Non-auditory effects of noise at work: A critical review of the literature post 1988

Prepared by the Institute of Occupational Medicine for the Health and Safety Executive
Non-auditory effects of noise at work: A critical review of the literature post 1988

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This report contains a critical review of the literature on the non-auditory effects of noise published since 1988. It was prepared to update a previous review prepared by Smith and Broadbent, also on behalf of the Health and Safety Executive (HSE). Focussing on occupational exposures, it encompasses behavioural and psychological influences of noise as well as its impact on physiological functioning and health.

The findings suggest that there is some evidence for a range of effects on performance and health due to continued exposures to noise at, or in some cases below, the levels specified by current UK legislation. However, due to limited and sometimes conflicting data, this evidence is not conclusive and it is not possible to estimate accurately the impact of these effects or to suggest thresholds below which there would be no adverse effects. The effects of noise on performance in particular is complex and dependent on many different variables including its control and individual (psychological) significance.

There is increasing evidence of a 'physiological cost incurred by working with noise' and suggestive evidence that chronic noise exposure may be associated with sustained increases in blood pressure. Evidence also suggests that maternal exposure to noise may affect foetal hearing ability.

This report and the work it describes were funded by HSE. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.
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The Institute of Occupational Medicine

The Institute of Occupational Medicine (IOM) is an internationally recognised scientific research organisation with charitable status, established in 1969. The headquarters are in Edinburgh, with regional offices in London, Newcastle and Cardiff.

The IOM is a major independent UK centre of research, problem-solving and training in the fields of occupational and environmental health, hygiene and safety. The IOM also provides extensive quality analytical and advisory services to industry throughout the UK and overseas.

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SUMMARY

In 1992, a review of the published literature on the non-auditory effects of noise at work was produced by Smith & Broadbent. This document provided comprehensive coverage of the topic, encompassing behavioural and psychological influences as well as the impact of noise on physiological functioning and health. However, with the possibility of noise and its effects featuring in the Physical Agents Directive currently being formulated by the European Union, there was an obvious need to update this document. The aims of this review were to assess critically all literature published since 1989 to provide a general overview of the current state of scientific knowledge on the topic. In addition, two specific questions have been addressed:

(a) What are the effects of habitual noise exposure on general health and well-being?

(b) What are the practical implications of our existing knowledge of the effects of noise on performance?

An extensive literature search was performed using all the occupational health related CD-ROMs and literature databases. Supplementary material was gathered by (a) contacting ‘noisy’ industries for personal experiences, and (b) advertising the research in relevant journals and asking for scientific opinions.

Each paper was then peer reviewed by selected experts who included an Occupational Physician, Psychologist, Physiologist/Ergonomist and Senior Statistician.

The findings of the review suggest that there is some evidence for a range of effects on performance and health due to continued exposures to noise at, or in some cases below, the current levels specified within the 1989 Noise at Work Regulations. However, due to limited and sometimes conflicting data, this evidence is not conclusive, and it is not possible to estimate accurately the impact of these effects or to suggest thresholds below which there would be no adverse effect on either performance or health. The effect of noise on performance is complex and dependent on various factors such as the nature of the noise, pattern and duration of exposure, predictability, frequency and controllability, as well as individual (psychological) significance.

There is increasing evidence of a ‘physiological cost incurred by working with noise’ and suggestive evidence that chronic noise exposure at current noise levels may be associated with long term sustained increases in blood pressure. Further reliable epidemiological evidence is however required to support this.

Effects on psychological ‘wellbeing’ are suggested at noise levels below current action levels, particularly for ‘susceptible’ individuals in the presence of other workplace stressors.

Evidence suggests that maternal noise exposures over 90dB in the last trimester of pregnancy may affect foetal hearing ability. Further follow up studies of children of noise-exposed populations may be helpful in determining whether there is any effect on childhood hearing ability. Based on the evidence currently available it would seem reasonable to consider an upper limit for noise exposures during pregnancy.

In conclusion, although there are demonstrable effects of noise on performance and general health at noise levels below current legislative limits (action levels), it is not possible to establish any consistent relationships with quantifiable physical characteristics due largely to associated psychological influences.
1. INTRODUCTION

The number of persons reported to be suffering from Noise Induced Hearing Loss (NIHL) differs widely according to which statistical survey is referenced. According to the 1994 Health and Safety Commission Statistics, figures range from the 13,300 reported by the Department of Social Security to 103,100 as cited in the Labour Force Survey. In 1989, legislation was produced in the UK with regard to the sound pressure levels (SPLs) allowed in the workplace. As a result of this legislation, sound pressure levels exceeding 85dB(A) require action by employers to provide hearing protection for employees and, above 90 dB(A), to reduce noise at source. However, due to the chronic nature of NIHL, it is anticipated that the effects of exposure from some years ago will only be realised in future statistical surveys. The results of this legislation will therefore only be seen in years to come.

In addition to the direct effects of noise on hearing ability it was recognised that noise could have other effects. Amongst these were psychological effects influencing concentration or disrupting mental processing; and also alleged physiological effects with implications for long-term pathological damage, such as prolonged elevated blood pressure. In 1988, the Health & Safety Executive commissioned a critical review of the literature specifically on the 'non-auditory effects of noise'. The result of this research was a reference document published in 1989 by Smith & Broadbent. This document provided comprehensive coverage of the topic encompassing behavioural and psychological influences as well as the impact of noise on physiological functioning and health. However, with the possibility of noise and its effects featuring in the Physical Agents Directive, currently being formulated by the European Union, there was an obvious need to update this document. The HSE has requested that all relevant literature published since 1989 be critically appraised. In commissioning this review, the HSE placed emphasis on the 'practical relevance' of the literature in relation to occupational noise exposure. The authors have therefore primarily accessed literature which directly relates in some form to the occupational field.

1.1 AIMS

The aims of this study are to assess critically the relevant literature published since 1989 and to provide a general overview of the current state of scientific knowledge on the topic. In producing this report, two questions were addressed in particular:

(a) What are the effects of habitual noise exposure on general health and wellbeing?

In addressing this question, the HSE asked that specific attention be given to whether information is available in the literature on the effects of noise exposure lower than that associated with NIHL. This review considers whether such effects should include biochemical markers, which may indicate stress responses, physiological as well as psychosocial.

(b) What are the practical implications of our existing knowledge of the effects of noise on performance?

Whilst considering the effects of noise on performance, the HSE drew attention to the effects which other factors or agents have on performance. They distinguished between the direct effects of the agents (comparable to NIHL) and indirect, non-specific, responses which might have parallels with the general syndrome proposed in some theories of stress.
1.2 EXISTING KNOWLEDGE ON NON-AUDITORY EFFECTS OF NOISE

Since this document is an update of the work conducted by Smith & Broadbent (1989), it is appropriate that the starting point be a statement of the conclusions of their work. The following is extracted from their overall conclusions.

(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 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.
2. **OUTLINE OF WORK PROGRAMME**

A multidisciplinary project team of specialists, involving an Information Scientist, an Occupational Psychologist, an Occupational Physician, a Physiologist/Ergonomist and a Statistician, was formed to conduct the critical review. The full work programme is reported in Appendix 1.

A literature search strategy was designed to address the project aims and objectives. The appropriateness of this strategy was then assessed by using the studies cited by Smith & Broadbent in the years 1987 and 1988 as a check. By using the suggested search strategy, comparative checks were made to determine how many of their cited studies were accessed via our strategy. Results of this trial showed that a high percentage of the papers cited were identified by our strategy.

An extensive literature search was then performed using all the occupational health related CD-ROMS and literature databases. Supplementary material was gathered by contacting 'noisy' industries for personal experiences, and advertising the research in relevant journals and asking for scientific opinions.

All abstracts accessed via the search were reviewed. Full copies of the papers were sought only if the details given in the abstracts identified it as being appropriate for full review. A 'filter' sheet was then completed for each paper which considered (a) the papers’ relevance in terms of study objectives, (b) the quality of documentation and (c) the significance of the contribution. Each paper was then peer reviewed by selected experts from the project team.

Section 3 of this report provides a summary of the findings from the review. Each of the papers have been reported in detail in Appendix 2 of this report.
3. SUMMARY OF FINDINGS

The review updates and, to some extent extends the review of the literature conducted by Smith and Broadbent and published in 1992. This section provides a summary of the findings from recently published literature. Each sub-section follows a standard format consisting of a summary of the major findings of Smith and Broadbent (in bold print); a synopsis of the new literature and then, where appropriate, a summary of how, these more recent papers have modified these findings (again in bold print).

3.1 CARDIOVASCULAR SYSTEM

This section considers whether chronic noise exposure can be implicated in the causation of cardiovascular disease, or whether there is evidence that acute noise exposure can result in biochemical or physiological changes in cardiovascular parameters which are sustained over time.

3.1.1 Cardiovascular Disease

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.

Published around the time that Smith and Broadbent concluded their literature searches, Kristensen (1989) presented a review document of Cardiovascular Diseases (CVDs) and the work environment which provides a comprehensive insight into the impact of noise and other environmental stressors. Based on a review of epidemiological quality, 23 of the 47 relating to noise indicated a positive relationship between noise and CVD. The other papers reviewed in this document however show that whilst supporting this trend, other environmental stressors such as physical inactivity and shiftwork have a more significant impact on CVDs. The author points out that hypertension is often the only endpoint considered, such studies therefore failing to consider the complex interaction of factors involved in cardiovascular disease causation.

Three of the papers published since this work and reviewed for this section relate to environmental rather than occupational noise exposure (two drawn from the same study). The pattern of noise exposure is likely to differ markedly between the two forms of exposure and the quality of any estimates of exposure likely to be less in environmental rather than occupational studies. These factors need to be considered in evaluating the findings of such research.

On balance, the papers published since the review by Kristensen probably present a similar pattern with approximately half the papers cited showing positive relationships between some measure of noise exposure and indices of cardiovascular health and some indications that the more robust papers are more likely to report an effect. Thus, Babisch et al (1991) reported some significant effects of noise on biochemical markers such as blood lipids (but not on blood pressure measures). Although a number of the main potential confounders are accounted for, the study is one of traffic noise and there may therefore be other traffic-related factors such as airborne pollutants which account for this pattern.

Most of the papers reviewed for this section have methodological deficiencies which may reduce the strength of their findings (positive or negative). Thus, in addition to the work of Babisch et al cited above, Lercher et al (1993); Lang et al (1992); Zhao et al (1991); did show some
indications of a positive effect of noise on indices of cardiovascular health with two others (Ising, 1991; and Elwood et al. 1992) showing non-significant trends in the same direction. In contrast, the papers by Mann et al. (1992) and Hessel and Sluis-Cremer (1994) failed to identify any significant relationships.

Finally, some papers e.g. Lercher et al. (1993), utilised ‘noise annoyance’ as their measure of exposure rather than actual or estimated levels and the positive results from this (limited) paper, together with the studies reported by Vera et al. (1994) manipulating psychological impact; and Melamed et al. (1993) on personality traits suggest that the adverse effects of noise on cardiovascular health may be mediated via psychological rather than direct physiological pathways which may well have contributed to the variability in the results obtained in the various studies.

The recent studies continue to be limited by poor quantification of noise exposures and adequate consideration of confounders. Whilst acute loud noise exposure can influence cardiovascular and biochemical parameters, there is still a lack of convincing evidence that chronic noise exposure at current action levels causes cardiovascular disease (including heart attacks). However, further research may provide more convincing results.

3.1.2 Physiological and Biochemical

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.

The majority of papers concerning the impact of noise on heart rate, blood pressure and catecholamines indicate the ‘expected’ trends as cited by Smith and Broadbent and confirm that acute noise exposure may adversely influence cardiovascular function and levels of ‘stress’ hormones, for example catecholamines. Many of the papers however, also consider possible links with other factors. For example, Melamed et al. (1993) looked at Type A/B (noise annoyance susceptibility) and suggested tension as a mediator of cardiovascular reactivity. ‘Type of noise’ was also found to be important with music unlike ‘noise’ failing to produce any increase in heart rate. Umemura et al. (1992) suggested that exposures over 80dBA reduced work output and were associated with significant increases in heart rate. These general findings are confirmed by a number of laboratory based studies, Lésnik et al. (1989) conclude that exposure to noise over 70dBA increases the physiological effort of work and Millar (1990) concludes that there is a physiological cost incurred of working with noise. Unfortunately these studies lack power because of small sample size. Animal evidence (Boer et al. (1989)) supports the physiological changes seen in humans.

Tomei et al. (1991) suggests a direct role of noise on vascular tone with groups exposed for larger durations to noise below 80-92dB having higher prevalence of hypertension and hearing deficits on audiometry. Unfortunately this is not discussed in detail.

In general, studies demonstrate an interaction between noise level and other factors such as task demand and predictability of noise on acute changes in BP. Most are laboratory based, and the BP increments are small and would not be of clinical significance unless sustained over time (Carter et al. (1994)). The study by Parrot et al. (1991) is at variance, finding no effect on BP and heart rate elevations restricted to men only. Theorell et al. (1990) suggest a ‘stress response syndrome’ with effects not simply related to changes to BP. A study by Evans et al. (1995) of school children suggests a similar hormonal response in chronically noise exposed groups, but effects on BP were not significant in this age group.
Whilst an acute biochemical and physiological response to noise is confirmed, it is not possible to extrapolate these findings to the longer term, due to the limitations of study design and of cardiovascular responses that are not sustained.

3.2 EFFECTS ON SLEEP AND FATIGUE

Noise influences sleep in that is 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.

Although Smith and Broadbent reported adverse effects of noise on perceived effort, the expected corollary, that of increased fatigue was not reported upon.

There was little evidence found within the papers reviewed to add to the knowledge as cited by Smith and Broadbent. Of the two laboratory based experiments reviewed, Libert et al (1991) looked at the effects of both heat and noise on sleep patterns. Although noise exposure was seen to influence sleep stages, number of changes toward awakening and number of ‘light sleep’ episodes, the impact of heat on sleep was found to be more significant. The small population size and predominantly laboratory based design limits the power of these studies when predicting possible occupational impacts.

Only two studies (Kjellberg et al (1996) and Vallet et al (1991)) were found which directly examined the influence of noise on level of fatigue. Although both related to occupational settings, the confounding effect of vibration was present in both, and components of the tasks undertaken may be important determinants of fatigue. Fatigue effects were certainly apparent in both studies, however extrapolation of results based on noise alone were unreliable due to limited consideration of the effect of vibration. Again these studies only consider small groups of workers.

3.3 PSYCHOSOCIAL/PSYCHOLOGICAL

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 effects of noise on psychopathology.

A considerable amount of research has been presented which examines the areas of psychosocial and psychological effects of noise. Noise sensitivity and annoyance appear to be the main outcomes studied. There is disagreement among authors as to whether 'noise sensitivity' is a stable personality trait which influences response to noise resulting in annoyance [Stansfield (1993) and Topf (1989)] or whether 'annoyability' is a trait which is influenced by a number of factors, not specifically noise, except in those with hearing impairment [Kjellberg et al (1990)]. In this review Kjellberg also challenges the conventional theory of noise directly increasing arousal and suggests a variable effect of noise on attentional selectivity. This detailed review also repeats the view that the evidence for noise exposure and long term cardiovascular and hormonal effects is contradictory. Researchers such as Stansfield (1992) have shown a correlation between a number of personal characteristics such as neuroticism and negative affectivity and noise sensitivity. It has been indicated that in vulnerable individuals, psychiatric disorders can emerge, [Stansfield (1992)]. In general, it appears that introverts show greater physiological arousal but report less deactivation in noisy conditions than extroverts, [Standing et al (1990)]. Deteriorations in task
performance are however seen in introverts working in noisy conditions, although the interaction of extroversion and neuroticism shows the most consistent impact on performance.

However, one of the most significant issues relates to poor person-environment fit in relation to intrinsic job factors and stress. Unfortunately, the results of the occupational studies are complicated by these confounding factors. McDonald et al (1989) showed that these factors were related, evoking more reports of ill health than noise level or noise annoyance. There was a relationship with high noise level and reports of ill health but this was not linear, and in general the interaction of workplace 'stressors' and reports of 'wellbeing' is complex.

