 28% in those
exposed to noise for over 20 years.

200 While a correction was made for age, the data were not corrected for
weight/height. It is also possible that the increased blood pressure might
reflect other adverse conditions. Van Dijk, Verbeek and de Vries (1987) examined
this in a field study in a shipyard. Two departments, the shipbuilding
department and the machine shop of the Dutch Royal Navy Shipyard were
investigated. The study involved 257 male workers (average age approximately 37
years), who underwent the assessments listed above. The level of noise (LAeq) was
measured by personal dosimeters. In the shipbuilding department the median LAeq
was 98.0 dBA, whereas in the machine shop it was 85.5 dBA.

201 No difference was observed between the two departments in either systolic or
diastolic blood pressure. In contrast, hearing loss was more frequently observed
in the shipbuilding department than in the machine shop. Another analysis
examined the relationship between length of noise exposure and blood pressure.
These results failed to confirm those of Verbeek, van Dijk and de Vries (1987) in
that there was little difference between workers exposed to noise for less than
10 years and those exposed for 20 - 30 years.

202 Analysis of other working conditions could not explain the absence of a
relationship between noise exposure and blood pressure. Indeed, the shipbuilding
department not only had the higher level of noise exposure but it had a larger
number of other negative features. One might have expected that the poorer
working environment in the shipbuilding department would have strengthened any
effect of noise on blood pressure. The authors argue that the cross-sectional
design may have obscured the noise-blood pressure relationship.

203 Van Dijk, Souman and de Vries (1987) studied the non-auditory effects of
noise on 539 male workers from seven industries. No correlation was observed
between blood pressure and total noise exposure after correction for age,
relative weight, and various possible confounding variables. A similar effect
was also obtained when the analysis was restricted to the younger workers (under
45 years).

204 The authors put forward five possible reasons to account for the absence of
a relationship between noise exposure and blood pressure:

(1) increased blood pressure may have produced a selection of workers
   (especially in combination with other risk factors). However, there was no
effect even in the younger workers, where such selection should be minimal.
(2) there may have been a masking effect due to other working conditions. This is unlikely because the data was corrected for these and for characteristics such as the age and relative weight of the worker.

(3) in previous studies which have shown a positive relationship between the noise level and blood pressure, it may not be the noise alone which produces the effect. It is possible that time pressure and activity interference may contribute, and these could not be assessed in the present study.

(4) the threshold limit for an increase in blood pressure might exceed that for the induction of hearing loss. This is extremely unlikely, and laboratory studies have demonstrated increases in blood pressure at levels as low as 80 dBA (see Mosskov and Ettema, 1977).

(5) long term exposure to noise does not increase blood pressure. However, it one accepts this view one has to then account for the positive effects in the literature. Indeed, the absence of a direct relationship between indices of exposure to noise and the prevalence of non-auditory effects does not "prove" that such a relationship does not exist. This reflects the weakness of epidemiological studies, for negative results almost never allow one to conclude a true absence of health effects.

205 Aro (1984) carried out a longitudinal study of the relationship between occupational stress (e.g. noise level, monotony, self-suppression, etc.), health-related habits (e.g. smoking, drinking, nutrition, activity, etc.) and blood pressure. The study was both cross-sectional and prospective (follow-up period = 5 years). In the initial cross-sectional study only relative weight was positively associated with both the systolic and diastolic blood pressure. Cigarette smoking and frequency of intoxication were associated with systolic blood pressure. The partial correlation (correcting for age) between noise and systolic blood pressure was 0.14, which was significant but not very meaningful.

206 The data from the prospective study showed that there were stronger relationships between changes in diastolic pressure than for changes in systolic blood pressure. However, the correlation between noise level and change in diastolic blood pressure was only 0.17, showing that noise levels account for a very small percentage of the variation in blood pressure.

207 One surprising feature of this study was that the impact of noise on blood pressure change was higher among white-collar workers, whose average levels of exposure were substantially lower than those of blue collar workers. This implies that (a) noise has its greatest effect on blood pressure at rather low levels, or (b) that noise is a stress factor in white-collar jobs but not blue-collar jobs.

208 It should be pointed out that all of these studies of noise and blood pressure have measured blood pressure at rest. This may not be representative of blood pressure values in normal working life, and future studies must examine this and use more sophisticated measures than mean blood pressure.

(a) Babisch, Ising, Gallacher and Elwood (1988) and Babisch, Gallacher, Otten, Schulte and van Eiff (1989) report preliminary results from surveys on the effects of traffic noise on cardiovascular function. The Caerphilley sample (small town, total sample) consisted of 2512 men aged 45 - 59 years and the Speedwell sample (suburb of a major city, random sample) of 2348 men of the same age group. While both studies have a prospective design, only the initial cross-sectional data has been reported so far. Daytime outdoor
noise level was used as a descriptor of the traffic noise and this varied between 50 - 70 dBA.

(b) The results showed statistically significant effects of noise on systolic blood pressure, total cholesterol, total triglycerides, blood viscosity, platelet count and glucose level. However, the findings were not consistent and some results supported the view that noise has a negative effect on cardiovascular function, whereas others suggested the opposite.

(c) In the prospective epidemiological Bonn traffic study the influence of noise on blood pressure was examined. The sample of 192 males and females aged 20 - 35 years were followed over 3 years in 6-month intervals. The results showed a high migration rate induced by noise. Transient changes in serum lipids and cigarette consumption were also observed.

209 While the methodology of the survey studies is improving there is still a great need to examine and control for other workplace factors. Matthews, Cottingham, Talbott, Koller and Siegel (1987) showed that many stressful work conditions (e.g. little opportunity for promotion and for participating in decisions at work, uncertain job future, unsupportive co-workers and foremen, difficulties communicating with others, and overall dissatisfaction with the job) are often associated with elevated blood pressure. A combination of being satisfied with one's work and being employed in a relatively good working environment protected against elevated diastolic blood pressure. This suggests that some of the effects of noise on blood pressure might reflect the workers' general reaction to the working environment. Indeed, we must not only consider the physical parameters of the noise but examine psychological reactions to it. Such an approach will enable us to obtain a better understanding of the epidemiology of hypertension.

210 Future studies must also examine whether any sub-groups are especially likely to show increased blood pressure when exposed to noise. Andrén, Eggertsen and Svensson (1989) examined the effects of 105 dBA noise for 30 minutes on the cardiovascular function of patients with mild essential hypertension. Loud noise caused a prolonged vasoconstriction and blood pressure elevation. There was no sign of attenuation with time, and the haemodynamic response remained even after the actual noise exposure stopped. The results suggest that loud noise increases the workload on the vascular smooth muscle cells, which may cause them to grow. In this respect noise may be a pathogenic factor involved in the development of the structural vascular changes seen in established essential hypertension.

211 We must also have further information on the effects of moderate intensity noise on cardiovascular function. The results of van Dijk, Souman and de Vries (1987) were largely negative, whereas other studies such as that of Wu, Ko and Chang (1987) have shown that noise over 85 dBA may increase the risk of high blood pressure. This last study compared 158 male workers from a high noise environment with a similar number of workers exposed to levels of less than 85 dBA. The physiological data was collected by physicians and nurses who knew nothing about the working place of the subject and who were unaware of the purpose of the examination. The subjects did not work before the examination and data was only collected in the morning to reduce any bias due to diurnal variation. Sound measurements of the worksites were carried out by a "blind" industrial hygienist, and although previous information on noise exposure was unavailable, it was reasonable to suppose that workers were exposed to a fairly constant level of noise throughout their working life due to the fact that these shipyard workers from Taiwan rarely changed worksites.
Workers exposed to noise over 85 dBA were matched with workers exposed to less than 80 dBA. Matching criteria were ± 6 months for age, ± 6 months for employment duration, and ± 0.5 kg/m² for body mass index.

Prevalence rates of hypertension were compared between the exposed and reference groups. There were 12 workers with hypertension in the group exposed to levels over 85 dBA whereas there were only 2 workers with hypertension in the lower noise exposure group. Both systolic and diastolic blood pressure were higher in the high noise group (means = 118.7 and 76.5 mmHg) than the group exposed to less noise (means = 114.0 and 73.2).