The nature of the noise appears to be important in determining response. As well as intensity, impulsiveness and frequency are just two components of 'risk' within noise exposure. Predictability and controllability have also been proposed as important factors in both reducing annoyance and changing attitudes to noise.

Finally, the nature of the noise and therefore its potential psychological significance is also likely to affect any responses.

The outcome of the present review is to qualify the main finding of Smith and Broadbent to 'noise may produce annoyance'. The degree of annoyance depends to some extent on the physical and psychological characteristics of the noise but is also influenced by underlying psychological traits and by short-term variations in susceptibility. Noise level is not necessarily a strong predictor with some negative effects being documented at levels as low as 51dB(A) (Kjellberg, 1990), well below current action levels.

3.4 REPRODUCTION AND DEVELOPMENT

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.

A number of studies have considered the effects of noise on various reproductive outcomes. Whilst there does not appear to be any substantive evidence that noise is a teratogen, there does appear to be a tentative link between increased noise exposure and low birth weight. Many of the research papers however, have methodological drawbacks which limit the strength of these associations. Exposure data is often limited and any study on pregnancy outcome must consider a wide range of confounding factors, such as socioeconomic status and obstetric history. Many of the studies fail to consider or quantify these effects. Hartikainen et al (1994) finds an association with low birth weight and noise exposures above 90dB(A) but no effect on maternal BP. However the effects of shift work and vibration are not considered.

There also appears to be a 'critical gestation period' when noise exposure has the greatest impact. Hepper et al (1994) suggest exposure in the last trimester is potentially harmful to the foetal auditory system. It is also suggested that low frequency noise (<250Hz) is less well attenuated through the maternal abdomen.

The concept of a critical period is also discussed by Pikus (1991) and Campo et al (1989). Both authors comment that there is limited confirmatory data currently available for humans, and that further research is required. However, Campo et al urge caution in the setting of exposure standards.

One paper, Lalande et al (1986) which was frequently cited in the other papers reviewed, suggests
an increased risk of high frequency hearing loss in children whose mothers were exposed to noise in the range between 85 and 95dB(A) during pregnancy. Niemtzw (1993) in a review of this and other studies concludes that maternal exposures in pregnancy should be kept below 90dB to prevent harm to the foetal auditory system. The evidence for this particular threshold is at present limited.

The strongest evidence from the research papers however highlights the negative impact that other work conditions, especially shiftwork, can have on pregnancy outcome. Nurminen et al (1995) showed a relation with shift pattern, delayed growth in utero and low birth weight. Henrikson et al (1994) show similar associations with high job strain in the last trimester of pregnancy. In this study poor exposure data again limits the assessment of the impact of noise alone.

In conclusion, there is some evidence for an effect of noise on pregnancy outcome, particularly on birth weight, although any effect is small and often submerged by other more potent factors. At the present time there is lack of conclusive evidence to support a causal link between noise exposure during pregnancy and foetal hearing loss. However there is evidence from animal studies to suggest a ‘critical period’ for the development of the inner ear, which corresponds to the last three months of pregnancy for the human foetus. There is also evidence to suggest that frequencies below 500Hz are less well attenuated in utero, and that the potential for harm increases with increasing noise intensity. Further studies are required, particularly prospective studies of noise exposure at or below the current action levels.

3.5 IMPULSE NOISE

Although Smith and Broadbent included some comments on noise of differing characteristics (eg. frequency, duration and intermittency) impulse noise was not examined as a discrete category.

None of the papers reviewed considered impulse noise from the point of view of startle effects which can be one outcome. The papers were to some extent conflicting, for example one showing that annoyance and subjective impulsivity were related and another showing that they were not.

The general indication would appear to be that whilst some impulse noises are likely to be annoying the psychological content is likely to be dominant resulting on occasions, in noise of a less impulse nature being more annoying than a highly impulsive noise.

3.6 NOISE AND PERFORMANCE

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.

The papers cited in this review clearly support the conclusion of Smith and Broadbent (1992) that noise can have an effect on performance at levels below those presenting a risk of damage to hearing. However, although some general patterns can be identified, such as a tendency for otherwise disturbing or distracting noise to produce an apparent narrowing of attention, the extent
to which such responses occur and the effect which such a response may have on performance cannot be generalised. Narrowing of attention may reduce the intrusion of other unwanted stimuli and maintain or even enhance task performance. Alternatively, where such apparently peripheral stimuli are essential elements of performance then a deterioration may well occur (see for example Bhattacharya et al., 1991).

The variation in the impact of noise depending upon task characteristics makes it difficult to generalise those noise characteristics which will influence performance. Thus whilst it can be stated generally that, for any specific noise, greater intensity will be equated with greater effort, some studies have demonstrated a ‘U’ curve relationship with an optimum (moderate) level of noise for best performance (eg Britton and Delay, 1989).

Physical characteristics of noise alone do not explain the variable effect of noise on performance. Again although some general principles can be stated, such that irregular intermittent noises are more likely to influence performance, the influence of other factors such as the psychological meaningfulness of noise may be sufficient to negate any such influences.

The psychological impact on the listener appears to have more impact than the physical impact both in terms of impact and outcome, several studies having shown perceived performance to be more affected than actual performance (eg Becker et al., 1995). Even psychological effects are difficult to predict with any certainty, for example many studies showed traffic noise to have a significant negative impact whereas in at least one study familiarity with this noise rendered it ineffectual (Rossi et al., 1991). The suggestion from some studies of a role for ‘necessary’ noise increases the uncertainty in attempting to relate even these generalisations to the industrial environment.

Although it can be stated with some certainty that noise can have an effect on performance it is by no means easy to predict when noise will have an effect or, indeed, what that effect will be. A number of studies have however shown that when performance effects do occur they can be evoked by noise levels well below those identified in relation to noise-induced hearing loss (e.g. 85 and 90dB(A)).

3.7 NON-SPECIFIC EFFECTS OF OTHER PHYSICAL AGENTS

Although Smith and Broadbent examined the effects of other physical agents in combination with noise they did not include independent indirect effects of these agents.

A brief examination of the literature relating to other physical agents (vibration, illumination, heat and cold) showed that, in general, the impact of these agents has been less exhaustively researched. The strongest evidence for indirect effects can be obtained for heat, where systematic influences of heat on task performance have been established although, as with noise, the relationship is to some extent task specific (eg Wing, 1965).

Some limited indirect effects of illumination and vibration have been reported although to date none have been found which examine the various physical characteristics of either agent (eg frequency and intensity).

It appears therefore, that with the exception of a body of literature on the effects of heat on performance few studies have been conducted to reveal indirect effects of other physical agents comparable to the non-auditory effects of noise.
3.8 INTERACTIVE EFFECTS WITH OTHER PHYSICAL AGENTS

Smith and Broadbent provided an annotated bibliography of papers relating to interactive or combined effects of noise and other agents. However, the balance of evidence from those studies reported was not discussed and no conclusions were reported.

Some further papers were identified which related to interactive or combinative effects of noise with other agents. Some of these reported laboratory studies, although most related to field studies involving exposures to broader environmental sources such as railway noise and vibration. However, although these papers do serve to confirm that such effects can be demonstrated, the relatively low number of papers, coupled with the potential variety of exposure variables, make it difficult to generalise the findings or develop firm conclusions or guidance.

In conjunction with other agents, noise can produce additive, cancelling or interactive effects. However, the complexity of exposure variables make it difficult to identify consistent and stable response patterns.
4. AN EVALUATION OF THE RESEARCH ON NOISE AND RECOMMENDATIONS FOR FUTURE RESEARCH

4.1 GENERAL COMMENTS

Since the review by Smith and Broadbent (1992) there has been considerable expansion in the research into ‘Non-Auditory Effects of Noise’, with studies covering all the areas highlighted as being of significance in the initial review and with the production of further review papers on this subject.

The findings of this review in general support the conclusions reached by Smith and Broadbent and provide further clarification of certain areas.

4.2 NOISE AND HEALTH

The results of the review confirm that acute noise exposure may influence cardiovascular function and hormonal levels. There is increasing evidence of a ‘physiological cost incurred by working with noise’ and suggestion that chronic noise exposure at current action levels may be associated with long term sustained increases in blood pressure. Further reliable epidemiological evidence is required to support this relationship. It is possible that chronic stimulation of adrenocortical pathways may have implications for immunoregulatory functions.

The available evidence on noise and sleep/fatigue effects supports Smith and Broadbent’s conclusions but the power of these findings is limited by sample size and aspects of study design.

It is very difficult to generalise about the impact of noise on psychological wellbeing in relation to health and performance, as these two outcomes are affected by a number of factors which are specific to the requirements of the task and the individuals concerned. However, effects on psychological ‘wellbeing’ are suggested at noise levels below current action levels, particularly for ‘susceptible’ individuals in the presence of other workplace ‘stressors’.

In considering the effects of noise on pregnancy outcome, whilst some studies suggest noise exposure is associated with low birth weight, the effect is small and may be attributable to other confounding factors. There is however evidence to suggest that low frequency noise may be less well attenuated by the maternal abdomen than high frequency noise, and that there may be a critical period during the last trimester of pregnancy when the developing foetal auditory system is particularly susceptible.

4.3 NOISE AND PERFORMANCE

Moderate noise at sound pressure levels below the current action levels (Noise at Work Regulations 1989) can influence performance. The effect is however complex and depends on the nature of the noise, pattern and duration of exposure, predictability, frequency and controllability. The impact is further determined by the requirements of the task being performed and individual factors such as personality trait and perception of the ‘value’ of the noise. The review confirms the effect of irrelevant speech as a distracting influence. The findings have implications for the performance of certain tasks in specific occupational settings.
There is still little epidemiological data relating noise exposure to accidents, absenteeism or productivity.

In general the studies which consider the impact of noise in comparison with other physical factors such as vibration, heat and illumination find similar effects on performance due to the effects of vibration and heat. There is at present little reliable data demonstrating non-visual effects of lighting on performance. As with studies considering the effects of noise on health impacts, there is often a paucity of personal noise exposure data, and poor quantification of other variables which confound the results in relation to noise.

4.4 RECOMMENDATIONS FOR FUTURE RESEARCH

The findings of this review suggest that there may be a range of effects on performance and health due to continued exposures to noise at, or in some cases below, the current levels specified within the Noise at Work Regulations (1989). However, due to limited epidemiological data and the quality of currently available data it is not possible to estimate accurately the impact of these effects or suggest thresholds below which there would be no performance decrement. The present review has indicated that, where indirect health effects of noise are apparent, they are largely confined to noise levels above those already laid down in noise control legislation. It seems likely that risk of significant health effects is limited to chronic exposures above 85dB(A). However, the reported effects of noise on foetal hearing do indicate a need for particular action where women of child-bearing age are employed, to avoid pre-natal injury. In order to address these concerns further research is suggested in the following areas.

The other main category of effect is that of the effects of noise on performance. There is evidence to suggest that performance decrements can occur well below current noise limits. This may be of particular significance in specific tasks where errors or performance decrement may have profound consequences on the health and safety of others. However, the psychological influences on these are such that the effects cannot be predicted from physical characteristics of noise alone. A further complexity is introduced by the interaction with the type of task with the effect that a given noise may have adverse or enhancing effects on performance, or no effects whatsoever, depending upon the nature of the task being performed. Further research aimed at defining acceptable noise levels for these activities may be helpful or further determination of ‘susceptibility’ factors may improve selection procedures for these activities. In particular the impact of noise perception on performance is worthy of further research.

Further epidemiological research is still required on the relationship between noise and accidents, absenteeism and productivity.

Estimating potential health effects due to noise exposure has been limited by small sample sizes, poor exposure data in occupational settings and limited consideration of confounders. Further research on the potential long term effects of noise on cardiovascular function are required which address these issues, do not rely on cross-sectional methodology, and monitor CV parameters over time in relation to personal noise exposure data. ‘Stress’ hormone production in association with chronic noise exposure can be associated with other health end points, for example effects on immune function. Larger scale studies may allow further evaluation of non-cardiovascular effects.

Potential interactions with other workplace ‘stressors’ such as vibration, heat and job-specific demands also require better quantification of exposures in occupational settings to determine the impact of specific variables on wellbeing and performance.

Evidence suggests that maternal noise exposures over 90dB may be critical in the last trimester
of pregnancy. Further follow up studies of children of noise exposed populations may be helpful in determining whether there is any effect on childhood hearing ability. Based on the evidence currently available it would seem reasonable to consider an upper limit for noise exposures during pregnancy. The potential impact of low frequency noise is also worthy of further research.
5. GLOSSARY OF TERMS

\( \text{dB} \) - Sound is measured in terms of a logarithmic increase in intensity relative to that at the threshold of hearing, this value is known as the sound level and is measured in decibels, (dB). In some instances the value is weighted according to some standard set of values. The most commonly encountered of these is the ‘A’ weighting where values are weighted in accordance with a simplified representation of the sensitivity of the human ear to different frequencies. This will usually be referred to as a dB(A) value.

\( \text{Leq} \) - Equivalent continuous sound (level) is a single value having the same energy content as a fluctuating or intermitent sound over the same period. Can be expressed as ‘\text{LEP,d}’ which refers to the level of daily personal noise exposure. Other noise levels are expressed as an 8 hour TWA (time weighted average), eg ‘the first action level’ - a daily personal noise exposure of 85dBA and ‘the second action level’ - a daily personal noise exposure of 90dBA.

\( \text{SPL} \) - (Sound Pressure level) represents a ratio measure of the strength of the sound being measured relative to a reference pressure fluctuation value eg a sound wave that is twice as strong as the reference value produces a 6dB increase in SPL.

**Threshold shift** - A change in a person's hearing acuity. This may be temporary or permanent.

**Teratogen** - Agent causing congenital malformation (foetal reproduction)
6. REFERENCES


7. APPENDIX 1 - METHODS

7.1 LITERATURE SEARCH

The literature search for this project was a fairly complex one considering the nature of the subject. The search was executed in various stages comprising of: structuring the search; determining the correct vocabulary for the search; and identifying the most relevant bibliographic databases. A database of references identified as being relevant was then compiled and hard copies of the references accessed. The search strategy was constantly reappraised in light of various constraints and problems. The actual steps the search took are outlined below.

7.2 STRATEGY FOR SEARCH

To ensure that the most up to date literature was accessed via this search, two methods of data collection were used. The first of these comprised a full literature search on CD-ROM, online and other library databases. The databases used included Psyclit, Medline and NIOSHTIC. The second, smaller search, was aimed at locating any as yet unpublished and/or ongoing work in the area. The details and results of this latter search method can be found in Section 8.10

7.3 DETERMINATION OF APPROPRIATE KEYWORDS/PHRASES

The keyword/phrase strategy was determined by dissecting the project aims and objectives. The following terms were ascertained by undertaking a logical dissemination.

Starting from a hierarchical stance, the primary search considered the following two keyphrases:

‘Non-auditory effects’ and, ‘Noise’

We then moved on to the first question to be addressed, ie “What are the effects of habitual noise exposure on general health and wellbeing?”, the integral keyphrases chosen here were:

‘Habitual Noise’ and ‘General Health’
‘Habitual Noise’ and ‘Wellbeing’

At a more detailed level, searches needed to be undertaken on the effects of noise exposure lower than those associated with noise-induced hearing loss. Due to the need for clarity when compiling keywords/phrases, it proved difficult to access literature citing the area of ‘low noise exposure’ as a key phrase. As a ‘backup’ facility, a more general search utilising ‘noise exposure’ was also detailed. As a consequence of this wider term however, a system of manual filtering was required to determine which literature related to low noise exposure. The literature search on this area took the following structure:

‘Low noise exposure’ and ‘Noise-induced’ and/or ‘hearing loss’
‘Low noise exposure’ and ‘Noise exposure’

Included in the above search was whether low noise exposure assessments incorporated biochemical markers, indicating stress responses. The following three keywords were therefore
entered in conjunction with the above search:

'Biocemical', 'Physiological' and 'Psychosocial'.

The second question as stated by the HSE, considered the "practical implications of our existing knowledge of the effects of noise on performance". To search through the literature on this subject the following two keyphrases were used:

'Effects of Noise' and 'Performance'

To ascertain the actual impact of such noise exposure on performance the HSE requested a review of comparison studies which look at the effects on performance of other factors/agents. Using the factors/keywords as cited by Smith & Broadbent, the following keywords were integrated into the search:

'Performance' and 'Shiftwork/Nightwork/Work day shifts'
'Performance' and 'Temperature'
'Performance' and 'Vibration'
'Performance' and 'Illumination'
'Performance' and 'Drug use'

It was also suggested that a broad search for other factors/agents be undertaken using the following as keywords:

'Performance effect' and 'Occupational hazard'

Once these main searches were undertaken, any 'gaps' in the literature search were assessed against the contents listing in Smith & Broadbent's review, (see below). Decisions were then made on whether any further searches would be of benefit to the central aims of the study.

Listing of research areas from Smith & Broadbent:

I  Noise and its measurement
II  Non-auditory effects of noise
III  The effects of noise on human performance: introduction
IV  Results from studies using loud noise (over 95dB): a summary
V  Nature of the noise
VI  Long-term effects of noise
VII  Individual differences
VIII Noise and time of day
IX  Importance of the nature of the task
X  Noise and performance: possible mechanisms
XI  Combined effects of noise and other occupational health hazards
XII An evaluation of the effects of noise and performance
XIII Noise, accidents and productivity
XIV Recommendations for future research on the effects of noise on performance efficiency and safety
XV  Non-auditory physiological and health effects of noise
XVI  Methods of studying non-auditory physiological and health effects of noise
XVII Recent research on the effects of noise on cardiovascular function
XVIII Effects of noise on excretion of catecholamines
XIX Other biochemical effects of noise
XX  Noise and sleep
XXI Noise and mental health
XXII Noise, reproductive function and birth abnormalities
XXIII Combined effects of noise and other agents on physiological functions and health
XXIV An evaluation of the research on noise and health and recommendations for future research.

7.4 FEASIBILITY OF CHOSEN KEYWORDS

Before the search could commence, a preliminary search was conducted on two of the main databases to be searched, i.e. PsycLit and Medline. This was to determine whether the keywords originally selected were going to lead to relevant references and how the databases could be manipulated to extricate the most appropriate information.

A pilot study to assess the feasibility of the chosen keywords/phrases was undertaken. The years 1987 and 1988 were taken as representative from the Smith and Broadbent study. Fifty one references were detailed in the Smith and Broadbent document for this two year span. Using the previously mentioned search tools and keywords/phrases, searches were conducted for this two year period. These showed that the majority, (45 out of 51), of the cited papers were accessed via these searches. An examination of those not identified showed them to be drawn exclusively from conference proceedings and also that these proceedings did not appear in specialist proceedings databases (see below). This highlighted the strength of the suggested search strategy.

7.5 DATABASE SEARCH

The databases which were identified as being the most relevant were:

(I) At the IOM:
   Our own in-house library catalogue (PRIME)
   NIOSHTIC, CISDOC and HSELINE databases (all on OSH-ROM CD-ROM)
   POLLTOX
   SIGLE ('grey' literature database)

(II) At Edinburgh University Library:
   Psyclit (on CD-ROM)
   Medline (networked CD-ROM)
   Index to Theses (CD-ROM)
   Dissertation Abstracts (US theses) (CD-ROM)
   Index to Scientific and Technical Proceedings (networked)

(III) On-line databases:
   Social Sciences Citation Index
   Science Citation
   Conference Papers Index
   Directory of Published Proceedings
   Biosis
   Embase
   NIOSHTIC
   HSELINE
   PSYCLIT
   TOXLINE (POLLTOX on-line)
   MEDLINE
The ways in which the keywords and phrases were used to find information on each database had to be modified for each database. This is because different software uses different search engines; for example some databases offer a thesaurus (eg Medline) as well as using a keyword in the title or abstract, whereas others only offer an index of the various keywords (eg NIOSHTIC). Furthermore the vocabulary of a database depends on its place of origin and its specialism - some words, phrases and concepts do not translate literally from one database to another. In each case, the term(s) giving the broadest (yet still as relevant as possible) "score" was employed.

Below is a table showing the search terms used when searching one such database - Medline. The text in **bold** shows when subjects could be chosen from Medline's thesaurus. The text in *italics* shows when a free-text search was done, only using keywords. This method of combining the use of the thesaurus with a free-text searches using keywords was employed in order to extricate the maximum number of possible relevant references from each database. (NB: This is only an example to show how the keywords had to be modified according to individual databases. A full description of each search is available on request.)

<table>
<thead>
<tr>
<th>Table 1 : Example of Search History on Medline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-auditory</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Habitual and noise</strong></td>
</tr>
<tr>
<td><strong>(Health or wellness) and noise</strong></td>
</tr>
<tr>
<td><strong>noise and exposure</strong></td>
</tr>
<tr>
<td><strong>biochemical and noise</strong></td>
</tr>
<tr>
<td><strong>physiological and noise</strong></td>
</tr>
<tr>
<td><strong>(psychological adaptation or psychology or psychosocial) and noise</strong></td>
</tr>
<tr>
<td><strong>(task performance and analysis or employee performance appraisal or performance) and (noise and (effect or effects))</strong></td>
</tr>
<tr>
<td><strong>&quot;performance&quot; (see above) and (work schedule tolerance or shiftwork or nightwork)</strong></td>
</tr>
<tr>
<td><strong>&quot;performance&quot; and temperature</strong></td>
</tr>
<tr>
<td><strong>&quot;performance&quot; and vibration</strong></td>
</tr>
<tr>
<td><strong>&quot;performance&quot; and lighting</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Non-auditory</td>
</tr>
<tr>
<td>“performance” and lighting</td>
</tr>
<tr>
<td>“performance” and drug utilization</td>
</tr>
<tr>
<td>(&quot;performance&quot; and (effect or effects)) and (occupational exposure or (occupational and (hazard or hazards)))</td>
</tr>
</tbody>
</table>

7.6 SUBSEQUENT CHANGES TO KEYWORDS/PHRASES

Due to the dearth of abstracts being accessed under the terms: non-auditory, noise, habitual, low noise exposure and performance effect and occupational hazard, steps were taken to revise these phrases with alternative terms.

The term ‘non-auditory’ does not, as yet, appear to be universally acknowledged. Databases were accessing it as ‘auditory evoked potentials and histochemistry’ etc. The rationale of using ‘noise’ as a keyword was to access the relevant literature which referred to noise as an auditory source. It was found however that noise was, in this context, used to depict a nuisance variable. The term ‘habitual’ was frequently linked to factors other than noise such as habitual smoking and habitual caffeine use. As with ‘non-auditory’, no studies were being accessed by the term ‘low noise exposure’. Replacement words and phrases were therefore determined which resulted in the citations listed in Table 2.

(NB: Words and phrases in bold show where terms were gleaned from the index (there was no thesaurus available) and those in italics were used as free-text keywords).
Table 2: Replacement keywords/phrases

<table>
<thead>
<tr>
<th>Description</th>
<th>NIOSHTIC</th>
<th>CISDOC</th>
<th>HSELINE</th>
<th>POLTOX</th>
</tr>
</thead>
<tbody>
<tr>
<td>(long-term or continuous or repeated or chronic) and noise and exposure</td>
<td>114</td>
<td>33</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>(low-level or background or below action level* or below 85dB(A)) and noise</td>
<td>54</td>
<td>16</td>
<td>22</td>
<td>68</td>
</tr>
<tr>
<td>accident* and work* and noise</td>
<td>58</td>
<td>89</td>
<td>61</td>
<td>17</td>
</tr>
<tr>
<td>(health or well or wellbeing or well-being) and noise, not (hearing loss or hearing impair*)</td>
<td>378</td>
<td>355</td>
<td>654</td>
<td>299</td>
</tr>
<tr>
<td>performance and (hearing loss or hearing impair*)</td>
<td>12</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>(noise adj stress) or (noise-stress) or noise stress</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

7.7 CONSTRUCTION OF REFERENCE DATABASE

As the search progressed, a database of references was created and constantly updated. This involved downloading, rather than printing, references from all of the databases searched. These downloaded sets of references then created and updated a word-processing file which was then edited and amended according to the relevance of individual references.

7.8 DATA FILTERING TECHNIQUES

To ensure that papers were relevant, with regard to the project objectives, a 'screening filter' was applied to each of the documents. Each paper was considered against the following criteria:

(I) Is the paper practically relevant to occupational noise exposure?

If not, - Does the study relate indirectly?, eg the effects of noise on sleep - this would have bearing with regard to general fitness for work etc.

(II) If animal based, do the findings directly relate to human experience?

(III) If interaction of effects is apparent, can these be extrapolated sufficiently to provide meaningful results?
(IV) Pattern of exposure - What is it?

- Long-term/epidemiological
- Short-term, experimental,
- Short-term, non experimental

(V) Sample size - Does the study involve enough subjects to be considered representative?

Once each paper had been assessed against these factors, a weighting was given which then dictated the amount of time spent reviewing the article. The weighting system was as follows:

1 = Highly Relevant
2 = Relevant
3 = Of interest
4 = Of no interest, or relevance

7.9 JOURNAL SCAN

To ensure an as up-to-date search as possible, the following journals were manually checked for relevant articles. The data from when the issues were checked have been detailed beside each respective article.

- American Journal of Industrial Medicine
- British Medical Journal
- Occupational and Environmental Medicine
- Work and Stress
- Ergonomics
- Scandinavian Journal of Work, Environment and Health
- Psychological Medicine
- Psychophysiology
- Journal of Experimental Psychology - General
- Journal of Experimental Psychology - Human Perception and Performance
- Journal of Applied Psychology
- Perceptual and Motor Skills
- Sleep
- Aviation, Space and Environmental Medicine (July’95)

7.10 SURVEY OF UNPUBLISHED MATERIAL

Attempts were made to identify if any research was currently being undertaken in this area, or if any industry had identified non-auditory effects of noise as a problem factor. This was done by the following two methods: (a) by direct contact, and (b) by advertising in relevant journals.

7.10.1 Direct contact

1. **British Airways**

“British Airways has been carrying out studies of noise and communications on the flight decks of our aircraft, including the assessment of active noise reducing headsets. The crew wearing these headsets have commented on the reduction in fatigue and increased awareness at the end of a long transatlantic sector as compared with flying a sector
without the benefit of noise reducing headsets.

These comments are subjective and do not form part of our study. Nonetheless, it adds to the body of knowledge”.

2. *A survey by the T&GWU Acts Voluntary Organisations Branch 7/148*
   In terms of the physical working environment, noise and overcrowding came top of the list with 62% of people reported working with a high noise level, of whom 34% found this moderately to extremely stressful.

3. *Scottish & Newcastle*
   In a recent stress survey, no differences were found between the quiet office environment and the shop floor.

4. *British Gas (off-shore)*
   No reported problems. Work currently being done in this area, as yet at early stage.

5. *British Steel*
   No reported problems.

6. *Linen Textile Mill*
   No reported problems.

7. *Heathrow Airport*
   No reported problems.

8. *Ford Cars*
   No reported problems.

9. *Jaguar Cars*
   No reported problems.

7.10.2 Advertising in relevant Journals

The following notice was published in the newsletters of both the Society of Occupational Medicine (SOM) and the British Occupational Hygiene Society (BOHS), in December 1995:

Non-Auditory effects of Noise

The Institute of Occupational Medicine (IOM) has recently been commissioned by the Health and Safety Executive to prepare a literature review on the above topic. The review will be based on papers published since 1989, supplementing the previous research by Smith & Broadbent, (Non-Auditory effects of noise at work: A critical review of the literature, 1992). In addition to the main theme, the HSE has asked for two specific questions to be addressed:

(a) What are the effects of habitual noise exposure on general health and wellbeing?

(b) What are the practical implications of our existing knowledge of the effects of noise on performance?
Experience shows that there are many experts working both in the industrial sector and other work environments who, although dealing with these issues, do not actually publish papers detailing their situations. We would therefore be pleased to hear from any Occupational Physician or others, with a knowledge of these 'problems', to provide any additional information to that gained from the literature.

Anybody interested in contributing to this work or hearing more about it is invited to contact Miss Maria Butler at the IOM in Edinburgh (Tel: 0131 667 5131. Fax: 0131 667 0136, or E-Mail: M.Butler@IOMHQ.ORG.UK)
8. APPENDIX 2 - REVIEW OF LITERATURE

8.1 CARDIOVASCULAR SYSTEM

8.1.1 Cardiovascular disease

Vera et al (1994) examined the role of the visual presentation of phrases designed to evoke an adverse reaction to a simultaneously presented noise (e.g. this noise is making me crazy), known as negative self-statements, on the cardiovascular effects of traffic noise. The study methodology was based largely upon previous work by Velten (1968). Eighty four female students took part in a physiological reaction test to two noise conditions (85-95dB(A)) both with and without negative self-statements. The impact on the students of these self-statements was increased for half the subjects who were given specific instructions to increase the impact of the statements by encouraging the belief that the phrases and the accompanying noise would have an adverse effect on health. The dependent variables measured included heart rate (HR), blood volume, pulse amplitude from both temporal arteries and subjective tension. All participating subjects were assessed for psychological, physical and psychophysiological disorders due to the potential for confounding. Results indicated that traffic noise provoked cardiovascular responses (HR and constriction of the temporal arteries) which did not habituate either within the 15 minutes of noise presentation or between the two sequences of noise presentation. A similar pattern emerged for effects on subjective tension which was measured by a battery of tests. When examining the conditions without negative self-statements however, HR was actually found to habituate to the second noise presentation. For those subjects who had been given extra instruction to increase the self-statement impact, subjective tension increased in addition to constriction of the left temporal artery. The role of negative self-statements on both cardiovascular responses and subjective tension does have obvious implications for contributory effects on general health and wellbeing. In conclusion, this would appear to be a very useful paper. The noise levels are realistically stressful and the paper demonstrates the biofeedback effect of negative emotions. Although it is inappropriate to draw conclusions for longer term effects, they are feasible and this study is useful for demonstrating noise with other workplace stressors as having a negative impact on short term variation in cardiovascular function.

Babisch et al (1991) examined the hypothesis that under chronic exposure conditions, exogenous factors (traffic noise) affect endogenous factors within the organism thereby causing heart disease. Investigating ischaemic heart disease (IHD) in particular, the model was tested as part of the Caerphilly and Speedwell Heart Disease study. Associations between road traffic noise and IHD risk were investigated both cross-sectionally and longitudinally among 63 subjects aged 45-49 years, who were observed on average for about three or five years of follow-up. Extensive medical data concerning both the prevalence of and risk factors for IHD were collected. Exposure to traffic noise was described by means of the daytime emission level assuming a 10-metre distance between source and dwelling (L_{eq} 6-22 hr, outside). The findings were adequately adjusted in relation to a range of potential confounding variables. The following tentative conclusions were drawn by the authors:-

1. No increased risk for IHD can be demonstrated among middle-aged men living in housing where the A-weighted averaged sound pressure levels (outdoors, measured from 6am to 10pm) caused by road traffic were less than L_{eq}=66dB(A).
2. In the loudest of the traffic noise categories considered ($L_{eq}=66-70\text{dB}(A)$) risk factors for myocardial infarction were slightly greater than in the quietest category ($L_{eq}=51-55\text{dB}(A)$). This applied especially to blood lipids (cholesterol, triglycerides) & homeostatic factors (plasma viscosity), whereas inconsistent or no noise effects at all were observed for blood pressure.

3. The relative risk for heart disease in the highest traffic noise category ($L_{eq}=66-40\text{dB}(A)$) is less than RR = 1.5 but may be greater than RR = 1.0.

As this publication is from the proceedings of a conference it does not contain extensive detail regarding these conclusions quoted from the paper. They appear to be based on at best ‘borderline’ statistical significance (conclusion 2) or non-significant trends (conclusion 3). The comments regarding relative risk for example relate to a number of measures where the results indicate a (non-significant) relative risk of more than 1.0. However, the authors indicate that the statistical power of the study would have been sufficient to detect a level of 1.5 as statistically significant.