This study has the methodological improvements of adjusting for age, employment duration and body mass index. It takes no account of other confounding factors such as smoking and exposure to toxins. These may be very important for Cherek (1985) has shown that increasing levels of industrial noise exposure led to more cigarette smoking. Noise may, therefore, influence cardiovascular functioning indirectly by changing health-related habits. Nevertheless, the results do suggest that long term noise exposure does increase the risk of cardiovascular disease. However, the size of the effect of noise in the present study is comparable to the difference between pre- and post-lunch blood pressure levels (see Smith, Leekam, Ralph and McNeil, 1988).

(b) Laboratory studies

Ray, Brady and Emurian (1984) have reviewed laboratory studies on the effects of noise on cardiovascular function, and concluded that the noise effects are not very compelling. Jansen (1969) found that sustained noise stimulation was associated with persistent, non-habituating digital vasoconstriction. In contrast to this, Kryter and Poza (1980a, b) found that noise-elicited vasoconstriction habituated rapidly, and they could find no evidence of an effect of noise on cardiovascular function. Kryter and Poza argue that the noise-elicited vasoconstriction is a component of an aural reflex and not indicative of physiological stress.

Ray, Brady and Emurian (1984) played intermittent pink noise (93 dBA) while subjects performed computerised tasks. The effects of the noise on tonic cardiovascular responding, blood pressure, digital vasoconstriction, respiration and heart rate was examined. The results showed that the noise produced non-habituating decreases in digital pulse amplitude and non-habituating increases in mean blood pressure. The noise-induced change in mean blood pressure was small in magnitude, and, over the time duration of the experiment, was unlikely to be associated with any risk to health. However, the results do show that one cannot dismiss noise-induced vasomotor changes as a component of the acoustic reflex.

The responses measured by Ray, Brady and Emurian (1984) represented changes in level measured 4 and 9 minutes after the noise stimulation began, and as such cannot be considered tonic responses. Some of the reviews of noise and cardiovascular change failed to make a distinction between phasic and tonic effects (e.g. Kryter, 1970). These reviews conclude, on the basis of single session studies of tone-elicited orienting responses, that the physiological effects of noise rapidly habituate. In contrast, Ray, Brady and Emurian (1984) found no long term or day-to-day habituation of the noise-elicited responses.

Other research has examined the effects of infrasound on blood pressure changes. In general, little is known about the effects of infrasound on health (see Broner, 1978). Some researchers (e.g. Slarve and Johnson, 1976; Harris, Sommer and Johnson, 1976) suggest that exposure to infrasound as high as 140 dB is safe. Danielson and Landström (1985) examined the effects of infrasound on
heart rate and blood pressure. The results showed that 6 - 16 Hz infrasound increased diastolic blood pressure and tended to decrease systolic. The changes were small for the first 30 minutes but became more marked after that. Pulse rate was unaffected. Exposure to 16 Hz had the most marked effect, and this was observed even at 95 dB. These results show that further studies are needed to clarify the role of long term infrasonic exposure in the development of essential hypertension.

219 Colletti and Fiorino (1987) examined the effects of 100 dB(A) noise on myocardial activity. The study involved examining the effects of short-term noise exposure on patients undergoing cardiac catheterization for diagnostic purposes. The aim was to investigate whether noise could temporarily modify coronary blood flow, intraventricular pressure and the contractile efficiency of the heart. The results showed that short-term noise exposure does not significantly alter coronary blood flow. Only transitory variations in systolic left ventricular pressure and heart rate were observed, and the short latency of this reaction indicated that it was mediated by the parasympathetic system. The experiment was carried out on patients suffering from ischemic cardiopathy and such patients are known to be hypersensitive to other forms of stress (e.g. cold, mental demand). The lack of any effect of noise in this type of patient is surprising and suggests that negative results are also likely to be expected in healthy individuals.

220 Other research has examined the importance of the nature of the noise. For example, Linden (1987) found that generally noise had little effect on the initial reactivity of blood pressure and heart rate, and did not influence the rate of adaptation to changes observed during a mental arithmetic task. The only exception to this was obtained when the noise varied considerably, and this led to an exaggerated heart rate response. 221 The nature of the activity being carried out in the noise is obviously also very important. For example, Linden, Frankish and MeCachern (1985) found that 90 dB white noise enhanced heart rate responses during mental arithmetic but not during Stroop tests. There has been a growing interest in having the subjects perform in noise rather than recording cardiovascular measures while the subject is doing nothing. These results are reviewed in detail in the section on combined effects.

(c) Animal studies

222 Many of the field studies of noise and cardiovascular disease can be criticised because the duration of the noise exposure has not been specified. In many studies exposure duration has been assumed to be correlated with years on the job, and in others hearing loss has been taken as the indicator of noise exposure.

223 Peterson, Augenstein, Tanis and Augenstein (1981) showed that prolonged exposure to moderate intensity noise produced sustained blood pressure increases of 23 to 38% in two different species of macaque monkey (without impairing auditory sensitivity). Peterson, Haselton and Augenstein (1984) used a similar methodology to examine whether there was a chronic dose response relationship based on the length of daily noise exposure. The noise consisted of pile driver impact noise (102 dB peak SPC). At the time, the maximum level associated with such noise was 102 dB for 8 hour exposures and 105 dB for 4 hour exposures. The total daily dose for the animals did not exceed these limits.

224 The results showed that compared to pre-exposure baselines, mean arterial pressure rose 8.2% during a 4-hour noise exposure and 16.5% during 8-hour exposures. Heart rate tended to return to baseline levels upon noise termination, whereas blood pressure, once elevated, tended to remain high. While
use of animals offers advantages in terms of control, further information is required on the generality of the above effects. Indeed, it should be remembered that Peterson, Haselton and Augenstein (1984) had only two monkeys in their experimental group.

225 Peterson, Augenstein, Haselton, Hetrick, Levene and Tanis (1984) confirmed the finding that moderate intensity noise increased the blood pressure of the monkeys. Furthermore, the noise also induced changes in the diurnal rhythm of heart rate, blood pressure, and "pauses" in cardiac rhythm. The value of this research is that it has examined the relationships between noise and the cardiovascular system with a degree of experimental control that often cannot be achieved in epidemiological studies. The studies have also been much longer than human laboratory experiments. However, the results from non-human species cannot easily be applied to man, and there is some evidence of inter-species differences in this area.

226 Turkcan, Heinz and Harris (1983) carried out similar studies to Peterson, Augenstein, Tanis and Augenstein (1981), but used baboons rather than rhesus monkeys. While noise produced initial increases in blood pressure, the chronic effect was to lower it. Similarly, noise depressed heart rate and catecholamine excretion. This study used traffic noise as a stimulus and it is quite likely that the significance of such noise varies across species. One way of examining such effects of noise in man has been to compare sub-groups of people who, for cultural reasons, live in very quiet environments.

(d) Humans in quiet environments

227 Rosen (1970) carried out a detailed study of the Mabaan tribe of the Sudan, who live in a very quiet environment. Not only did the members of the tribe have excellent hearing, but they had lower blood pressure. Unfortunately, it is unclear whether one can attribute the lower blood pressure solely to lack of noise, as the diet of the tribe was typically very low in cholesterol. However, it is interesting that good hearing should go with low blood pressure, for other researchers have argued that noise-induced hearing loss may frequently be accompanied by increased blood pressure. Some of these studies are briefly reviewed in the next section.