The results of this study indicate certain trends in heart disease-related parameters although they should clearly be treated with caution due to the small study population. The actual impacts of these however may have been underestimated due to the relatively low level noise exposures. However, these trends may also represent other risk factors associated with a high traffic density such as pollutants.

**Mann et al (1992)** undertook a case-control study examining myocardial infarction, shiftwork and occupational exposure to noise in the period 1986-88. Sixty five patients with first myocardial infarction were matched, with controls from the same company, for age, length of employment, sex and nationality. The data collection was questionnaire based with subjects asked to detail shift patterns, noise exposure and temperature levels. Noise levels recorded were subjective with workers asked whether their working noise was perceived to be stressful. Attempts to provide objective dB(A) data were made by the company’s noise-level expert who analysed each participant’s working history against data available in noise survey reports. Anecdotal evidence points towards noise levels in the company exceeding 90dB(A). Temperature levels were also based upon subjective assessments. Results indicated that shiftwork which included night work had the highest odds-ratio (OR) in relation to myocardial infarction, yielding a value of 3.60 which was statistically significant. This finding was however confounded by smoking. In terms of noise, neither the subjective nor objective reports of noise reached significance for impact on risk of myocardial infarction. Other significant work-related variables were high temperature, lack of time, overwork, lack of support and lack of appraisal. The subjective noise assessments also weaken the study in that it is difficult to assess true impact of personal noise exposure on cardiovascular health. The population size is also small. Like the previous paper, this publication is drawn from a set of conference proceedings and does not therefore include the level of detail which might be expected from a full paper in a peer-reviewed journal. The low statistical power of the study, coupled with the weak noise exposure estimates mean that the failure to identify any significant effect of noise on cardiovascular health should be interpreted with caution.

**Melamed et al (1993)** reviewed type A behaviour, tension and ambulatory cardiovascular (CV) reactivity in workers exposed to noise stress. Previously reported work had failed to demonstrate differences in blood pressure (BP) and heart rate (HR) reactivity between type A and B workers. The authors noted that it was highly likely that this was a result of the short-term noise exposures of the workers. In an attempt to evaluate the effect of this factor, the authors monitored BP and HR under varying levels of ambient noise, amongst 123 normotensive males.
The investigations also tested the hypothesis that the cardiovascular reactivity of type A individuals is mediated by affective (emotional) arousal. The relationship between such arousal and ambulatory CV reactivity has been indicated in a number of studies. Having controlled for baseline values and workers' activities and body positions at the time of measurement, subjective mood ratings were found to be significantly related to BP with higher BP changes found for negative emotions than for positive emotions. The marker used to indicate emotional arousal was 'reported tension'.

In total 123 men participated in the study, (all of whom were employed in a heavy machinery workshop). Those with existing hypertension were excluded. Three types of data were collected for each worker: ambulatory CV (BP and HR which were recorded every 30 minutes), individual noise exposure levels, and a full diary record of body position, tension ratings and activities during the ambulatory measurements. Prior to the field measurement, baseline measures of ambulatory CV parameters were measured in a controlled environment and psychological questionnaires were administered to each worker. These included a modified Thurstone Temperament Schedule Activity subscale which has been demonstrated to predict CV reactivity. This was used to categorise the men into two groups: Type A and Type B.

Sound pressure levels (SPLs) were measured continuously during the work-day with a personal noise dosimeter. Investigation of SPLs revealed that noise levels ranged from ≤79dB(A), mean 72.5 dB(A) (labelled as 'low') to ≥80dB(A), mean 86.1dB(A) (labelled as 'high'). Both groups were exposed to similar noise levels. Results indicated that type As had slightly higher mean baseline BP and HR measurements than type B. The results of t-test analyses indicated that there was a trend for type A/B differences existed for systolic BP, however no such trend was seen for diastolic BP or HR. Results of multiple regression indicated that under high noise conditions type A behaviour was significantly related to diastolic BP reactivity (p=0.029) and HR reactivity (p=0.0001), after adjusting for control variables including physical activity and posture. No such relationship was found between type A behaviour and CV reactivity under the low noise condition. Further analysis, using tension as the outcome variable, indicated that type A behaviour was significantly associated with tension intensity recorded during the ambulatory BP measurement. Inclusion of this tension variable in the regression analysis reduced the strength of the relationship between type A behaviour and CV reactivity, thus appearing to support the hypotheses of tension as mediator.

As this is a gender specific study however, the findings could not be extrapolated to the general population. As it appears that women are more sensitive to noise, it would have been appropriate to use a mixed population. In general however, the study design is satisfactory, the personal diary system allowing a good consideration of confounders. There are however limitations with the Type A/B scoring system used and no details are given of how the varying levels of physical activity involved in different tasks were taken into account. It should be noted that the study was examining cardiovascular reactivity to noise rather than the absolute level of such parameters. Therefore other longer-term factors such as smoking status, diet etc. are less likely to have an effect although they may have an indirect effect via cardiovascular fitness therefore differentially influencing reactivity to confounding variables. The measurement of ambulatory blood pressure is not straightforward and may be subject to artefacts and errors. However, these are unlikely to have had a systematic effect related either to noise exposure or type A/B status. Despite these reservations the authors do appear to be demonstrating a genuine effect.

Lercher et al (1993) examined the effect on blood pressure of occupational noise annoyance and its combined effect with social support at work, nightshift work and job satisfaction. The study population was selected from all persons aged 25-65 residing in a chosen rural community. Of the 255 subjects selected, 197 (77%) completed the study questionnaire and 174 (68%) took part in the blood pressure trials (which occurred over a six month period). In terms of socioeconomic
status of the participants, the sample was not representative of the population due to the high prevalence of women and young people. Data was collected in relation to the following factors: (a) noise annoyance, (b) social support at the worksite, (c) work satisfaction and (d) presence or absence of night work. The characterisation of the noise variable is not well described. The presence of noise was apparently assessed by checking ‘exposure opportunity and duration of exposure’. No indication is given as to the manner of presentation although it was clearly a subjective self-report. A positive noise annoyance response was apparently then only accepted if the duration was indicated as greater than 50% of work time. A considerable amount of data was collected regarding socioeconomic status and dietary habits which provided a good insight into potential confounders. The effect of work related factors on blood pressure was measured via both systolic (SBP) and diastolic blood pressure (DBP).

First analysis of the data indicated that subjects who experience noise annoyance at work exhibit an 8.5 mmHg elevation in SBP and a 6.4 mmHg elevation in DBP. Further investigation of this data however, highlighted that workers expressing noise annoyance are also more likely to have associated risk factors such as higher body mass index (BMI), higher alcohol intake and presence of nightshift work. Multivariate analysis, subsequently showed that the effects of the different factors considered were small. However, with the exception of social support, the effects on BP follow the predicted direction. A small effect was shown for noise annoyance on DBP which reached statistical significance. The effect of noise annoyance on diastolic BP is small, but it was suggested that when combined with other workplace stressors this may have public health implications.

The use of a ‘rural’ community may influence response to noise in this group. The skew towards a younger age group and predominance of female subjects will affect interpretation of the results and their application in other industrial settings.

The questions used to assess noise annoyance and social support only give a yes/no option and are of limited reliability. The study does not consider other work factors such as job demands, autonomy etc. There is no noise exposure data to assist the ‘annoyance rating’, only one measure of BP was considered in the analysis and does not account for normal fluctuations in BP within individuals. The results and subsequent conclusions are not therefore particularly satisfactory as presented, particularly in view of the unsatisfactory nature of the noise annoyance variable.

Hessel and Shuis-Cremer (1994) have provided one of the few longitudinal studies of occupational noise exposure and blood pressure. Based on white male South African miners, researchers collected data from historic medical and personnel records. Records from 1958–82 were used to extract data on job title, diastolic and systolic blood pressure, height, weight and use of medication. Time-weighted averages for dB(A) levels were determined by experienced mining engineers who estimated values according to job description and actual dB(A) levels recorded in the various working areas. This noise data together with age and body mass index (BMI) data were used as independent variables. The authors noted that data on socioeconomic status, alcohol use and smoking were not abstracted. Anecdotal information however indicated that the use of tobacco and alcohol were quite high in this group. In addition, wages were relatively high and educational requirements modest. Analysis of the data showed no association between occupational noise exposure and diastolic or systolic blood pressures when viewed cross-sectionally at several points in time, or when evaluated longitudinally in several ways. Results did however highlight that obesity, as represented by BMI, and change in BMI were strong predictors of blood pressure and change in BP respectively. The authors conclude by stating that additional studies are required in this area due to general inconsistencies in the literature and shortcomings in the present study.

In general, this is a useful study in that it has good longitudinal follow-up of a large population and
produces negative findings for both systolic and diastolic BP with noise exposure. The exposures in this case, although estimated, are likely to be reliable. The lack of adjustment for socioeconomic status, alcohol and smoking is a weakness but this would only further support the negative association with BP and noise suggested in this study.

Kristensen (1989) provides an extensive overview of the literature relating to cardiovascular diseases (CVD) and the work environment. More specifically, the paper is a critical review of the epidemiological literature on nonchemical factors. A number of nonchemical factors are reviewed, namely, physical inactivity at work, stressors at work, shift work, noise, cold, heat and electromagnetic fields and waves. Due to the subjective nature of this review document it is not intended to detail the findings on any factors other than noise. It is however helpful to consider the impact of these other factors on cardiovascular function as opposed to noise effects. The author states that the hypothesis of a causal relationship between physical inactivity at work and risk of CVD is substantially supported by the literature. As regards work stressors and shift work several good studies have been published over the last 10 years which strongly suggest a causal relationship. Heat and cold appear to have an acute effect on the incidence of CVD, but the possible chronic effect has seldom been investigated. The author states that to-date more than 200 studies on noise and CVD have been published. Five ‘central methodological points’ were used on which to base this judgement, covering: ‘the time dimension’; ‘confounding’; ‘selection’; ‘measuring of exposure and diseases’; ‘adequate design and statistical analysis’. In addition, studies were subjected to a screening process which required them to fulfil at least one of a series of criteria: published in 1980 or later; published in English; a score of three or more on the above points; and often cited in other reviews. As a result of applying these criteria 47 papers were deemed suitable for inclusion in the review. Table A1 shows the results of this critical review.

A clear correlation is shown between study quality and the results, so that the share of positive studies increases with increasing quality. Among studies with low epidemiological quality (‘x’ or ‘xx’) there are 41% positive results, against 60% positive among the best (‘xxx’ or ‘xxxx’). This trend appears to support the hypothesis of a causal relation between noise and CVD. The author concludes the discussion by highlighting epidemiological deficiencies in the noise and CVD research. Briefly, these concern (i) cross-sectional basis, (ii) lack of cardiovascular endpoints other than blood pressure and/or hypertension, (iii) distinction between ‘noise’ and ‘sound’, and the suggestion that in future studies noise should explicitly be regarded as a stressor, (iv) past studies highlight insufficient/inappropriate control for confounders, and (v) inappropriate use of hearing as a measure for previous noise exposure.

### Table A1
Methodological quality and results of 47 epidemiologic studies of cardiovascular diseases (CVD) and noise.

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* 0 = no relationship between noise and CVD, (+) = slight or inconsistent relationship between noise and CVD, and + = positive relationship between noise and CVD.
The author draws attention to the differences between ‘noise’ and ‘sound’ in relation to non-auditory effects. This distinction is extremely important when undertaking further research in this area. In this paper noise is defined as unwanted or uncomfortable sound. The following five factors are cited as responsible for turning sound into noise:

(i) lack of control  
(ii) lack of predictability  
(iii) lack of meaningfulness  
(iv) the volume of the sound  
(v) other characteristics of the sound (intermittent sound, disharmonious sound etc).

Finally, in discussing the remaining epidemiological shortcomings of the papers included in the study, the author suggests that if stricter criteria were applied by excluding those studies which used defective hearing as a measure of previous noise exposure then the percentage of negative studies would fall from 32% to 20%.

In conclusion, although only a little detail is given of the papers included, this does appear to be a well-constructed review and its conclusions of ‘reasonable support for the noise-cardiovascular disease hypothesis’ appears to be valid.

Lang et al (1992) investigated the duration of occupational noise exposure in relation to changes in blood pressure. Based on a cross-sectional study design, a total of 7901 subjects participated in the research. Of these, 432 subjects were found to be exposed to occupational noise equal to or greater than 85dB(A). Years of exposure for subjects ranged from 1 to 25 years, levels based on 8 hour shifts. Data included in the research was obtained from (1) clinical examination, (2) working conditions, (3) consumption of alcohol, coffee and tobacco and (4) arterial hypertension related information.

Results of the first analysis of all workers showed that systolic blood pressure was higher among exposed subjects than unexposed. The same tendency was found for diastolic BP. These results however did not reach statistical significance after adjustment for age, body mass index, alcohol consumption and occupational category. A second analysis was undertaken based on a homogenous group of workers with respect to crude ‘occupational category again allowing for the influence of confounding variables’. Findings highlighted were (a) systolic and diastolic BP were significantly higher for exposure durations equal to or greater than 20 years; (b) prevalence of hypertension increased from 8.2% for exposures lasting 10-19 years, to 19% for 20-24 years and 37.8% for longer than 24 years exposure. Using World Health Organisation (WHO) criteria, a long (>25 years) occupational exposure was associated with an increased prevalence of hypertension (p < .06). The authors conclude that the minimum duration of exposure necessary to observe a relationship with BP is at least 20 years and more clearly 25 years.

In terms of methodological quality, certain potential confounding factors were not taken into account such as a) non-occupational exposures, b) stress factors specific to the job, c) dietary habits and d) individual noise exposure patterns. This study is noteworthy as the implied duration of exposure required to produce a sustained elevation of BP has implications for other studies, but more detailed consideration of confounders and a prospective rather than cross sectional design would have improved the quality of the study.

In addition, although described as ‘homogenous’ the occupational categories employed were very broad and not mutually exclusive (e.g. assembly line and shiftwork).

Despite its methodological shortcomings the paper has many positive merits including noise classifications based on direct measurements and the inclusion of several established confounding
variables. The authors acknowledge several deficiencies but suggest that many of these would, if anything, have tended to result in any relationship being underestimated. It would appear therefore to provide further positive support for an association between noise exposure and blood pressure.

Zhao et al (1991) investigated the development of a dose response relation for noise induced hypertension. Study participants involved 1101 female workers in a textile mill in Beijing, all of whom had at least five years experience working in exposure levels ranging from 75-104dB(A). Data was collected over a one month period and included blood pressure measurements and SPL (Sound Pressure Level) recordings. Each subject also completed a questionnaire which sought information regarding occupational and disease history, the incidence of parental hypertension, drug use, smoking and drinking habits and self-reported salt intake.

Results highlighted the prevalence of hypertension increasing particularly at higher exposure levels. The researchers then carried out logistic regression using hypertension as the dependent outcome variable. The predictor variables incorporated into the analysis were SPL, age, years worked, use of salt and history of parental hypertension. Family history of hypertension, use of salt and SPL were all significantly associated with the probability of hypertension; these have been ordered in terms of importance. The analysis then considered the production of a dose-response model for estimating the probability of hypertension, which assessed the impact of predictor variables.

In terms of methodological quality, although personal factors such as family history and lifestyle are included in the regression analysis there is no consideration of other occupational factors within the textile mill such as dyes and solvents which may also have an impact on blood pressure. In addition, no consideration was given to comparison of male, female and different shift effects. The dose response relationship does however suggest a relationship with increased noise exposure when other variables are included. The final model gave an OR=1.031 (95% CI=1.0006, 1.0612) which was just significant at the 5% level. This implies an increase in odds of 3.1% for 1dB increase and 25% for a 30dB rise. This gives evidence for the statement that a 30dB rise roughly doubles the risk of hypertension (it is closer to 2½ times).

This is a cross-sectional study and so does not give a direct measure of individual risk (rather it measures the odds of hypertension). An improved estimate of dose-response would come from a prospective cohort study where the time sequence of noise and development of hypertension would be clearer. An evaluation of the validity of this study depends largely on whether or not other potential confounders such as solvent exposures would have had a significant effect. Unfortunately, the nature of the work in the different mill workshops is not specified and, as this is completely confounded with noise exposure, this could be important. One further significant factor is the exclusion of body weight (and height) data. Although the authors suggest that a systematic allocation of different size workers to different workshops (and therefore noise exposures) was unlikely this is clearly an important limitation. However, the magnitude of the effect suggests that although it may in part be due to other factors the positive association should be accepted with caution rather than totally discounted.

Ising (1991) reviewed three studies based on investigating the risk of myocardial infarction (MI) from exposure to road traffic noise. Whilst none of the cited studies showed a statistically significant increase in the risk for myocardial infarction, the author points out that they show the same trend whereby road traffic noise above $L_{eq}=65-70$dB(A) appears to increase slightly the relative risk for MI (RR=1.0 - 1.2). As this paper is a short review document, there was not enough information detailed to make a thorough assessment of these findings or to reach firm conclusions as to their validity.
Elwood et al (1992) undertook a prospective study of traffic noise and cardiovascular disease based on the Caerphilly and Speedwell studies. Based on a total population of 5,000 men, data was collected on medical history, blood samples and other confounding factors, namely, social class, employment status, smoking and physical activity. After a three year and five year period (the duration dependent on locality of study) data was gathered on both non-fatal myocardial infarctions and deaths due to ischaemic heart disease (IHD). Personal noise exposures were calculated via ‘noise maps’ drawn up through local traffic noise studies. Although there was a positive trend with increasing noise exposure in the Caerphilly Study, which was significant allowing for confounders, the same trend was not identified in the Speedwell Study. The authors themselves note ‘serious limitations’ in their data ranging from limited power, low noise exposures and from limited assessment of confounding factors. It would therefore be unwise to report the results of this study with any confidence.

8.1.2 Physiological and Biochemical

Umemura et al (1992) investigated the correlation between physiological function (measured by heart rate) and the quantity of work performed under various sound pressure level (SPL) conditions. A multifactorial experiment was constructed based on a total of 16 combinations of types of mental work (calculation and letter cancellation/erasion), type of noise (two levels of factory and construction sound noise) and A-weighted SPLs (four levels). Three male university students aged between 21 and 23 (otologically sound) were used as a sample group. Heart rate measurements were taken both with subjects at rest and whilst undertaking the tasks. Test sessions lasted 10 minutes each whilst the rest sessions lasted 20 minutes. Analysis of the data highlighted the following.

1. HR elevation occurred due to exposure to noise, and further increase in HR resulted from an increase in the A-weighted SPL. The authors attributed this effect to the action of the noise as a stressor, which excites sympathetic nerves, leading to an elevation of HR.

2. The quantity of work performed decreased with an increase in the A-weighted SPL. This effect was marked at 70dB(A) and particularly at 80dB(A).

3. When the subjects were exposed to music with an A-weighted SPL of 70dB(A) instead of sound noise of the same level, almost no elevation of HR was observed. The authors explain this finding by proposing that unlike sound noise, music does not act as a stressor, hence sympathetic nerves are not stimulated, but are inhibited by listening to music. At the same time, parasympathetic nerves are stimulated, thereby leading to a decrease in cardiac function. This implies that the factor affecting HR is not the magnitude of the SPL, but instead is the feeling of pleasure or displeasure (noise annoyance) when listening to the sound. However, it was also found that the quantity of work completed when exposed to music was less than that performed when exposed to sound noise of the same A-weighted SPL. This finding may be explained by suggesting that less work is performed because of lowered attention to the work task due to the enjoyment of the music. From this explanation, the authors state that background music which does not absorb the listeners attention (instrumental), but improves the subject’s mood during the performance of work may decrease the stimulation of sympathetic nerves caused by noise, and therefore, suppress the increase in HR. The authors conclude that if this proposal is valid, it may be beneficial to expose people to background music during work.

As the study only uses three young people the results could not be applied to all workplaces without further investigations - including: (1) different age groups; (2) a variety of tasks (vigilance, dexterity etc.) and (3) background noise and superimposed workplace noise. There
are many elements of this research open to conjecture including the potential impact of individual variability in musical tastes; the possible effect of longer periods of exposure etc. In conclusion the methodology used in deriving these results is satisfactory.

Theorell (1990) investigated the hypothesis that men with a family history of hypertension differ from normotensive men not only with regard to blood pressure reactions to occupational strain, but also with regard to endocrine reactivity patterns. The study was longitudinal in design, comprising of monitored blood pressure during work and leisure hours, and of endocrine factors (the methodology of which could not be examined as it was presented elsewhere). Participating subjects were 51 males and 22 females from six different occupations ranging from musicians to air traffic controllers. Although blood pressure was self-reported, blood sampling was undertaken by a trained nurse. Data on job strain was collected by a demand/decision latitude questionnaire. Information on certain confounding factors such as smoking, alcohol and medication data was also collected. The aim of the endocrine part of the study was to elucidate the interaction between family history of hypertension on one hand and changes in endocrine activity on the other, during a stressful period. The effects of noise on blood pressure was examined using subjective data based on responses to the question ‘Is it noisy in your workplace?’ Five response categories ranging from ‘never’ to ‘daily’ were provided for scoring purposes. It should be noted however that the use of such self-reported noise measurements has proved to be questionable. Results show that men with a family history of hypertension showed a stress response syndrome that was not limited to blood pressure only. Low cortisol levels during peak strain, the lack of prolactin response and the strong decrease in testosterone levels during job strain appeared to support the hypothesis. Although the use of cortisol is a validated indicator of stress response, the argument for a drop in prolactin in non-complainers is not well validated. High levels are typically seen in depression. The depression of testosterone normally relates to periods of extreme prolonged stress such as seen in active combat. Again it would not be relevant to draw comparisons in this study. The small population size is also a problem especially as it was spread across six varying job types. The study would have been strengthened by some indication of noise range, which is likely to be considerable between musicians and air traffic controllers. The strength of findings is also limited by the small number (4) of measurements undertaken. However, the ‘susceptibility’ factor is worthy of note, but evidence would be more convincing had there been an increase in diastolic BP which is the parameter of choice when assessing hypertension.

Bhattacharya et al (1990) examined the effects of heat and noise, both individually and jointly on certain physiological responses and on cognitive and neuromotor based functions. Using controlled climatic chamber conditions, 12 male participants were tested under six experimental conditions. The conditions were based on combining three levels of heat (25°, 30° and 35°) and two levels of white noise (70 and 100dB(A)). Physiological measures included heart rate (HR), oxygen uptake (VO₂) and both core and skin temperature. Neuropsychological measurements were: (i) critical flicker fusion frequency, (ii) Muller-Lyer illusion test, (iii) card sorting test, (iv) digital symbol test and (v) reasoning ability test. Results indicated elevations in HR, VO₂ and the body temperature measurements due to the independent effect of heat or the combined effects of heat and noise. The independent effect of noise was found to depress both HR and VO₂ and elevate the latter measures. This is interesting as it appears to indicate a dichotomy in terms of metabolic activity between the depression of cardio-respiratory parameters and an increase in temperatures. In addition, the depression of HR does not accord with the increase in physiological arousal often associated with noise exposure such as that reported in the paper by Umemura et al reported earlier. In terms of the effects of noise and heat on the neuropsychological parameters, heat significantly affected the speed components in card sorting (by design configuration) and in error rates in card sorting (by design configuration). The combined effects of heat and noise indicated higher error rates in card sorting (by face value), decreased accuracy in reasoning ability and performance improvements in accuracy scores and error rates in digital symbol testing.
Although the methodology and tests used appear appropriate for the experimental conditions, the results are difficult to interpret in terms of their practical implications. As both critical flicker fusion and card sorting are tests of vigilance/concentration, there was a need to assess the impact of fatigue as a potential confounding variable, this was not however taken into account. In addition, the actual sample size limits interpretation and power.

Muzet A (1991) carried out a study to determine the impact effects of noise on noise sensitive subgroups. Three separate research establishments were employed in the study, at Dusseldorf, Dijon and Turin. The 357 participating subjects were grouped according to the following classifications: (a) specific age groups sought; (b) male and female; (c) those resistant to noise; (d) those sensitive to noise; (e) those with normal blood pressure; (f) those with high blood pressure; (g) those qualifying as ‘anxious’ and (h) those qualifying as non-anxious.

Impulse noise (gunfire) and traffic noise were used in 15 minute noise exposure periods. The noise levels were set at 75dB(A). Arterial BP was used as a selection criteria. In terms of physiological measures of effect, heart rates were recorded before, during and after exposure. Mood and self-estimated noise sensitivity questionnaires were used to ascertain psychometric response.

The results showed that, in two out of the three studies, there were significant increases in HR related to noise exposure. In gender terms, sensitivity to noise appeared greatest in females. Positive results based on age group were only seen in one of the research studies. Older subjects appeared to show more noise annoyance than females. Young females however had responses to noise that were 4-5 times longer than older females. ‘Anxious’ subjects, as would be expected, showed more noise annoyance than those who were categorised as non-anxious. Alterations of mood and HR appeared related to noise intensity. Alterations were described as becoming larger with increases in sound pressure levels.

The methodological design of the study limits wider application of results, especially in terms of longterm health endpoints. As the three research establishments used different groups of subjects cross-comparison of results is problematic and weakens the overall conclusions. As the study focuses on ‘sensitive’ subgroups, it should be remembered that sensitive individuals may produce different heart rate/blood pressure response to several stimuli, as well as noise. In conclusion, it is reasonable to point out the effects that occurred on exposure to the 75dBA level of noise for the stated exposure period but it is not appropriate to generalise beyond these findings.

Schwarze and Thompson (1993) produced a review document entitled “Research on Non-Auditory Physiological Effects of Noise since 1988: Review and Perspectives”. Due to the ‘review’ nature of this paper, the validity of the authors’ conclusions cannot be evaluated. The review of long-term cardiovascular effects centred on 10 studies based on industrial noise published since 1988. Eight of these repeatedly demonstrated positive associations between noise and blood pressure for at least one sub-group of workers, while two showed no such relationship. With the exception of one investigator who followed a noise exposed and control group of workers over a 4-5 year period, all of the studies were cross-sectional in design. The authors sought to explain the disparate findings in terms of varying exposure levels and presence or absence of confounding factors which many of the papers had not controlled for in conducting their research.

When considered with previous research, the studies suggest that long-term exposure to extremely high noise levels, especially when the ears have been unprotected, may lead to sustained blood pressure elevations. This association is evident when there is long average duration of noise exposure even after adjusting for other major cardiovascular risk factors.
A pattern of increased prevalence of hypertension among subjects with longer exposure to noise compared to workers exposed for a shorter time has been observed to occur within both high and low exposure groups.

One study, reported a dose-response relationship suggesting that the odds of hypertension increased by 1.2 for each 5dBA increase in noise (odds ratio -1.8 at 95dBA), after adjusting for age, working years, salt intake and family history of hypertension. The other study found that BP was not associated with noise exposures of 85-100dB(A) after adjusting for age, body mass index and alcohol consumption. However, exposure to noise for 25 years or more was associated with elevated systolic and diastolic BP and with prevalence of hypertension (OR -2.59, p=0.06) after adjusting for the three confounders. For a more detailed discussion of these latter two studies, please refer to Zhao et al (1991) and Lang (1992), which have been detailed in an earlier section (6.1) of this review document.

Studies based on environmental noise were also drawn upon but detailed exposure data was lacking. None of the three cited studies produced significant results but did show ‘trends’. Results from the Caerphilly & Speedwell quoted a relative risk for Ischemic heart disease of 1.1, the Berlin studies showed a relative risk of myocardial infarction of 1.2, and the Luebeck study indicated a slightly higher prevalence of hypertension for men living in the high exposure areas compared to the low noise areas (odds ratio -1.32).

The hypothesis that noise can exert harmful effects during pregnancy is mainly based on the model of noise-induced vasoconstriction leading to a decrease of the uteroplacental blood supply, and elevated levels of stress hormones causing higher contractility of the uterus. No clear relationships were found between noise and pregnancy outcomes such as prematurity, low birth weight or selected structural malformations. The author concludes that, in contrast to these, positive effects were observed with respect to elevated maternal blood pressure levels during pregnancy. Two studies indicated that noise exposed pregnant women may have a higher risk of hypertension, especially in combination with shiftwork or lifting of heavy loads.

In conclusion, this paper provides an interesting review of cardiovascular, general health and reproduction effects. Many of the papers cited are in fact reviewed in greater depth within this report. As the paper is, essentially, a review document, the exclusion of much of the statistical information, i.e. confidence intervals, odds ratios and relative risks makes it difficult to interpret the significance of the stated results.

Tomei et al (1991) studied certain cardiovascular parameters after chronic exposure to noise in a study based on a sample size of 300 males, chosen from a homogenous occupation category. A control comparison methodology was used. The subjects were categorised into two groups dependent on intensity of exposure to noise. The first group, (75 subjects), were exposed to noise levels in the region of 80-92dB(A). The characteristics of the noise in this group was one of variability and fluctuation, with both harmonic and low frequency qualities. The second group, with 225 subjects, were exposed to noise levels 20dB(A) lower than the first group. Noise quality was referred to as the ‘same type’ of noise as that of the former group.

The following factors were taken into consideration for each subject: age, serum cholesterol, blood glucose, smoking habits, sports, family history of cardiovascular disease and body mass index (BMI). The physiological measurements used to monitor any cardiovascular changes were heart rate, blood pressure and electrocardiogram. The following results were reported:

(1) Higher prevalence of hypertension in the subjects exposed to greater noise than in the subjects exposed to lower noise (p<0.001).
(2) Prevalence of electrocardiogram anomalies was significantly higher in subjects exposed to greater noise than in subjects exposed to lower noise ($p<0.001$).

(3) The Stress test (induced hypertension) revealed a higher systolic hypertension ($p<0.001$) in diastolic hypertensive patients both in the group exposed to noise and in those less exposed. This trend persisted in the recovery period. Heart rate increased with BP, though slightly more steeply. There was no significant difference however between those exposed to more or less noise.

(Analysis of non-occupational risk factors revealed no significant differences between the two groups)

(4) Audiometric deficits, found predominantly in the high exposure noise group, was said to be associated with a significantly higher prevalence of hypertension in subjects exposed to both high and low noise, than among subjects without audiometric deficits. On examination of the data, it is not clear how these results were obtained.

(5) A higher prevalence ($p<0.02$) of hypertensive subjects were found in those with longer noise exposures (>3000 hrs) - both high and low exposures. This result corresponds closely to some results from other studies.

(6) There was a greater prevalence of electrocardiographic anomalies among subjects with longer noise exposures (>3000) in both high and low exposure groups. This outcome however is multifactorial in origin and should not be related to noise alone.

The authors conclude that these findings suggest that noise seems able to influence vascular tone through either an indirect or direct mechanism. They also refer to the possibility of identifying certain predictive signs which could be easily recorded such as diastolic pressure ≥95 mmHg and electrocardiographic anomalies. They suggest that these indicators may also be specific for a particular sensitivity to noise.

The authors consider several confounders and the results are of interest in terms of the sustained Cardiovascular effects demonstrated. However, these conclusions are based on male subjects and can not be extrapolated to the general population. In addition only 25% of the total group were exposed to higher noise levels. The noise exposure also included low frequency components, considered by some authors to exert an effect independent of noise intensity. The authors unfortunately do not discuss the suggested associations between audiometric results and hypertension. Nevertheless, the high level of significance associated with the cardiovascular effects reported does add credence to these findings.

Wu et al (1988) investigated the effects of noise exposure and task demand on cardiovascular function. Using 40 subjects (20 male and 20 female with a mean age of 16.7), a laboratory-based study was constructed. Three white noise exposure levels (60, 85 and 90dB(A)) and two task demand scenarios (either absent or present) were used to formulate six experimental design sessions. All subjects participated in the six sessions, each of which lasted 33 minutes. The task demand sessions were a combination of mental arithmetic (3 min) and abacus arithmetic (30 min). Blood pressure (BP) levels were measured both before and after each experimental session.