(e) Noise, hearing loss and blood pressure

228 Jonsson and Hansson (1977) carried out a study to determine whether a permanent rise in blood pressure had occurred in individuals exposed to noise severe and prolonged enough to cause an irreversible loss of hearing. At a health examination an audiometry test was carried out on each subject. A normal audiogram was defined as a loss of acuity less than 20 dB at all frequencies tested (range 250 - 8000 Hz). A severe noise-induced impairment of hearing was defined as a loss of acuity amounting to 65 dB or more at 3000, 4000 or 6000 Hz. Blood pressure was measured in the recumbent position after the subject had rested for 15 minutes. Upon completion of the examination 74 out of the 196 workers were found to have normal hearing, whereas 44 had a severe noise-induced loss of hearing. The resting blood pressure (both systolic and diastolic) was significantly higher in those with hearing loss than those of the same age who had normal hearing. The proportion of hypertensive subjects was also significantly higher in the group with noise-induced loss of hearing. The authors state that it cannot be claimed with absolute certainty that noise caused the increased blood pressure and higher hypertension. Yet there were no other obvious differences between the groups that could easily explain the results. Indeed, they argue that the most plausible explanation is that prolonged exposure
to a stressful stimulus (noise) may have caused repeated rises in blood pressure leading to circulatory adaptations and a permanent rise in blood pressure.

229 Manninen and Aro (1979) investigated whether noise-induced hearing loss was associated with elevated blood pressure. In the older sample (41 - 64 years) the mean systolic blood pressure of subjects with moderate hearing loss was 12mmHg higher than subjects with normal hearing. The mean diastolic pressure was 5mmHg higher in those with hearing loss. However, the older workers with severe hearing loss had only slight elevations in blood pressure. In the younger age group (26 - 40 years) no differences in either systolic or diastolic blood pressure were observed between the hearing categories.

230 Cohen, Taylor and Tubbs (1978) sought to confirm that workers showing marked high-frequency hearing losses in their audiograms, which is considered evidence of excess occupational noise exposure, also display increased blood pressure and hypertension in disproportionate numbers. The results did not agree with those of Jonsson and Hansson (1977) in that there was no evidence of elevated blood pressure and increased hypertension in workers with hearing loss. Several possible explanations of the apparent discrepancy are offered by the authors. First, the noise conditions in the Cohen et al. study were not as extreme as those studied by Jonsson and Hansson. Indeed, Cohen et al. studied workers in a paper-making factory where the noise was quite steady and free from impact sounds. Second, the workers studied by Jonsson and Hansson were significantly older than those studied by Cohen et al. It is possible that noise augments the usual elevation in blood pressure associated with aging. Third, only 31 of 1200 workers met the screening requirement for inclusion in the hearing loss group. This could mean that Cohen et al. were studying a group who were unique in terms of its physiological adaptation to stress. Finally, measurements of blood pressure are influenced by a host of factors. The levels reported by Cohen et al. were low compared to available norms and this may reflect the method of taking the blood pressure (with the person lying down) or the time of year. The study was conducted during hot summer months when heat-induced vasodilation and salt and fluid loss through sweating could lower blood pressure.

231 Kent, von Gierke and Tolan (1986) examined the relationship between prolonged exposure to noise and chronic cardiovascular disease. The degree of high tone hearing loss diagnosed with a high probability of being noise-induced was used as an indicator of the extent of relative noise exposure. This retrospective study reviewed the medical records of 2,250 Air Force aircrew members (mainly pilots and navigators) who had been referred to the USAF School of Aerospace Medicine between 1957 - 1980 for evaluation of borderline conditions potentially disqualifying the aircrew member from flying duty. Aircrew members have to meet stringent medical criteria prior to selection for flight duty. If the person's blood pressure is greater than 140/90 he has to undergo a course of treatment. In other words, the sample in this study could be considered to be very fit. Age ranges from 19 - 57 years were considered. A polynomial regression of blood pressure data with age as the independent variable was determined for the maximum (upper third) and minimum (lower third) hearing loss groups. The quadratic regression provided the best fit for both hearing loss groups, and there was little difference in the regression curves of those with maximum hearing loss and those with minimum loss.

232 The above results are from a population which is not representative (either physiologically or psychologically) of a typical civilian occupationally noise-exposed population. Indeed, the blood pressure in the aircrew population was consistently lower than that in the general public. Individuals in the aircrew population were also generally younger than subjects in studies which have found an association between hearing loss and cardiovascular function. It is possible
that the negative cardiovascular effects due to noise exposure do not develop until quite late in life. However, in the aircrew population there were 102 subjects in the 51 - 60 age bracket and results from this group were consistent with other age brackets.

233 Attitude to noise has been shown to be very important in determining its effects. If aircrew members were highly motivated in their flying jobs then this positive attitude to the flying-related noise may insulate them from possible adverse effects of noise. Overall, this study does not support the hypothesis that a positive association exists between prolonged exposure to noise and chronic cardiovascular disease. The strengths of the study are the comprehensive clinical evaluations and the size of the data base. The weakness is that the aircrew population is not, for several reasons, representative of a typical occupationally-exposed population.

234 Delin (1984, 1988) also found no relationship between noise-induced hearing loss and hypertension. In the first study 112 men from the engine rooms of ferries were studied over an eight-year period. The noise levels in the engine rooms were 100 - 115 dB, and 75 - 80 dB in the control rooms. Hearing and blood pressure were tested every second year. There was no significant difference between those with impaired hearing and those with normal hearing with regard to systolic or diastolic blood pressure or frequency of hypertension. Similarly, exposure to noise did not result in a greater frequency of hypertension than that observed in a normal population of similar age. An interesting anecdotal finding of this study was that those who had been exposed to noise for a long time tolerated their noisy surroundings surprisingly well. It may be that the degree of stress is more important in producing cardiovascular problems than is the actual noise level, which could explain why some studies have obtained positive results and others negative. An important methodological point is that some researchers have only collected single measurements of blood pressure and hearing loss. This is not adequate - longitudinal studies are clearly required, and further information about the noise, and other risk factors must also be obtained.

235 Delin (1988) reports similar data for the period 1976 - 1987. The results showed no significant difference in either the systolic or diastolic blood pressure of those with hearing loss or those with normal hearing. There was also no evidence of noise-induced hearing loss being associated with an increased risk of hypertension.

236 Verbeek, van Dijk and de Vries (1987) also examined the relationship between noise-induced hearing loss and blood pressure. Only for hearing loss in the left ear was there a weak correlation (0.1) with blood pressure.

237 Najenson, Melamed, Korn, Jucha, Green and Bergman (1988) examined the effects of industrial noise on cochlear function (frequency selectivity), blood pressure and annoyance. The study applied this combined auditory and non-auditory test battery to a sample of 185 workers in a textile factory. Testing was carried out at the beginning and at the end of a typical workday's exposure to noise. The matched noise frequency selectivity test was sensitive to the auditory effects of noise in workers with normal hearing, in that increasing disturbance of cochlear function was found with increasing ambient noise levels. Workers who had poor frequency selectivity also tended to report high noise annoyance. There was also a trend relating poor frequency selectivity with higher blood pressures, although this effect was not statistically significant.

238 One important issue is how reliable are the effects of noise on cardiovascular function. Parrot, Petiot, Lobreau and Smolik (1988) found that
only the heart-rate response to noise (not systolic or diastolic blood pressure) was similar on re-test.

239 Another important issue is whether there are sub-groups who show large effects of noise on cardiovascular function. Petiot, Lobreau and Smolik (1988) examined whether individual differences in heart rate response to intermittent noise were related to Type A/B patterns. The results showed Type A subjects had significantly lower mean systolic and diastolic blood pressure levels. Mean heart rates were also lower for the Type A subjects, although this effect was not significant.

240 Stansfeld, Clark, Turpin, Jenkins and Tarnopolsky (1985) attempted to delineate the physiological characteristics of noise sensitive subjects. Three groups consisting of high, intermediate and low noise sensitive subjects were identified by questionnaire. Subjects lived either in high or low aircraft noise areas. Unlike most studies the subjects were studied in their own homes, rather than in the laboratory. Blood pressure, skin conductance and audiology were measured. In the high noise area there were significantly more skin conductance responses than in the low aircraft noise area, irrespective of the subject’s noise sensitivity. Indeed, the physiological measures did not clearly distinguish between noise sensitive groups, except that highly noise-sensitive women had consistently slower heart rate.