First analysis results showed that in terms of task performance, noise exposure has a significant influence ($p<0.05$), in terms of both abacus and mental arithmetic performance. A significant variation in task performance was found between 90dB(A) and 85dB(A) ($p<0.05$). When considering gender effects, it was found that whilst task performance was not influenced by noise
stimulation for males, the opposite was true for female subjects.

Blood pressure levels increased in later sessions under the 'task present' conditions, but no such association was found for level of noise exposure. At least for the abacus task, which occupied most of the experimental period, differences in physical activity level could account for these blood pressure changes. Examining the gender variable, differences were found in terms of increased diastolic BP influenced by task demands, for males. In contrast, the systolic BP of female subjects tended to be influenced by task demand.

Analysis using a within-subjects two-way ANOVA showed that while systolic BP was influenced by noise stimulation, there was no interaction between task demand and noise exposure on systolic BP. This negative finding was also identified for diastolic BP.

The authors pointed towards researchers such as Baker et al (1984) and Cohen et al (1981) to explain issues such as the gender differences in attention differentiation to tasks. The authors conclude that based on their results, there are different mechanisms operating in the blood pressure response of noise and task demand.

In conclusion, it should be noted that the power of the study is limited by population size. The age group of the subjects considered would also affect the results obtained. Differences in findings between the male and female subjects could also be explained by recorder bias due to different investigators measuring BP for each of the groups. Whilst it is not possible to directly extrapolate these findings to an occupational setting, the trends identified are worth noting.

Carter and Beh (1989) reported the results of an experimental study of the effects of noise exposure on cardiac function during performance of a vigilance task. The authors suggested that differences in the literature regarding cardiovascular responses to noise could relate to whether the exposed subjects were occupied on an experimental task at the time. They also identified predictability of the noise as a potentially important variable. An experimental design was adopted where subjects performed a vigilance task (visual monitoring) whilst exposed to one of four noise conditions: No noise; 4.5 second bursts at 60 second intervals; 4.5 second burst at irregular intervals and irregular bursts at irregular intervals. In all cases the noise used was one third octave noise centred on 4.0 kHz at a level of 92dB(A). The duration and frequency of noise bursts were manipulated such that the total acoustic energy presented was constant.

Measures were taken of speed and accuracy of task performance, blood pressure changes, heart rate and two measures of heart rate variability. The results for the performance measures indicated that noise significantly reduced accuracy (correct detections) and increased response speed which is consistent with theories of attentional narrowing in noise. The blood pressure responses showed no significant effect attributable to task performance (no noise) on any parameter. Diastolic blood pressure and mean blood pressure (but not systolic blood pressure) were significantly increased by all three noise treatments. However, none of the three parameters were differentially affected by different forms of noise. Different effects of the various forms of noise were however apparent within the heart rate results (measured as inter-beat intervals). All trials showed a trend for increasing heart rate across the experimental session (55 minutes). Those sessions with irregular noise showed an immediate significant increase at the onset of the experimental session whilst the heart rate increase during no noise or regular noise sessions did not attain significance until the third of the four time blocks. Visual inspection of the plots suggest that the slope of the trends was basically the same across all four sessions. It should be noted however that although statistically significant, the largest increase in heart rate is equivalent to less than one beat per minute. Heart rate variability was analysed using two measures, the variance and a second measure described as the Successive Difference Mean Square (SDMS). Variance measures all showed a progressive decrease over time across the experimental sessions. These
changes only attained statistical significance for the quiet sessions at the third time interval and at the second time interval for the other three sessions. Despite this there were no significant differences between quiet and noise, although a visual inspection of the mean data shows the results of the three noise conditions clustering separately from the quiet condition. In contrast, the SDMS means show the two irregular conditions clustering separately from the steady noise and no-noise conditions.

Although there were no significant differences between conditions there was a significant effect across time for all conditions with SDMS values decreasing from time period 1 to time period 3. The authors suggest that SDMS is a 'more accurate' measure of heart rate variability. Graveling and Brooke (1978) reported the use of these two measures, indicating that SDMS takes account of any trend in the underlying baseline of the data rather than the variation around the line. It therefore provides a different measure, not necessarily more accurate. In concluding, Carter and Beh suggest that the results provide strong support for the suggestion that noise has a deleterious effect on cardiovascular function and, because the effect persists, suggest that chronic noise could produce hypertension. It should be noted however that the magnitude of the blood pressure changes reported is well below what would be considered indicative of hypertension and that no evidence was produced regarding persistence of the changes after cessation of the noise stimulus.

Parrot et al (1991) reported on the results of a study of the physiological responses to noise in which the influence of gender, age and anxiety on these responses were examined. The study then went on to determine whether physiological response was related to noise sensitivity or annoyance. Physiological measures studied were: Brainstem auditory evoked potentials; pulse oximetry; heart rate and blood pressure. Subjects also completed a series of questionnaires and scales including Cattell's anxiety scale, EPI, subjective sensitivity to noise, mood, coping and annoyance. The results are reported briefly, and it is not always apparent whether these reached statistical significance. Auditory brainstem response results showed a number of gender-linked differences with males generally being more responsive. All noise-related responses were apparently only influenced by noise level and not their characteristics. Noise produced an increase in heart rate which was noise-type dependent, particularly for men. However anxiety level did not have a significant influence on these responses. Unlike other studies, noise had no effect on blood pressure other than a minor response when the noise signal was initiated. Noise-evoked reactivity was greater in men and the strongest responses were evoked by the road traffic and pile driver noise recordings. Anxiety level did not influence the responses.

For the psychometric variables, older females scored highest on general noise sensitivity with anxiety making a further positive contribution. Coping ability did not differ significantly between the four noises. All four groups ranked pile driver noise as the most annoying followed by gun fire, intermittent pink noise and traffic noise, which coincides with 'impulsivity'. Prior ratings of noise sensitivity were not related to annoyance ratings which also were not related to coping. No relationships were demonstrated between physiological responses and psychometric data.

The authors suggested that brainstem responses could be used as preliminary measures of auditory strain (prior to temporary threshold shift (TTS)) although this was not studied in the work reported. The main effect on vasomotor response was vasodilatation which is not consistent with the vasoconstriction normally associated with increased blood pressure. The lack of concordance between physiological and psychological responses (anxiety, coping, sensitivity) was most marked with traffic noise which was least annoying (comparatively steady, familiar noise) and evoked the largest cardiac response.

In conclusion, a number of the results reported in this paper seem not to agree entirely with other publications. In the absence of any detail regarding the results it is difficult to derive any explanations for this. All noises were of equal L\text{Aeq} intensity. However, to achieve this, the
intermittent and impulse noises would be required to be presented at much higher short-term intensities and this may have contributed to the effects.

Evans et al (1995) reported the results of tests of non-auditory responses to noise of schoolchildren. They examined the impact both of chronic (neighbourhood) noise exposure and acute (experimental) noise exposure on physiological responses (chronic effects) and cognitive function (acute effects). Two groups of children were involved, living close to or distant from an airport. The groups were matched for socioeconomic status and households did not differ in type of occupation, parental education or family size. Those living in the noisy community had significantly higher urinary catecholamine levels overnight than did those from the quiet community although cortisol levels did not differ. These are indicators of a ‘stress’ response. The two groups differed in baseline systolic blood pressure although the difference could not be considered to be significant. Systolic cardiovascular reactivity (calculated from the initial blood pressure response to a reading task) was significantly lower amongst the chronic noise exposed group.

The noise exposed group chose a lower signal-to-noise ratio (meaningful sound being of similar intensity to background noise) for listening to a story suggesting they were more used to noisy backgrounds. However, the two groups did not differ significantly on either of two cognitive tasks. Long-term memory, reading ability and motivation were all significantly poorer amongst the noise exposed group.

These results clearly have important implications for the learning abilities of schoolchildren. It is not immediately apparent however how the findings might relate to the workplace. No indication is given as to whether the physiological responses are a direct response to noise exposure or secondary to an increased physical activity level. The blood pressure difference (≤2mm Hg) is probably too small to be of significance although the catecholamine differences if persistent with chronic exposure could have implications for levels of resting blood pressure in the noise exposed group.

Gold et al (1989) examined Biochemical and Cardiovascular measures in subjects with noise-induced hearing loss (NIHL). A sample of 800 male noise exposed (Military) subjects were divided into two age-matched hearing group (NIHL and audiologically sound). Using various cardiovascular and biochemical measures, attempts were made to compare the means of the factors across the two groups. Results showed that the mean values of all the variables examined in both hearing groups were within the normal range, with no significant differences. Although the findings of this paper do not lend themselves to the current investigation of non-auditory effects of noise, this a very useful paper when considering possible predisposing factors for NIHL.

Irwin et al (1989) undertook an examination of individual, behavioural and neuroendocrine differences in responsiveness to ‘Audiogenic Stress’. In this study, an analysis of the association between the physiological and behavioural measures revealed that the degree of noise-induced suppression of both general activity and ingestive behaviour was significantly correlated with activation of adrenal steroid secretion following both acute and repeated noise exposures. Whilst this paper is of interest in terms of physiological and biochemical effects, it is difficult to extrapolate these findings to obvious health endpoints.

Green et al (1991/92) undertook a study to evaluate a possible association between exposure to ambient noise and temperature in the workplace and silent ST-Segment depression on short-term ambulatory ECGs, (part of the CORDIS study). Data from 3,747 blue collar workers indicated that, after excluding subjects with a history of heart disease, silent ST-Segment depression was found to be most prevalent in those workers exposed to more than 80dB(A) compared with those
exposed to less than 70dB(A). Again, however, the findings from this work are different to quantify in terms of predicted health endpoints, and other possible explanatory variables are not considered in sufficient detail.

Lésnik (1989) examined haemodynamic reaction to monotonous work performed in silence and in noise of 70dB(A). Based on two types of task (either 4-hours monotonous work with moderate exercise, or monotonous visual work performed in laboratory conditions) and two conditions of noise (silence or 70dB(A) industrial noise), the following haemodynamic parameters were evaluated: cardiac contraction rate, ejection volume, arterial blood pressure and total vascular peripheral resistance. Participants were all female and numbered 31 in total. The findings reported were that whilst noise did not appear to affect work efficiency, it did result in an increase of ejection volume and a rise in arterial (especially diastolic) BP. The authors conclude that noise of 70dB(A) brings about an increase in the physiological effort of work. No mention was made however of other factors which may have been responsible for these effects, rendering the methodological design relatively weak. In terms of meaningful data, the exposure time was too short for long-term effects to be accurately evaluated.

Tomei et al (1992) undertook a Doppler ultrasonography study of the carotid vessels in two groups of subjects exposed to various intensities of noise. The rationale behind this study was to ascertain whether noise alters brain blood flow and whether this technique could be used as a screening tool for detecting early vascular change. The study population comprised of male subjects. The same type of work was undertaken by both groups of subjects with the noise condition being the independent variable. Test group 1 (80 subjects) were exposed to a continuous 93dB(A) Leq with a few phases (each shorter than 10 minutes) when the intensity rose 10dB(A) or more. Subjects in test group 2 (310) were exposed to noise 10-15% less intense than that of group 1. Data was also collected on other cardiovascular risk factors which may influence the parameters being measured. The authors conclude that the findings confirm that noise does play a role in causing vascular modifications which can be detected at an early stage and therefore helpful in screening campaigns. However, it should be remembered that the use of noise was in a way coincidental to the main purpose of the study and the findings detailed here would be difficult to incorporate into a workplace programme due to their abstract physiological basis in relation to disease end points.

Griefahn et al (1991) investigated mood and cardiovascular function during noise, related to sensitivity, type of noise and sound pressure level (SPL). A sample group of 150 otologically sound subjects whose ages ranged from 30-60 years, were divided into three categories, namely, 'resistant', 'indifferent' and 'sensitive'. Criteria for the allocation to the different groups were based on self reported sensitivity to noise. Subjects participated in two trials each of which consisted of 48 sounds (pink noise, traffic noise and gunfire) which were presented for 19 seconds with Leq in the range of 62-80dB(A). The parameters measured were peripheral blood flows, autonomic responses, heart rate (HR) and mood (which was assessed using six objectives on an analogue scale). Although the results are of interest in respect of short-term effects, the extremely short durations of exposures render the methodology unreliable for predicting long term exposure effects on health.

Millar et al (1990) examined the effects of exposure to continuous noise on pulse volume (vasoconstriction) and rate, whilst undertaking a four-choice serial reaction test (SRT). The subject group comprised 24 male and female undergraduates. Two noise conditions were used, one of which was white noise with a dB(A) of 93 (experimental condition), whilst the other, referred to as the 'quiet' control condition used 50dB(A) white noise. Pulse volume, amplitude and rate were chosen to reflect the physiological parameters. A four-choice SRT was used over a 20 min test period to assess trends in the physiological parameters under the two noise conditions. Pulse volume showed a marked reduction, implying increased arousal, in the first
three minutes of exposure to noise. Whilst some habituation of vasoconstriction occurred, pulse volume continued to remain significantly higher in the experimental condition in comparison to that of the control. In general, serial choice performance was unaffected by noise. The authors conclude that a physiological cost is incurred when working in noise, and concerns are raised for long-term effects on noise-exposed people. However, due to the small sample size and short duration of exposure, the extrapolation of these findings to a longer term perspective should be viewed with caution.

Boer et al (1989) investigated plasma catecholamine and corticosterone (CS) responses to both predictable and unpredictable noise stress in rats. Noise exposure was either 20 regularly or irregularly scheduled white-noise stimulations (4 min, 100dB(A)). Results showed that initial noise-induced CS release was partially reduced following the regular noise presentations, as would be anticipated in terms of adaptation. The increase after irregular presentation, however, remained high. The plasma noradrenaline (NA) response to noise was partially attenuated following irregular administration of noise. Regular exposure however produced increased NA levels prior to noise presentation and a subsequent decrease during stimulation. The authors discuss these results by drawing attention to the sympathetic adrenomedullary and adrenocortical systems. In general however it is difficult to draw conclusions from this study as: (a) rats have less control over their surroundings and (b) interspecies variation will undoubtedly contribute to results, particularly in view of the undoubted psychological component to the human non-auditory responses to noise.

Tarakanon & Aronov (1993) examined the influence of acoustic noise and functional state of a subject on the generation of long-latency auditory evoked potentials. Although of obvious interest when assessing techniques for determining noise impact, the nature of the data included in this paper renders it inappropriate for extrapolation to potential health endpoints.

8.2 EFFECTS ON SLEEP AND FATIGUE

8.2.1 Effects on sleep

Libert et al (1991) examined the relative and combined effects of heat and noise exposure on sleep in humans. Based in laboratory conditions, eight healthy males participated in all eight experimental conditions. Prior to the testing, subjects were assessed against the normative values in both the Horne and Ostberg’s morningness-eveningness questionnaire and the Eysenck Personality Inventory (EPI). All subjects were found to be in the ‘normal range’ for both these tests. Further selection requirements included: (1) the BMI values of subjects not differing greatly; (2) that the subjects had not lived in a hot climate during the last six months, and (3) they were otologically sound. In the experimental design, four nocturnal environmental conditions (20°C, no noise; 20°C, noise; 35°C no noise; 35°C noise) were used. Daytime noise comprised of a background noise level set at 45dB(A) with peak intensities ranging from 79-86dB(A) and night-time noise in which background and peak intensities were all reduced by 15 dB(A). Physiological variables monitored were oesophageal temperature, local skin temperatures and electrooculograms, electromyogram and electrocardiogram. After awakening, subjects were also asked to complete a 7-point scale questionnaire of sleep quality (depth, stability and efficiency of sleep).

Analysis of sleep variables indicated that heat was more disruptive to sleep than was noise. It was found that the thermal loading had a longer impact on the EEG measures of sleep quality than on the different stages of sleep. This trend was confirmed by the morning questionnaires which examined subjective estimates of sleep quality.
An interaction was seen between ambient temperature and noise at night. At 35°C, total sleep time decreased with a reduction in REM (rapid eye movement phase), probably reflecting general disruption to sleep pattern. REM episode length decreased in no noise conditions whereas REM cycle lengths were unchanged. When noise was present at night, ambient temperature (Ta) did not modify this effect significantly. The sleep measures which showed significant changes when only noise was present were number of sleep stage changes, number of changes toward awakening, and number of Stage I (light sleep) episodes. In general, the authors found that, relative to heat, sleep appears to be more resistant to the type of traffic noise used in this experiment.