Effects of noise on the cardiovascular functioning of children

241 Cohen, Evans, Krantz and Stokols (1981) examined the effects of chronic aircraft noise exposure on the physiological, motivational and cognitive functioning of children. The four noisiest schools in the air corridor of Los Angeles International Airport were selected as experimental schools (peak sound levels were as high as 95 dBA and there was approximately one flight every 2½ minutes during school hours). Three control schools were matched with the experimental schools for grade level, ethnic and racial distribution of the children, and the occupations and education levels of the parents.

242 All the data were collected in a quiet setting - a noise insulated caravan parked directly outside the school. The effects of noise on systolic and diastolic blood pressure were significant, with higher levels being found in those in the noisy schools. The pattern of the means for systolic and diastolic pressures suggest that the noise-quiet differences was greatest during the first two years of exposure, with differences remaining consistently smaller after that point. However, the interaction between noise and months in school failed to reach significance.

243 While the noise-quiet differences in blood pressure were statistically reliable it should be noted that the levels for children attending noisy schools did not exceed the normative levels for children of similar ages. In addition, the long-term health consequences, if any, of these blood pressure elevations remain unknown. Nevertheless, the data do provide support for the general view that noise does have a cardiovascular effect.

244 The greater difference between noise and quiet during the first few years of school could either reflect the fact that the children habituate to the noise as the duration of exposure increased, or it could reflect a selection bias produced by children with noise-induced blood pressure elevations moving out of the neighbourhood. The results showed that the latter explanation was correct. Parents of children with elevated blood pressure may show similar responses, and this may have motivated them to move from the area. This has implications for industrial studies of noise and blood pressure. If noise-induced blood pressure
causes people to move, then selective biases may have been operating in many of the other field studies.

245 Noise-abating architectural interventions were constructed both before and during the course of the study. Hence, it was possible to assess the effectiveness of noise abatement. Longitudinal analyses revealed no significant effects of noise abatement on blood pressure. However, the cross-sectional data did show that the blood pressure levels of the noise-abated group fell in between those of the quiet and noise groups.

246 Cohen et al. (1981) also examined whether living in a relatively quiet home would lessen the impact of school noise. The children living in the 20 quietest homes were isolated and compared with the rest of the noise sample and the quiet sample. The results showed that those in the quiet homes still had higher blood pressure than children in the quieter school did. In other words, living in a relatively quiet neighbourhood did not appear to lessen the impact of the noise at school.

247 Svensson and Hansson (1985) examined the effects of noise on the blood pressure of children with hypertensive mothers or normotensive mothers. There were no significant differences between the children with regard to age, height or weight. The diastolic blood pressure was increased by noise for all subjects, as was mean arterial pressure and cardiac output. There was no effect of noise on systolic blood pressure or peripheral vascular resistance.

248 These studies with children may not seem relevant to the problems of noise at work. However, Cohen et al.'s (1981) study has methodological features which should be incorporated into future studies carried out in industry. It has also been shown that factors that influence blood pressure in childhood still have an effect, and produce the same pattern of individual differences later in life. The studies of children in noise may, therefore, be very relevant to occupational problems.
XVIII EFFECTS OF NOISE ON EXCRETION OF CATECHOLAMINES

249 Noise is a stressor and the level of catecholamines acts both as a stress marker and an indicator of modified sympathetic nervous system reactivity. Markiewicz (1973) states that many studies have found increased excretion of catecholamines in urine due to high intensity noise, especially when it comes on unexpectedly and is short-lasting.

250 These studies have usually been animal experiments and one must now consider whether similar effects occur in humans, both in the laboratory and workplace, and whether they are observed at noise intensities where there is no risk to hearing.

251 Once again contradictory results have been obtained. Buczynski and Kedziora (1983) examined changes in concentrations of adrenalin and noradrenalin in the peripheral blood of men exposed to noise while doing exercise. Noise increased noradrenalin, especially when the noise was impulse noise (pistol shots). Plasma adrenalin levels were also influenced by noise, and here it was pulse noise which produced the greatest effects. Continuous acoustic stimulation produced a relatively low rise in blood catecholamines in relation to the effects of intermittent or pulse noise.

252 Cavatorta, Falzoi, Romanelli, Cigala, Ricco, Bruschi, Franchini and Borghetti (1987) compared glass workers exposed to 96 dBA noise with machine shop workers exposed to levels of less than 78 dBA. They measured blood pressure, adrenalin, noradrenalin, dopamine and cortisol. Noradrenalin and adrenalin levels were about 70% higher in the high noise group, and a similar trend was demonstrated in the metabolite of these found in the urine (vanilmandelic acid). There was no effect of noise on dopamine or its principal metabolite homovanillic acid. Similarly, there was no effect of noise on cortisol, systolic, diastolic or arterial blood pressure. The noradrenalin and adrenalin values had returned to baseline levels by the start of the next shift. It should be pointed out that there were many differences between the two groups of workers other than noise exposure, and factors such as heat, or job-related characteristics, may have had a large influence.

253 Cesana, Ferrario, Curti, Zanettini, Grieco, Sega, Palermo, Mara, Libretti and Algeri (1982) demonstrated selective effects of noise exposure - with noise increasing levels of noradrenalin but having no effect on adrenalin levels. The effect of 90 dBA noise was not restricted to working time and levels were higher even during rest and leisure time.

254 There are other pieces of research where the effects of noise have been negative. Brandenberger, Follénius and Trémolières (1977) examined whether noise of different intensities, frequencies and durations modified the diurnal pattern of plasma cortisol excretion. The data showed that noise below the "safe" limits for hearing conservation did not modify the temporal pattern of plasma cortisol levels in man. Similarly, plasma K levels and plasma glucose were not influenced by the noise. This last result conflicts with results from a study by Bloom, Daniel, Johnston, Ogawa and Pratt (1973), which showed that noise increased the level of glucagon in the plasma, and this was followed by an elevation of blood glucose but not of plasma insulin.

255 Follénius, Brandenberger, Lecornu, Simeoni and Reinhardt (1980) examined the effects of intermittent noise (alternating between 45 dBA and 99 dBA) on circulating catecholamines, growth hormone, ACTH and cortisol. There was no effect of the noise on plasma levels of noradrenalin, adrenalin or dopamine. Similarly, there was no effect of noise on urinary catecholamine excretion.
Plasma levels of GH and ACTH did not differ in noise, but cortisol excretion showed a brief effect of noise exposure. The normal diurnal trend for cortisol excretion is a decrease from 8.00 to 12.00 followed by an increase. The effect of noise was to halt the decrease between 10.00 and 12.00.

256 Brandenberger, Follénius, Wittersheim and Salamé (1980) measured the levels of plasma catecholamines and pituitary adrenol hormones related to task performance under quiet and noise conditions. A significant rise in cortisol was observed when the task had to be performed in noise. The size of the noise effect depended on whether the task had to be performed or not, and whether it was the first or second session. The percentage rise in cortisol over the corresponding controls were:

(a) 1st session + task + noise 84.1%
(b) 2nd session + task + noise 35.8%
(c) 1st session + noise 21.8%

257 There were no statistically significant increases in ACTH or GH due to the noise or task + noise. While both adrenalin and noradrenalin were higher in conditions involving the task there was no significant effect of noise. This was true for both plasma assays and urine assays. Indeed, one of the main conclusions one can draw from this research is that changes in catecholamines and pituitary adrenol hormones due to noise are very small compared to the impact of task demands.

258 Further research on the effects of noise exposure on catecholamine excretion is clearly required. The positive results obtained in the workplace could, in some studies, reflect factors other than noise. The negative results obtained may be due, in some cases, to the small sample sizes used. There is also a need to carry out studies of the after-effects of noise for Frankenhaeuser and Lundberg (1974) found that adrenalin excretion was greatest after the noise exposure, not during it. The implications of changed levels of catecholamine excretion for long-term health must also be studied and the area extended to examine susceptible sub-groups, combined effects, and long-term rather than acute effects.
XIX OTHER BIOCHEMICAL EFFECTS OF NOISE

259 Rehm (1983) cites studies which show that exposure to noise leads to an increase in cholesterol, lymphocytes and neutrophils. Ising, Dienel, Gunther and Markert (1980) found that working in a noisy environment (Leq 85 dBA) for a day led to significant increases in cholesterol, urine and serum Mg, and a decrease of erythrocyte Na and renin. The increase in Mg in the serum probably reflects intracellular loss due to released catecholamines. Decreased levels of Mg in the cells are followed by intracellular increases of Ca, especially in the heart muscle, which increases vasoconstriction and sensitises the muscle for catecholamines. These processes may be important in linking noise exposure with the development of cardiovascular dysfunction.

260 Most studies have examined biochemical changes after noise exposure. Rai, Singh, Upadhyay, Patil and Nayar (1981) compared the effects of noise levels ranging from 88 to 107 dBA with a control group not exposed to machinery noise. The results showed that noise exposure increased free cholesterol, serum cortisol and gamma-globulin levels. The increased gamma-globulin levels could be due to sub-clinical infections, which suggests that long exposure to noise may have an effect on the host defence mechanism.

261 Overall, the biochemical effects produced by long term exposure to noise suggest that it is plausible for noise to produce cardiovascular pathology. Further studies must now examine whether exposure to levels of noise which produce no risk to hearing also leads to similar biochemical changes.
XX NOISE AND SLEEP

In the 1970's most of the research on this topic was concerned with either the development of methodology (e.g. Globus, Friedman, Cohen, Pearsons and Fidell, 1973; Lukas, 1973), or the introduction of standards (e.g. Lukas, 1978). Rather special types of noise were also investigated in detail (e.g. jet noise - Muzet, Schieber, Olivier-Martin, Ehrhart and Metz, 1973; "pings" - Johnson, Townsend, Naitoh and Muzet, 1973; and sonic booms - Collins and Iampietro, 1973).

Recently there has been growing interest in the relationship between daytime noise and subsequent sleep. Blois, Debilly and Mouret (1978) found that daytime noise led to a reduction in total sleep time, especially REM sleep. Fruhstorfer, Fruhstorfer and Grass (1984) examined the effects of 8 hours of 80 dBA pink noise during the day on sleep EEG, ECG and respiration. Baseline data was collected for two nights, the subjects were then exposed to the noise for two days, and on the fifth day they were in quiet again.

EEG sleep data from the first post-noise night showed an increase in slow wave sleep with a simultaneous decrease in stage 2 sleep. During the second post-noise sleep these effects were smaller. The autonomic parameters were not affected by the daytime noise. An influence of daytime noise on sleep could reflect two things. First, daytime noise could arouse the CNS with the consequence that sleep onset is delayed and deep sleep reduced. Second, daytime noise could strain the CNS thus causing an increased demand for recovery, and, as a consequence, deep sleep could be augmented. The increase in slow wave sleep in this study supports the second view rather than the first.

Fruhstorfer, Fruhstorfer, Grass, Milerski, Sturm, Weseman and Wiesel (1985) report a similar study on the effects of daytime noise on sleep. The results differed from the previous study in that stage 4 stability was increased in all subjects and stage 3 stability decreased. However, the increase in stage 4 stability could also be a sign of an increased need for the CNS to recover after daytime noise exposure.

There has been a detailed evaluation of the effects of noise exposure during sleep on the different sleep stages. Nakagawa (1987) examined the effects of various conditions of artificial noise on EEG's and on subjective reports of sleep disturbance. Although there were individual differences in reported sleep disturbance, the general picture was that sleep disturbance was proportional to the amount of noise during the night. The total sleep time was not influenced by noise exposure, whereas latency to sleep onset increased when tone pulses with one second intervals were played. Similarly, noise exposure increased the rate of change of sleep stages and number of awakenings. However, total time and percentage of time in stages 2, 3, 4 and REM showed no significant effect of noise. This study provides support for the view that noise increases the number of awakenings and increases the shifts of sleep stage. It also confirms that, at the moment, it is still unclear whether intermittent noise influences the amount of sleep in each stage or REM latency.

Öhstrom (1989) examined the effects of traffic noise (maximum 60 dBA) on the sleep of noise-sensitive and non-sensitive subjects. The results showed that noise-sensitive subjects were slightly more disrupted by the noise (in terms of increased heart rate and increased body movements) than were non-sensitive subjects. Both groups were worse on reaction time tests carried out after sleep.

The above study was carried out in the laboratory and in order to study the long-term effects of noise exposure, Öhstrom (1989) compared areas close to a
road with heavy traffic, with a quiet area far from the road. The people in the
two areas were interviewed and asked about sleep quality, fatigue, mood and
various medical symptoms. The results showed a deterioration of sleep quality
and mood, and a higher frequency of other symptoms in the area close to the road.
Further data is going to be collected after a night ban on heavy traffic is
introduced and the road re-surfaced with noise-reducing asphalt. Comparison of
the re-test data with the baseline data will be of considerable interest.

269 Other research has examined the effects of noise-abatement methods (e.g. the
introduction of double-glazing - see Jurriens, Griepahn, Kumar, Vallet and
Wilkinson, 1983) on sleep, and performance after sleep. By reducing the noise
level indoors the amount of REM sleep and/or slow-wave sleep can be increased
(Jurriens, 1981, and Vallet, Gagneux, Blanchet, Faure and Labiale, 1983). This,
in turn, may be reflected in improved performance during the next day (see
Wilkinson and Campbell, 1984).

270 There is now evidence that noise can produce sleep disturbances, change
physiological responses during sleep, influence perceived sleep quality and
subsequently change performance and mood. However, what these mean with regard
to long-term health, well-being, work performance and safety cannot yet be said
for certain.

271 Research has shown that the nature of the noise is very important. It is
very important to distinguish between noise peaks and background level
(Eberhardt, Strâle and Berlin, 1987), to consider the duration of the noise
(Thiessen, 1983), and whether it is intermittent or continuous. Continuous noise
appears to affect mainly REM sleep, whereas intermittent noise can affect stages
3 and 4 (Eberhardt, Strâle and Berlin, 1987).

272 Research on long-term effects of noise exposure on sleep suggest that
complete habituation to the noise does not occur. However, many of the effects
are small and the increase of 1-2 beats per minute in heart rate observed
during sleep is within the range of the normal variations in the waking state.
This makes it difficult to argue that such effects are likely to give rise to
long-term health problems. However, one could argue that the cumulative effects
of these small changes, combined with other daily loads, may lead to impaired
health.

273 As in other areas of noise research there has been a growing interest in the
combined effects of noise and other factors on sleep. Results from a study by
Arnberg, Bennerhult and Eberhardt (1987) show that the combination of vibration
and noise clearly disturbs sleep more than noise alone does.

274 The literature provides only limited information about individual
differences in noise-disturbed sleep. Elderly people are affected far more by
noise during sleep (Eberhardt, 1982). However, other individual differences
often change according to the parameter measured. For example, children seem
less sensitive than adults to road or aircraft noise (Mills, 1975) and this
applies to the tendency to wake up, REM disturbance, and changes in slow-wave
sleep. However, the impact of noise during sleep on heart rate is greater for
children (Muzet and Eberhardt, 1978).

275 Several studies have shown that equivalent level measurements are unsuited
for the prediction of noise-induced sleep disturbance. The number of noise
events exceeding a certain level has been found to be a useful measurement. For
example, Eberhardt (1982) observed objective sleep disturbance when there were
more than 50 noise events per night with maximum levels of 50 dBA or more.
Noise-abatement measures should, therefore, aim at reducing the number of high-level noise events. In order to avoid the negative effects of continuous noise on REM sleep the equivalent sound level should not exceed 40 dBA. If this level is achieved, and the number of sounds over 45 dBA is kept to a minimum, then there should be little disturbance of sleep. In terms of noise-abatement, those measures which reduce noise during the first part of the night are going to be the most cost-effective (Eberhardt, 1982).