As the study is based on only eight subjects, it would be presumptive to apply the results to a wider population. In addition, gender differences could not be ascertained due to only male subjects being used. The examination of the data led to the conclusion that heat effects are the more significant. Although, the results do indicate that noise at this level is capable of altering sleep characteristics these findings are only of relevance to specific environmental conditions which may arise in certain occupational settings, or to the impact of these work conditions on resulting sleep pattern.

Nivison and Endresen (1993) undertook an analysis of relationships among environmental noise, annoyance and sensitivity to noise, and the consequence of these in terms of health and sleep. Subjects with hearing loss were excluded. All participants were volunteers and given incentives for taking part. In a community based survey, a sample of 82 (47 women and 35 men), were chosen to participate in the study. All subjects were considered to live beside a street with moderate to heavy traffic. Twenty-four-hour equivalent noise level (L_{eq}) and maximum noise level (L_{max}) were calculated outside each residence. The average L_{eq} and L_{max} values for that part of the street with the least traffic were 67.1 and 85.5 respectively (quiet). In contrast, for that part of the street with the most traffic, the average L_{eq} and L_{max} were 70.9 and 89.3dB(A) respectively (noisy). As the minimum detectable level of change is 3dB(A), their distinction between 'quiet' and 'noisy' does not suggest that results would show significance on this basis. In addition, the sound levels measured give no indication of actual noise exposure within each unit of the buildings, and are extrapolations. This may have therefore led to incorrect estimations of personal exposure. However, it should be noted that on average (per week) men spent 10.3 hours, and women 7.9 hours away from the home. Noise levels for these periods were not included in the study.

A number of variables were measured by means of seven questionnaires, four of which were standard and three of which were constructed specifically for the study. Those were the Health Inventory, Holmes and Rahe's Social Readjustment Scale, Bortner's Short Scale of Type A Behaviour, Spielberger's Trait Anxiety inventory, Sleep Patterns Inventory, Subjective Sleep Report and Milieu Anamnesis. This latter questionnaire assessed epidemiological and socioeconomic factors. An analysis of variance performed on subjects living in the 'noisy' and 'quiet' areas showed no differences with regard to sex, age, marital status, health complaints, use of medicine, sleep quality, anxiety, number of life events and subjective noise response. The only difference found between the two groups related to daytime naps with p = .036 for persons living in the low-noise area taking more naps than persons living in the high noise area. As was stated previously, it was unsurprising that no significant differences were found between the two noise level groups due to the 'slight' difference in L_{eq} levels.

The subjective noise responses, denoted 'annoyance' and 'sensitivity', were positively related to health complaints and to poor sleep. The pattern of this relationship however, was different according to gender of the individual. Total health complaints was correlated with annoyance for men and with sensitivity for women. These two variables, sensitivity and annoyance, however were not related to noise levels and were not significantly correlated with each other in men. This
relationship only reached significance between poor sleep quality and sensitivity. The authors explain the stronger relationship among noise sensitivity, health complaints and poor sleep quality for women than for men by citing the degree of exposure to noise as evidenced by their longer time spent in the home. However, the failure to demonstrate a significant effect of noise, even amongst women, must cast some doubt on this explanation. In general, this study group is too small to enable conclusions to be drawn about the significance of results.

Carter et al (1994) set-up a study of the effects of environmental noise on sleep, based on arousal, cardiac arrhythmia and urinary catecholamines. Using laboratory conditions, nine subjects, each of whom had documented arrhythmia, were studied over four nights of sleep. There were two nights of noise exposure, one using truck noise and the other aircraft noise. Maximum levels of noise were in the range of 65 and 72dB(A). Responses to the noise were assessed by comparing electroencephalogram (EEG), electrocorticogram (EOG), electromyogram (EMG) and ECG responses during the noise with those occurring during quiet periods of the same duration. Overnight urinary catecholamines were also assessed. Results indicated that noise increased the likelihood of arousal responses to the same degree during all sleep stages (p<0.05). Four of the nine subjects showed frequent ventricular premature contractions (VPCs) during the course of the experiment. These VPCs however were significantly related to actual sleep stage rather than noise event per se. No differences were noted in terms of urinary catecholamines. Results of this study however should be treated with caution due to both the small sample group and their atypical status with regard to 'normal' occupational groups.

Topf (1992) reported the results of a study of the effects of Critical Care Unit noise on subjects trying to sleep. Although not of direct relevance to occupational noise exposure it is interesting to note that in the experimental context used, so-called control over the noise had no effect on the experimentally induced effects of the noise. The study showed a significant effect of noise on subjective stress but not for physiological indicators (urinary epinephrine). However, noise control was perhaps a misnomer as the equipment appeared to offer the facility to mask the noise with other sounds rather than actually control the noise level. The absence of any significant experimental effect should therefore be regarded with caution.

8.2.2 Fatigue effects

Kjellberg et al (1996) examined the possible fatigue effects of noise on aeroplane mechanics. Subjective fatigue and reaction time performance were measured in a group of 24 aeroplane mechanics using a comparison study of 1 week of high noise exposure and 1 week of low noise exposure. The measurement tools used were (a) a simple reaction time (RT) task used as a measure of fatigue, and (b) a mood adjective checklist which contained 16 sub-scales divided into the following three mood dimensions: energy, stress and wakefulness.

The main task during the high exposure week on the runway was to prepare the aeroplanes ready for take-off and secure them after landing. In general there were four main take-off periods, two in the morning and two in the afternoon. Time between take-offs was spent in a control building near the runway. Sound level (Lw) during the runway week varied between 94 and 100dB(A) with 10-min periods of work with the aeroplanes at 100-110dB(A), with maximum levels of up to 138dB(A). A level of 90 dB(A) was exceeded 10% of the time and 115dB(A) was exceeded about ten times per day. The mean difference in equivalent sound level between the runway and base condition was approximately 20dB(A). Tasks undertaken during the week at base involved check-ups and repairs. The authors state that comparable tasks were undertaken in the two weeks. However, as it is not stated if the mechanics completed any tasks in the control building at the runway, it is feasible to expect a boredom factor to confound results with this group. The task itself in the two groups may be just as significant as noise level. The nature of the task that the groups were performing on the runway and at base is very different in terms of the psychological
demands on the individuals’ vigilance and possibly physical effort and could therefore affect subjective mood ratings or morning/evening energy levels.

Runway - rapid service to planes on take off/landing (errors crucial - reaction time rapid)

Base - routine checks and repairs (response time not so critical, can work within own time limits)

This may determine their response at the time of the task and after the task, in terms of the stress/performance curve.

The mood adjective list was completed before and after work each day, whereas the RT test was only performed before and after work on the Thursdays.

Results indicate that the mechanics would feel more sleepy and less energetic during the week of work at the runway than after repair work at their base. The authors point toward a cumulative effect on fatigue during the runway week. In addition, reaction times were prolonged in the morning after exposure to noise.

In terms of possible confounding factors, the authors looked at boredom and vibration effects. Investigations concerning fatigue ratings indicated non-correlation with workload or boredom. Indications were that the mental load was similar for the two conditions. Vibration was mentioned by the subjects themselves who said that they could not only hear the sound, but also feel it as vibrations. The authors do state that this factor may have contributed to fatigue. Further evidence of the non-specific effects of this factor have been detailed in Section 6.7.1 of this report.

Although of interest in terms of fatigue effects, it is difficult to extrapolate the data based on noise exposure alone. It is also difficult to extrapolate to other occupational groups and the healthy worker effect is likely to be significant within this group.

Vallet and Fakhar (1991) reported the results of a study of the effects of noise and vibration on driver vigilance. The experiment was conducted on nine adults driving for three hours at a speed of 130kmh⁻¹ on a French motorway. Two levels of noise and vibration were studied, normal levels and enhanced levels produced by (a) amplifying the traffic/car noise and (b) by modifying the seat in the car. Recordings were obtained of postural changes and of selected electrophysiological signals (EEG, EOG, ECG). Both were then used to provide indices at either intensity. Louder noise (+4dB(A)) resulted in decreased vigilance as shown by postural change (head dropping forwards) and the electrophysiologically derived index. This effect became apparent after two hours driving. The authors stated that the drivers were not aware of this decrease although they do not indicate how this was determined. Although based only on a small sample, the significant findings have clear implications for road safety but it is not immediately apparent how such results can be extended to the wider occupational context.

8.3 PSYCHOSOCIAL/PSYCHOLOGICAL

Ivanovich et al (1994) investigated both specific and non-specific health indicators in telephone operators. The investigation was undertaken as a result of concerns regarding the number of complaints received from telephone operators using an inner telephone receiver, (monaural receiver microphone which is put into the ear canal). A total of 260 female telephone operators,
with similar job activities, employed in the International, Intercity and Information service departments participated in the study.

In terms of noise levels at the field sites, the following background (BG) and telephone receiver (TR) noise were measured in dB(A): (1) International BG Leq x1 = 63.26, TR = 86.6; (2) Intercity BG Leq x1 = 71.1, TR = 79.2 and (3) Information BG Leq x1 = 69.66, TR = 78.4.

In addition, the following experimental indices were determined for each subject:

1. Hearing threshold (in dB) of the left and right ear, at frequencies of 0.5, 1, 2, 4, 6 and 8 kHz by pure tone audiometry.

2. Questionnaires: (a) subjective symptoms questionnaire; (b) EPI-C; (c) mental health Langer T.S. for depression and anxiety detection, and (d) subjective 5 degree evaluation of intensity and duration of noise during work and at home, annoyance due to noise and state of health.

3. Laboratory examination of urine catecholamines (11-OCS, adrenaline (A), and noradrenaline (N) excreted during both the morning and afternoon shifts.

Results indicated that there was no marked decrease of hearing sensitivity in subjects from any group. Symptoms related to stress factors did not differ significantly between the groups. However, the subjective symptoms, mental health disorders, depression, anxiety and subjective health evaluations of the Intercity operators showed many of the values to be above the critical levels. It was also found that many of the operators perceived noise intensity and its annoyance effect as very high both at work and also at home. In terms of the catecholamine measures, there was an elevation of these observed in all groups, with greatest prevalence in the intercity operators.

The authors themselves highlight the potential problems in extrapolating these results, due to the extensive number of confounding factors such as high job demands, work organisation deficiency and low social support. Indeed the higher evaluations of the Intercity operations, despite similar background and telephone receiver noise, suggest that other psychosocial indices are important factors in annoyance reporting. The sample population used may also skew the data due to the recognised association of gender and annoyance reports.

A major review of noise and noise sensitivity in relation to psychiatric disorder was reported by Stansfield (1992). Although focusing primarily on environmental rather than occupational noise exposure it does provide a useful exploration of the relationship between noise sensitivity, noise annoyance and psychiatric disorder, including some new experimental data.

The relationships between noise sensitivity, noise annoyance and noise exposure level have been described previously and will not be repeated here. However, the examination of the relationship with psychiatric disorder is worth reporting because of the potential implications for non-auditory effects of noise in occupational contexts. Briefly, the results show that noise sensitivity is partly associated with psychiatric disorder with some evidence for a reduction in sensitivity with improvement in psychiatric condition. Examining this relationship further, it was suggested that noise sensitivity was associated with a 'cluster' of personal characteristics including neuroticism, inadequacy and negative affectivity. However, the author cautioned against over emphasizing such issues, going on to examine a possible physiological correlation with noise sensitivity, having excluded the explanatory variable of heightened hearing ability.

The experimental results reported may be biased because they were obtained from studies of
psychiatric patients. However, they did show that noise sensitive people apparently demonstrated slightly higher levels of physiological arousal, as shown by number of spontaneous fluctuations in skin conductance (but not mean level) and in mean heart rate. Levels of skin conductance were not reported and heart rate differences were very small and unlikely to be of any clinical significance. These findings were contrary to previous work cited by the author who suggested that this variation may be explained through by differences in the experimental context.

In conclusion, Stansfield suggests that noise will be of greater significance to noise sensitive people who will react and adapt to noise exposure more slowly. This turn will result in them expressing annoyance more frequently and more strongly. It is further suggested that, in vulnerable individuals, this can result in the emergence of symptoms of psychiatric disorders.

Stansfield et al (1993) reported the results of a study of the relationships between noise exposure, noise annoyance, noise sensitivity and psychological disorder carried out as part of a large-scale study of male coronary heart disease. Noise exposure was determined on the basis of traffic noise maps, based on measurements of $L_{eq}$ emission levels between 6 a.m. and 10 p.m. Noise sensitivity was determined using Weinstein’s scale and a single question ‘Do you think that you are sensitive to noise?’ Noise annoyance was assessed by responses to the question ‘Does traffic noise at home annoy you?’ Psychological disorder was assessed using the General Health Questionnaire - 30 (GHQ-30) with Trait anxiety measured by the Trait Scale of the State-Trait Anxiety Inventory.

The results showed a strong positive association between traffic noise level and noise annoyance. The scores from Weinstein’s noise sensitivity scale showed a significant positive association between noise sensitivity and noise annoyance. More detailed analysis of both sensitivity scores, annoyance and noise exposure suggested an additive relationship. Men claiming increased sensitivity to noise are disproportionately more likely to complain of annoyance from increased traffic noise, although the Weinstein’s scale just failed to reach statistical significance ($p = .05$). Turning to psychological disturbance, the authors suggest a weak trend for more psychiatric ‘caseness’ (ie presence of a range of traits which are known to be associated with psychiatric disorder) with greater noise level although any trend is very slight, is not consistent, and did not reach statistical significance. Correction for various sociodemographic factors removed even this slight trend. However, the results did show a significant trend between psychiatric disorders and noise sensitivity (either scale) and also between Weinstein’s noise sensitivity and trait anxiety (no results are reported for the single sensitivity question for this comparison). The authors then examined whether noise sensitivity was a moderating variable in the relationship between psychiatric ‘caseness’ and noise exposure (although this relationship was not strong). A complex pattern was identified by a logistic regression whereby the percentage of individuals demonstrating psychiatric ‘caseness’ generally increased with noise exposure level amongst the group reporting low or moderate levels of noise sensitivity, whilst amongst those reporting high sensitivity a clear trend was less apparent but appeared to show a decreasing trend with increasing noise level.

Although the findings reports in this paper have important implications for understanding the complexities of some non-auditory effects of noise the study does have a number of significant deficiencies in relation to noise exposure data. Exposure levels were determined from daytime measures of traffic noise and may over estimate personal exposures in some cases. Conversely, exposure may be under estimated for some individuals as no account is taken of possible occupational noise exposure. Although reference is made to a separate publication no information is given on possibly relevant demographic information such as employment, years resident in that location etc. Finally, few of the results attained conventional levels of statistical significance. The results should therefore be interpreted with caution.

Melamed et al (1994) reported a positive benefit arising from the non-auditory effects of noise
by studying the effects of noise annoyance on hearing protection use and other factors. A large-scale study of 1200 non-users and 387 users showed that those who found noise annoying were more likely to wear hearing defenders and that this was independent of noise level. As would be expected, more people exposed to higher noise levels (≥85dB(A)) wore hearing defenders than those exposed to lower levels but a similar proportion in both groups were classified as highly annoyed by noise. The results also showed that the use of hearing protection reduced the incidence of somatic complaints and post-stress irritability, but only for low or moderately annoyed workers. Highly annoyed workers reported higher levels of somatic complaints and irritability with hearing defenders (statistically significant for the latter parameter). The authors suggested that this could be attributed to the annoyance effect of the hearing protectors themselves, although no evidence was cited to support this. Nevertheless, the motivational properties of noise annoyance appears to have a useful side-effect where hearing protection use is concerned.