In order to evaluate what effect noise-induced sleep disturbances have on long-term health further longitudinal studies, and research on combined effects of noise-disturbed sleep and other factors, are required. Sensitive sub-groups must also be defined, and we must compare any negative effects of daytime noise on sleep with those produced by other stressors.
XXI NOISE AND MENTAL HEALTH

277 There is little reliable evidence on the connection between noise and mental illness. Several lines of research do suggest that noise is related to mental health, but these findings must be viewed with caution because of methodological inadequacies. McLean and Tarnopolsky (1977) have reviewed the early literature on this topic and the reader is referred to that paper for detailed support of the points made below.

278 Prolonged exposure to loud noise produces deafness, and deafness is associated with significantly higher rates of mental illness both in hospital and community populations. This effect is clearly an auditory one and, as such, is outside the range of topics considered in this review.

279 Symptoms commonly considered expressions of stress, or early signs of mental illness, are often reported in the literature on noise (e.g. an increase in nervousness, irritability, headache, and insomnia). Such effects are either considered as indicators of annoyance or as signs of morbidity.

280 Some categories of patients suffering from neuroses show responses to noise which are very different from the responses of normal subjects. For example, hysterical patients fail to habituate to repeated noise and anxious patients show much greater responses of the adrenal cortex and medulla when exposed to noise (see McLean and Tarnopolsky for detailed support of these points).

281 The main evidence put forward to support the view that noise influences mental health comes from studies of aircraft noise and mental hospital admission rates, and research on the effects of aircraft noise on the use of medicines and health care services. The current position on these topics is summarised below.

Aircraft noise, use of medicines and health care services

282 Grandjean, Graf, Cauber, Meier and Muller (1973) found that the proportion of the population taking drugs was greater in areas of high aircraft noise. This result may be suspect because the survey question mentioned noise ('Has aircraft noise led you to......?') and such questions can strongly bias the responses (see Barker and Tarnopolsky, 1978). Knipschild and Oudshoorn (1977) used pharmacists' purchase data to monitor use of drugs in low and high noise areas. They found that an increase in aircraft noise was associated with increased purchase of sleeping pills, sedatives, antacids and anti-hypertensive drugs. Despite the uncertainties of the drug purchase data, and the lack of statistical analysis, this paper warrants some attention.

283 Grandjean (1974) and both Knipschild (1977) and Knipschild and Oudshoorn (1977) found that noise increased the GP contact rate. Knipschild and Oudshoorn (1977) even claim that there is a relationship between the level of noise in a patient's home area and the GP contact rate for psychiatric disorders or psychosomatic symptoms.

284 Other research (e.g. Relster, 1975) has found that various indices of morbidity and use of health services are related to complaints about road traffic noise, but not to the noise itself.

285 Watkins, Tarnopolsky and Jenkins (1981) studied a sample 6000 people in areas of different aircraft noise exposure. Their use of medicines, general practitioner services, hospital facilities and community services were investigated in relation both to the level of aircraft noise and the degree of
annoyance it causes. None of the indicators showed increased values in the high noise areas.

286 In areas of high noise, the use of non-prescribed drugs was significantly higher among 'very annoyed' than 'less annoyed' respondents. However, the use of psychotropic drugs and general practice services increased with increasing annoyance both in the high and low noise areas (although not all cases were statistically significant). The authors explain the results in the following way. They argue that self-medication is a response to severe noise stress, but that the expected excess in the high noise area was offset by the better previous medical history of the population there. In contrast to this, the use of psychotropic drugs and GP services can be explained in the following way. Noise has no effect on the use of these but it does sort out vulnerable subjects from the remainder. Whether this explanation is correct or not, the results do show that one must take into account both the nature of the physical stressor and the annoyance it produces.

Aircraft noise and the prevalence of symptoms of mental illness

287 Tarnopolsky, Watkins and Hand (1980) report further data from the Heathrow airport study. There was no effect of noise exposure on the overall incidence of psychiatric disorders and so the frequency of 27 individual acute and chronic symptoms was investigated. Many acute symptoms were more common in the high noise condition than in low noise. The ratio of high-noise prevalence to low-noise prevalence exceeded 1.2 for depression, irritability, waking at night, difficulty in getting to sleep, minor accidents, swollen ankles and skin troubles. Both chronic and acute symptoms were more frequent in people who reported high annoyance, in both high and low noise areas. However, more chronic symptoms were reported in the low noise area.

288 The authors argue that the acute symptomatology in high noise cannot be attributed to differences in socio-economic status. They also suggest that the absence of an effect of noise on chronic morbidity may be a consequence of selective migration, with individuals prone to mental disorders tending to avoid high-noise conditions.

Aircraft noise and psychiatric hospital admissions

289 Jenkins, Tarnopolsky, Hand and Barker (1979) compared three studies of aircraft noise and psychiatric hospital admissions conducted in the same area. Abey-Wickrama, a'Brook, Gattoni and Herridge (1969) reported results suggesting an association between aircraft noise exposure and psychiatric hospital admissions. Gattoni and Tarnopolsky (1973) carried out a similar study in the same area and could not confirm the earlier results. A third study examined standardised rates of admission to the same hospital for a longer period and for a larger area (divided into 4 bands of aircraft noise). Statistically significant trends of decreasing admissions with increasing noise levels were found.

290 Two main reasons for the discrepant results can be put forward. First, the studies used different populations and relatively small areas in London, Abey-Wickrama et al. (1969) may have selected two contrasting areas by chance, which also happened to be exposed to high and low noise levels. Alternatively, they may have observed a transient phenomenon not repeated in later years.

291 Overall, the results show that noise admissions. Nevertheless, it may be a contributory factor in a more complex causal net. Indeed, other results,
reported by Hand, Tarnopolsky, Barker and Jenkins (1978) show that at least in one other hospital the noise hypothesis may be tenable.

292 The above research has shown that it Broadbent (1980) has summarised the relationship between noise, noise annoyance and mental health in the following way.

(1) Noise increases annoyance

(2) Annoyance is associated with psychiatric ill-health

(3) Noise does not increase the proportion of people with psychiatric

In other words, the annoyance reflects the symptoms rather than the symptoms being produced by the noise annoyance.

293 There has been considerable recent interest in noise annoyance and Stansfeld, Clark, Jenkins and Tarnopolsky (1985) report that high noise-sensitive women exhibited significantly more psychiatric symptoms, higher neuroticism scores and greater reactivity to other sensory stimuli than intermediate and low noise-sensitive women.

294 One must ask whether results obtained in studies of aircraft noise generalise to noise present in the workplace. Aircraft noise is usually viewed as something which is uncontrollable and also a form of environmental pollution. Noise which is associated with a particular job may, however, be perceived differently and produce a different level of annoyance and/or change in mental health.

295 Melamed, Najenson, Luz, Jucha and Green (1988) have carried out one of the few studies on industrial noise exposure and mental health. High noise annoyance was associated with less job satisfaction, more complaints, irritability and anxiety. Noise annoyance appeared to be a better predictor of adverse psychological effects than did the measured noise exposure levels.

296 In conclusion, it is again apparent that further investigation of the effects of noise in the workplace on mental health is required. We are now in a position to carry out such studies following the improvements in methodology that have taken place in recent years.

XXII NOISE, REPRODUCTIVE FUNCTION AND BIRTH ABNORMALITIES

297 The Council on Scientific effects on reproductive function. Baird (1985) has argued that this does not reflect all the epidemiological data. For example, Rachootin and Olsen (1983) found that infertile female patients had elevated odds for occupational exposure to noise (OR 2.1 for women with hormonal disturbances, OR 2.2 for women who had an OR of 1.9. In reply Bond (1985) argues that "The results are not precise enough to be of value except, perhaps, to stimulate a more thorough investigation by these authors and others."

298 McDonald, Armstrong, Cherry, Delorme, Diodati-Nolin, McDonald and Robert (1986) carried out a large-scale survey in Montreal to assess the effects of work in pregnancy on the occurrence of spontaneous abortion, pre-natal health and congenital defect. Apart from associations with febrile illness, smoking and alcohol consumption, there are few indications of an environmental cause for abortion. Retrospective studies such as this are susceptible to bias which might influence recall or reporting of circumstances generally thought to adversely affect pregnancy.
The results showed that women whose work entailed exposure to noise had an increased risk of spontaneous abortion. However, when occupational groups were ranked according to work demands (thus avoiding potential bias from prior knowledge of outcome) increased risks were associated only with heavy lifting and other physical effort.

The possibility that noise may be a reproductive hazard has been widely studied. While there are abnormalities, it is unclear to what extent this reflects the noise per se or other factors associated with working and living in a noisy environment. Future studies, with improved methodologies, must seek to provide a more conclusive answer.
XXIII COMBINED EFFECTS OF NOISE AND OTHER AGENTS ON PHYSIOLOGICAL FUNCTIONS AND HEALTH

301 In recent years there has been a growing realisation that occupational health problems do not merely reflect variations in the intensity of individual agents, but are due to combinations of the physical, chemical, biological and psycho-social environments (see Manninen, 1983). Noise is not the only form of occupational stress present in the workplace, and other environmental factors or negative features of the work are almost always connected with it. The study of the combined effects of noise and other factors is, therefore, justified, and the literature shows that noise is the most frequently examined factor in the studies of combined effects.

302 Much of the research on the combined effects of noise has been concerned with hearing thresholds (e.g. Hamernik, Ahroon and Davis, 1988) or vestibular function (e.g. Manninen, 1988a). Other research has examined non-auditory functions but has used noise levels which would, if presented for a long period, have auditory effects (e.g. Okada, Kajikawa and Nohara, 1988). There are also studies which have considered combinations of stressors without examining single conditions (e.g. Bielski, 1987), which makes the results very difficult to interpret.

303 The next sections consider results from the areas where there has been most research on the combined effects of noise and other factors.

Noise and workload

304 Noise and physical or mental load have been reported to have additive effects on heart-rate (e.g. Steele and Koons, 1968), although other researchers have reported contradictory results (e.g. Finkelman, Zeitlin, Romoff, Friend and Brown, 1979).

305 Mosskov and Ettema (1977) carried out a laboratory study of the effects of 15 minutes' exposure to aircraft noise (84 - 91 dBA), traffic noise (Leq 83.5 dBA), mental load, and combined noise and load on performance and physiological functioning (heart rate, systolic and diastolic blood pressure, pulse pressure, sinus arrhythmia and respiratory rate). Mental load was increased by having the subjects perform a two-choice reaction time task.

306 The results showed that aircraft noise decreased heart rate and systolic blood pressure. This effect was not observed in the combined noise and task conditions. A significant increase in diastolic pressure and a decrease of pulse pressure and sinus arrhythmia was found in the noise alone, task alone and combined noise and task conditions. An increased respiratory rate was observed in the task alone and task and noise conditions, but not when noise was played and no performance was required. The effects of traffic noise were similar to those of aircraft noise. In general, a combination of exposure to noise and performance of a mental task did not cause an enlarged or additive effect, except in the case of respiratory rate.

307 Koller, Kundi, Korenjak and Haider (1986) report results from an experimental study of the combined effects of physical load and noise during day and night shifts. The physical work consisted of pedalling an ergometer. Noise increased heart rate and skin temperature, but the addition of the ergometer load did not produce additional effects. These effects did not differ during the day and night.
Ray, Brady and Emurian (1984) examined the effects of intermittent pink noise during performance of a computerised task. The noise elicited non-habituating decreases in digital pulse amplitude and increases in mean blood pressure. These noise-induced changes in vasomotor activity and blood pressure were superimposed on similar changes elicited by the performance of the tasks. The overall response to noise and to work performance differed in that work performance was associated with increases in heart rate and respiration rate, while noise stimulation was not.

Wu, Huang, Chou and Chang (1988) also examined the effects of noise exposure and task demand on cardiovascular function. Six experimental conditions were constructed by the combination of levels of noise exposure (60, 85 or 90 dBA) and task demand (presence or absence). Blood pressure measures were taken at the beginning and end of each 30 minute session. Blood pressure increased when the subjects had to perform the arithmetic task, but there was no effect of noise level on blood pressure.

Jansen and Schwarze (1988) carried out a longitudinal study of the effects of workplace stress on health. Six factors - time stress, noise exposure, noise annoyance, odour annoyance, lead exposure and carbon disulphide exposure - proved to be important in determining the health of the workers. A multiple regression analysis showed that time stress was the most important factor, followed by noise annoyance. The relative importance of the factors varied across the different forms of ill-health. Time stress was the dominant factor associated with gastrointestinal-renal disease. For neurovegetative disorders and diseases of the ear, nose and throat, time stress and the noise variables (exposure and annoyance) were the best predictors. In contrast to this, cardiovascular disorders were most strongly related to noise annoyance and noise exposure. It should be noted that noise annoyance was a better predictor of ill-health than noise exposure.

Noise and nightwork

Lees, Romeril and Wetherall (1980) carried out a paired cohort study of 140 industrial workers. Seventy of these workers had been exposed to levels of 85 dBA or less and the other seventy had been exposed to noise levels of 90 dBA or over. Their medical records were reviewed for the previous 15 years to assess the effects of noise on the incidence and type of illness, and on the frequency of absenteeism, headaches and accidents. There was no significant relationship between noise exposure and ill-health. However, workers on a rotating shift exhibited a significantly higher incidence of days absent and headaches.

Ottmann, Rutenfranz, Neidhart and Boucsein (1987) also found that noradrenaline excretion and electrodermal activity show independent effects of noise and nightwork. Noradrenaline excretion and electrodermal activity were higher during the day than at night but there was no direct effect of noise on these functions. After-effects of noise were, however, observed and during sleep after noise exposure there were higher levels of noradrenaline excretion and electrodermal activity. Adrenalin excretion was higher during the day than at night. However, this pattern was changed by noise exposure, with noise increasing adrenalin excretion in nightworkers and decreasing it in dayworkers.

Koller, Kundi, Haider and Cervinka (1988) report that shiftworkers are very noise sensitive. They suggest that it might reflect the fact that noise sensitivity discriminates between shiftworkers who are more or less prone to sleeping problems in noisy environmental conditions. Alternatively, there may be a synergism between the load imposed by nightwork and noise exposure, which is
moderated by noise sensitivity. Noise sensitivity is also highly correlated with neuroticism, and this may be responsible for some of the observed effects.

**Noise and vibration**

314 Manninen (1988b) reports data which suggests that the combined effects of noise and vibration are different from those of the individual agents. This is supported by results from a number of studies. For example, Pykkö and Starck (1985) found that a combination of noise and vibration increased EEG’s in the dorsal hippocampus, amygdaloid complex, midbrain reticular formation and frontal motor cortex. The authors take this to be related to non-specific dizziness found in aerospace workers exposed to a combination of excessive noise and vibration. The effects of the combination of noise and vibration could not be predicted from the response to the single factors.

315 Okada, Ariizumi and Inaba (1988) report that the noradrenalin content of the midbrain decreases after exposure to 100 dBA noise. Vibration decreased noradrenalin in the hypothalamus, and a combined exposure to noise and vibration led to decreased noradrenalin in the whole brain. It is important to note that the effect of the combination on noradrenalin excretion was not an additive effect of noise or vibration alone. Okada, Kajikawa and Nohara (1988) found that the level of plasma uric acid was the same in the combined exposure of noise and vibration as in the vibration alone condition. However, plasma glucose was unaffected by noise exposure but increased significantly when noise was paired with vibration.

316 Nakamura, Nohara, Nakamura and Okada (1987) examined the effects of noise and vibration on finger blood flow. The results showed that the direct effects on the digital vessels of local vibration and handle grasping were very large. In contrast, the effects of noise via the sympathetic nervous system made little difference to vessels already damaged by the local vibration.

317 A recent study by Idzior-Walus (1987) examined the combined effects of occupational vibration and noise on blood pressure and hypertension. A sample of men exposed to vibration (four times the legal limit) and noise (105 - 116 dB) again, above permissible levels were compared with a control group matched for age, sex, socio-economic class and level of occupational physical activity. The mean blood pressure values and the percentage of workers with hypertension were significantly higher in the group exposed to noise and vibration. Clearly, another study comparing lower levels of noise and vibration is required, and separate noise and vibration groups should be examined so that we know how the combined condition compares to the effects of each factor on its own.

318 Most of the studies considered so far have examined only two factors. This is still not representative of the work situation and the effects of dual stress exposure may be influenced by other variables. For example, Manninen (1983) reports data which shows that the effect of noise and vibration on cardiovascular function varies according to the room temperature.

**Other combined effects**

319 Other research has examined the combined effects of noise and solvents (Kurnayeva, Burykina, Zel’tser, Dasayeva, Kolbeneva, Veselovskaya, Demin and Loshchilov, 1986), noise and electromagnetic fields (Bielski, 1988), noise and illumination (Rentzsch, Haenel, Hanisch, Joiko and Prescher, 1987), and noise and air pollution (Haider, Kundi, Gross-Knapp and Koller, 1988). Most of this research has provided preliminary data and needs to be replicated before firm conclusions can be reached. The studies have usually examined pairs of stressors.
and we are not yet at a stage where a detailed profile of the working environment is being examined. The studies have also tended to use young, fit, healthy males as subjects. Further research must examine gender differences, the older worker, and try to determine which sub-groups are especially susceptible to a combination of stressors.

Noise and recovery from illness

320 Other research has been concerned with the effects of noise on the recovery of hospital patients (e.g. Keipert, 1985). Topf (1985) tested the hypothesis that patients exposed to high levels of noise would have poorer recovery. The results failed to support the view that noise is negatively related to recovery. It is possible that noise exposure has to be prolonged before health is influenced, which means that speed of post-operative recovery is not a particularly sensitive measure. Nevertheless, it is certainly worthwhile to determine whether illness makes people more sensitive to noise effects, and whether noise does influence symptomatology and immunological changes.
AN EVALUATION OF THE RESEARCH ON NOISE AND HEALTH AND RECOMMENDATIONS FOR FUTURE RESEARCH

Have the research techniques been adequate?

321 Many of the studies reviewed here have had methodological weaknesses, and it is apparent that certain results from epidemiological research could reflect factors other than noise. One must, therefore, treat some of these positive findings with caution. It should also be pointed out, however, that many of the negative results could be due to the size of the sample examined. This means that one recommendation for future research is to carry out similar studies but use the improved methodology that we now have.

Are the effects negligible?

322 In many cases the observed effects are small. For example, many of the noise-induced changes in blood pressure are similar in magnitude to the normal variations seen over the waking day. However, these usually represent acute effects of noise and it is possible that prolonged exposure may lead to much greater cumulative effects. Indeed, there is some indication of this from some of the epidemiological studies. While small changes may have little impact on the majority of the population they may be critical for certain sub-groups. Future research must, therefore, examine the effects of noise on the health of at-risk groups. Similarly, we must know whether the acute physiological changes do lead to a significant pathology when exposure to noise is prolonged.

Are the results mutually consistent?

323 In several areas (e.g. the effects of noise on cardiovascular functioning) the results obtained using different research techniques do point to the same conclusion. Unfortunately, it is difficult to say whether results obtained in the laboratory, or from community studies of aircraft noise, apply in the workplace. Indeed, one of the obvious features of research on non-auditory effects of noise is how little of it has been conducted on occupational exposure. The few studies which have examined noise in the workplace have failed to control for other factors, or failed to examine the interaction of noise and other factors, and should, therefore, be treated as preliminary studies.

324 There is evidence from the laboratory and from field studies which shows that it is quite possible that noise at work may influence health. The acute physiological reactions to noise have been widely studied and provide a potential mechanism for effects on health. However, it is less certain whether prolonged exposure does lead to definite health effects in a wide range of situations. Indeed, like the area of noise annoyance, the health effects of noise exposure may reflect psychological reactions to the noise as well as objective exposure levels. What is required, therefore, is a longitudinal prospective study considering noise parameters, other factors present in the workplace, and characteristics of the people exposed to the noise. Many physiological parameters should be considered, and we should examine effects of noise on the immune system. Appropriate noise interventions should be carried out and the efficacy of these assessed over a much longer period than in previous studies.
XXV OVERALL CONCLUSIONS

325 Noise is often regarded as one of the major occupational health hazards and subjective reports from workers confirm that it is often perceived as a major problem in the workplace. Our knowledge of the auditory effects of noise has advanced to where dose-response relationships are clearly defined. The present review has been concerned with the non-auditory effects of noise and here simple dose response studies are inadequate. Any study of the effects of noise in the workplace must consider the person’s perception of the noise, the extent to which it interferes with activities, whether it is also present outside the workplace and whether it interferes with sleep, and the reactions of exposed people to protect themselves.

326 The results on noise and performance efficiency and on noise and health do suggest that there is a possibility that noise affects safety and health. It is hard to be more definite about the effects of noise at work, mainly because there have been few good studies of this topic. Some of the effects attributed to noise could reflect other factors and it will not be until further more sophisticated research is carried out that we will have a more definitive answer.

327 It is argued that previous research provides enough evidence to warrant such a large scale study. The main evidence is summarised below:

(a) Laboratory research has shown that moderate intensity noise, where there is no risk to hearing, can influence performance efficiency. The effects depend on the nature of the noise and the effects of irrelevant speech require further study. Similarly, the nature of the task being performed is very important, and we should, perhaps, aim to specify which activities should or should not be carried out in this level of noise. The person’s perception of the noise and other features of the situation (such as whether the person has control over the noise) are also important in determining whether impairments are observed or not.

(b) Most laboratory studies have been concerned with the acute effects of noise. In order to get information about longer exposures one has to turn to the field. Research on noise and accidents, absenteeism and productivity suggests that noise is at least a contributory factor. Further research with better methodology is required to provide clearer information on this topic.

(c) There is considerable evidence that acute noise exposure may influence cardiovascular function and levels of catecholamines. Epidemiological studies also suggest that noise may be a risk factor, although it is difficult to be more precise given the methodological weaknesses of some of the research.

(d) Noise influences sleep in that it may prolong the time needed to fall asleep, may cause awakening once asleep, may interfere with returning to sleep once awake, and may cause a shifting from deeper sleep to shallower sleep. While such effects are quite reliable we do not yet know what their significance for long term health is.

(e) Noise produces annoyance, and certain signs of annoyance may reflect the development of psycho-pathology. The degree of annoyance or psychopathology often reflects psychological characteristics of the individual not just the level of noise. Generally, we may conclude that noise increases annoyance, annoyance is associated with psychopathology, but there is little direct effect of noise on psychopathology.
(f) There is some suggestion that noise at work may be associated with abnormalities of reproductive function and birth defects. At the moment there is little evidence on this topic, which must be reconsidered in future studies.

328 There are health problems which cannot be accounted for by known risk factors. For example, heart disease accounts for a large percentage of all deaths and so a reduction in noise might reduce the risk for many people even if the association between noise and cardiovascular dysfunction is only slight. This suggests that further research in this area is warranted. Indeed, future research can not only rectify the mistakes made in earlier studies, but it can greatly aid our knowledge of the mechanisms linking stress to ill-health. In other words, further studies of the non-auditory health effects of noise could help us explain health problems for which, at the moment, there is no other known cause.

329 One might suggest that taking care of hearing conservation would also remove non-auditory effects of noise. This is clearly not the case as both performance effects and health effects have been reported at levels well below those where there is a risk to hearing. Indeed, it would seem more sensible to reduce noise to avoid non-auditory effects which would, of course, remove the effects of noise on hearing.

330 The main problem is that we do not know how much noise reduction is required to remove non-auditory effects at work. While results from previous studies in the laboratory and field provide a prima facie case for expecting non-auditory effects of noise we do not know whether they adequately reflect the situation in the workplace. In order to obtain information on the impact of noise at work it is necessary to carry out a longitudinal prospective study which considers many types of noise and different jobs. Such a study should also be multi-disciplinary as subjective responses and objective measures of health and efficiency must be obtained in order to provide a detailed profile of the effects of noise.
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