Kastka (1991) published a brief report on the results of studies of impulsivity and annoyance. An initial experiment showed annoyance to mainly be related to noise level regardless of the nature of the source. However, the circumstances of the testing appeared to influence the outcome for different noises in a varying manner. A second experiment showed that, for a single noise type, the subjective impact can be defined and objective correlates identified. This experiment used a single set of subjects in a controlled (laboratory) setting. Thus most of the potential sources of subjective variation had been removed. However, the particular nature of the noise used (explosion) limits the applicability of this work.

A collection of case reports from the Low Frequency Noise Sufferers Association (Anon, 1990) gives an interesting insight into the sometimes debilitating effect that noise can have, particularly when its source is not known. Somatic effects described include irritation, headache, nausea, disorientation, digestive disorders and disturbed or no sleep. It would be interesting to compare the symptoms of such sufferers with those reported by other individuals living close to a known noise source, as not knowing the source of the noise appears to be a major contributory factor in providing health effects. The data presented is subjective and not linked to specific exposure levels, limiting its usefulness for this review.

Howell (1993) reported on a series of investigations of prolonged low intensity low frequency noise by British Gas personnel. The report illustrates the potential pervasiveness of noise and its ‘nuisance’ quality but contains little formal scientific reporting of relevance to the non-auditory effects of noise in an occupational context.

Topf (1989) examined the issue of noise-induced stress in critical care nurses in relation to noise sensitivity and the characteristic of personality ‘hardiness’. The target noise level in hospitals in the USA is 45dB(A) (24 hour average). The author cites survey work as showing a typical average of over 50dB(A) with extensive periods of 50-60dB(A) and, for about 25% of the time, values of 60-70 dB(A) were recorded. However, Topf then cites work suggesting that physical noise level is not necessarily the best correlate of noise stress.

The study reported by Topf involved 100 critical care nurses who voluntarily completed a battery of tests. Four tests comprised a composite measure of personality hardiness. These were the Alienation from Work Scale (work commitment); the Alienation from Social Institutions Scale (social commitment); the Locus of Control Scale (control) and the Security Scale of the California Life Goals Evaluation Schedules (challenge). Noise sensitivity was assessed using Weinstein’s scale and noise-induced stress using the ‘Disturbance Due to Hospital Noise Scale’ previously developed by the author.

The 100 nurses were recruited from two hospitals, representing response rates of 92% and 48%
at the two locations. Preliminary analyses showed that despite this variation in participation there were no significant differences in study variables between the two sites.

Statistical analyses showed a significant positive correlation between both sensitivity to noise and lack of hardiness and noise-induced stress. A subsequent multiple regression analysis of noise-induced stress showed that sensitivity to noise accounted for 26% of a total explained variance of 31%, and a hardiness x shift correlation accounted for a further 3%, with shift itself accounting for the remaining 2%.

A subsequent analysis was carried out to examine the role of the different elements on the composite ‘hardiness’ dimension. The two commitment measures were significantly correlated, both with each other and with the noise-induced stress dimension. However, neither ‘Control’ nor ‘Challenge’ were significantly related to the stress measure. Consideration of the individual factors used in the multiple regression did not markedly improve the overall prediction of noise-induced stress from the composite hardiness model.

The authors suggest that lack of perceived control over noise sources and consequently failure to regard it as a challenge to be overcome possibly accounted for the failure of these individual parameters to show any significant effect. Although not discussed by the authors, it is apparent that the parameter of noise sensitivity is the dominant factor in this study.

The issue of the influence of personality in noise sensitivity was examined by Dornic and Ekehamer (1990). They utilised the Eysenck Personality Inventory (EPI) to examine the effects of extroversion and neuroticism on noise sensitivity as measured by the Noise Sensitivity Scale (NSS) devised by Weinstein. The authors examined the scores on the 21 items which make up the scale as well as the total score.

The relationship between noise sensitivity and extroversion appears to be particularly robust. As well as a highly significant correlation between the NSS total and extroversion, all 21 individual items showed the expected negative relationship with extroversion with at least ten achieving statistical significance. (The authors report a further eight achieving significance at the p < 0.10 level). In a second analysis, adjusting for the effect of neuroticism score, this robust relationship between extroversion and noise sensitivity still remained. Neuroticism however showed a much less clear trend. The correlation with total noise sensitivity was only weakly significant (p < .10) and correlation for individual items was not always consistent. Adjusting for the effect of extroversion reduced the relationship still further, possibly indicating an interaction. A two-way ANOVA with extroversion and neuroticism as independent variables, and noise sensitivity score as the dependent variable confirmed a significant interaction between the two independent variables. This suggests susceptibility to noise sensitivity in neurotic extroverts.

Noise was one of the physical environmental factors studied by Klitzman and Stellman (1989) in an examination of the impact of such factors on psychological well-being. The results are based upon the responses to a self-administered questionnaire developed by the authors and administered to over 2,000 employees at four different office sites. An impressive response rate of 86% was achieved. The questionnaire identified psychosocial and physical work environment factors as loading variables and satisfaction and mental health parameters as response variables.

The final outcome of multiple regression analysis was a series of formulae examining the contribution of the physical environment to five different psychological measures of well-being (job satisfaction; office satisfaction; fatigue; irritation and general distress). Allowance was made for the effect of demographic variables (particularly age and sex), occupation and psychological factors such as supervisor support and job future. Excessive noise featured in each
of these regression equations along with air quality and, in most instances, ergonomic stressors. However, in most instances, although statistically significant, the contribution of the noise parameter to the explained variance \((R^2)\) is very small. The apparent exception to this is in relation to office satisfaction. However, a noise-related variable (satisfaction with noise) was earlier shown to be part of this office satisfaction parameter, and the subsequent inclusion of excessive noise in the regression may reflect an interaction between these two variables. No actual measurements of the physical environment are reported. In conclusion, although self-reported excessive noise is shown to be statistically significant in predictions of psychological well-being in office environments, the magnitude of the effect is small when considered with other factors of ‘well being’.

Studies of the effects of noise at work are frequently complicated by the effects of other occupational factors on the variables measured. For example, stress at work may be influenced by noise exposure but is also influenced by a host of other factors. McDonald and Ronayne (1989) carried out an extensive multi-site study of noise and a range of other occupational factors in an attempt to elucidate the psychological impact of work in noise. Over 900 blue collar workers from nine separate companies participated in the study. The core data were provided from a 45 minute questionnaire interview of each worker, with noise exposures determined from sample measurements lasting at least one hour at a variety of representative sites. Interview results were used to determine self-reported effects of noise (seven categories); occupational stressors (three categories); occupational strains (three categories) and mental health (GHQ-12). Other variables considered were age, gender and shift system (days vs. shifts). Noise exposure was mainly categorised as ‘less than 80dB(A)’ or ‘85 dB(A) or greater’, although some subsidiary analyses examined exposure at lower levels. Noise level was the only variable used to define noise exposure. Although some information on frequency content was provided, changes in pattern of exposure with time were not discussed.

Results showed that higher noise exposure was significantly associated with an increase in reported levels of all seven impact measures (headaches; fatigue; negative affect eg. uncomfortable; irritated; nervous reactions eg. jumpy, jittery; speech interference; hearing deficits; and after-work effects). Fewer than 10\% of those in the low noise group reported these impacts except for ‘negative affect’. Further analyses showed no reports amongst those exposed to less than 70dB(A) other than again a small number reporting ‘negative affect’. However, a subsequent analysis showed that many of these impact measures were significantly correlated with the other occupational factors (stress and strain); the demographic variables; and mental health. Many of the occupational factors were significantly correlated with ‘negative affect’ and two noise-related factors ‘noise constraints’ (ability to avoid the noise) and ‘noise annoyance’. At this first level of analysis, the results clearly demonstrate the complexity of factors apparently influencing non-auditory effects of noise in an occupational context.

The next section of the analysis explored in particular the factors influencing mental health as indicated by the GHQ-12. Shift workers and younger workers showed poorer mental health. However, whilst noise exposure did show a significant association with mental health the trend was not linear, with poor health increasing with noise category up to the 85-89dB(A) range, but decreasing thereafter. It is possible that this is due to some change in the sample population exposed at these levels, because there were far fewer workers in the ≤90dB(A) category than in any of the other three. Mental health scores also showed significant relationships with each of the six stress and strain scores, with high stress at work being associated with the highest overall score.

These six stress and strain variables together with age, noise exposure and mental health were presented in a table of bivariate inter-correlations (all factors significant at \(p < .001\)) Poor mental
health was significantly correlated with all other factors excluding noise level.

Noise annoyance however (rather than actual exposure) was significantly correlated with all factors other than age supporting the idea from experimental studies that the impact of noise on well being is primarily mediated via its psychological importance rather than physical level.

Finally, in an attempt to explain these inter-relationships more fully, the authors conducted a series of multiple regression analyses, to determine predictors of mental health status. Although noise level, noise constraint and annoyance due to noise all featured among the explanatory variables, they were not identified as strong direct influences. Poor person-environment fit in relation to intrinsic job factors and stress at work were shown to be the most important predictors. In conclusion, this paper presents an extensive examination of the effects of noise and many other factors on mental health and well-being and amply demonstrates the complexities of any explanation.

Standing *et al* (1990) reported the results of two laboratory experiments aimed at studying the influence of the extroversion-introversion trait on the effects of noise on performance. It was suggested that effects would be mediated via changes in arousal level. The first experiment utilised white noise at two intensities (45 and 60dB(A)) as background to a reading comprehension test. Activation was measured by an adjective checklist, physiological arousal by heart rate recordings. The authors also devised a 'preference for noise' scale. Task performance in noise was unaffected for extroverts but that of introverts deteriorated significantly (p < .01). Although the introverts had a significantly lower pulse rate in the quiet than did extroverts there was no significant effect of extroversion or noise upon pulse rate. Similarly, there was no significant effect of these two parameters upon subjective activation. However, subjective deactivation was significantly affected with extroverts showing a greater decrement in noise than in the quiet and also the effect was greater than seen in introverts. Finally, introverts showed a significantly higher preference for less noise than extroverts. Overall, the authors conclude that the results support the hypothesis with introverts showing greater physiological arousal and less subjective deactivation in noisy conditions than the extroverts and this being accompanied by a deterioration in task performance.

The second study examined the impact of mood changes in noise amongst extroverts and introverts. Student subjects completed two exercises whilst exposed either to 70dB(A) garbled speech or 45dB(A) white noise. The exercises were the State-Trait Anxiety Inventory (STAI) and a word association test devised to assess aggressiveness. The results showed noise to have a significant effect on state anxiety for both introverts and extroverts with no significant differences between the two groups. No significant differences in aggressiveness were identified.

In summary, the results repeat the findings of previous researchers that the effects of noise on performance can be influenced by psychological characteristics, notably extroversion-introversion.

Kiltzman and Stellman (1989) reported the results of a survey of psychological well-being amongst office workers. Over 2,000 employees participated in a study which identified noise as being one of the strongest correlates of psychological well-being. It cited other research to indicate that the unpredictability of noise rather than level had the main influence. It also suggested that the data obtained were consistent with experimental work showing psychological effects of low noise exposure. However, it should be noted that this study was entirely based on subjective reporting with no actual physical measurement. This weakness was referred to by the authors who also rightly questioned the value of spot measures of physical parameters. No experimental evidence was presented relating to unpredictability.
Kjellberg (1990a) published an extensive review on the subject of the non-auditory effects of noise classifying effects under three categories: subjective responses, behavioural effects, and psychophysiological effects. In introducing subjective responses, the author commented on the general lack of studies relating to subjective state (mood) although one study which showed an increase in distress in noise was cited. The first area discussed was that of the extent to which physical characteristics of the noise influenced the response. Sound level was important in that the same type of noise would have more impact at higher levels. However, the influence of other factors was such that, for differing noises, the loudest would not necessarily have the greatest impact. No evidence is presented at this point regarding whether the effects are only apparent at higher levels (e.g. >90dB(A)). The review differentiates between the variations in sensitivity to hearing different frequencies (approximately the A-weighting curve) and the tendency of different frequencies to cause more annoyance. Low frequency noise is considered to be proportionately more annoying and this is reflected in the D-weighting curve which has been produced (but is seldom featured on noise measuring instruments).

Turning to exposure time, the author states that very brief (10 ms) exposures can appear less loud because the ear appears to integrate the signal across approximately 100 ms. With longer exposures the author suggests that the belief that people become less annoyed by noise with prolonged exposure over a week is erroneous, citing a study which shows that some people become progressively more annoyed. Variable noise is undoubtedly more annoying than steady state noise. Kjellberg suggests that sudden variations are even more annoying.

The masking effects of noise produce varying outcomes. In some instances the sound may mask an even more annoying noise and can therefore be perceived as beneficial. The author uses the example of a dripping tap to illustrate this point. Similarly, background noise can be seen as an aid to privacy as in preventing overhearing conversation. Alternatively of course, masking of desired sounds can be very annoying. In many work situations, the unwanted noise arises from other peoples' speech, and studies have shown speech sounds, even when incomprehensible, are particularly intrusive. Some evidence is cited that predictability or controllability can also reduce the annoyance caused by noise as can the attitude towards the noise or its source. An adverse view of a noise source is more likely to be associated with a negative response to the noise itself. Similar factors prevail with the perceived need for the noise. Thus, workshop noise may be seen as a necessary adjunct to the work in the workshop itself but may be annoying in an adjoining office. The author does state however that this has not been studied in occupational environments. Finally in this section the author discusses work on noise sensitivity and other individual factors influencing the annoyance potential of noise. The author questions the concept of noise sensitivity as a stable individual trait, suggesting that it is often influenced by the characteristics of the noise and that it appears to be part of a general characteristic of 'annoyability' rather than a noise-specific phenomenon. The exception to this are those who are hearing impaired, who are often more annoyed by noise, although this probably reflects the greater impact which noise can have on such individuals (e.g. distortion or masking) rather than an underlying psychological trait.

The second section of the review addresses the behavioural effects of noise, particularly the effects on performance which it describes as having attracted most attention.

Masking of one noise by another clearly provides an avenue for impairment of performance and this effect may occur even where tasks are not primarily auditory. Similarly, the distracting effects of noise, particularly with its sudden onset (possibly resulting in startle) or cessation are well known. The reviewer also makes specific reference to irrelevant speech as a source of distraction.

The next issues discussed are the linked factors of arousal and attention. It is suggested that many performance-related effects of noise have been attributed to the influence of that noise on the level
of arousal of the listener. However, the author appears to favour a mechanism linking these arousal effects to attentional selectivity and the adoption of an alternative response strategy (usually associated with a narrowing of attention).

The following section, on safety and efficiency, refers to the paucity of workplace studies on this topic and the difficulties of isolating auditory influences from other factors. The papers cited have all been widely quoted elsewhere.

The author then addresses the multitude of studies of the effects of noise on laboratory tasks, initially drawing attention to the fact that different reviewers have arrived at differing conclusions as to the existence of non-auditory effects of noise on performance. Certainly the phenomenon does appear to be more complex than some theories suggest. Thus noise can improve performance in low arousal tasks such as monotonous signal monitoring tasks, but may not always do so. Other tasks, such as simple reaction time tasks, motor performance and visual acuity task appear to be relatively insensitive to noise, or at least to continuous meaningless noise. Most of the studies and issues are encompassed within the review by Smith and Broadbent (1989) and will not be detailed here. However, it is worth noting that any effects of noise on task performance appear to be influenced both by the detailed task requirements and by the specific characteristics of the noise. Another comment of great importance is that at least some of the effects reported are present at levels of noise 'previously considered harmless'.

The author then addresses the influence of noise characteristics, repeating the above conclusion with reference to at least one paper by the author which reported performance effects of noise at 51dB(A). Only one paper is cited to show frequency-dependent effects (high frequency impaired performance more than low). However, an increased effect of noise with increased duration of exposure is described as generally recognised. Increased variability, decreased predictability and reduced control of noise have also all reportedly been shown to impair performance.

A section follows describing the after-effects of noise, where an effect occurs after the noise has ceased (even where no effect has been demonstrated during noise exposure). It is suggested that this phenomenon is not specific to noise, attributing it to the influence of any uncontrollable and unpredictable stressor.

Finally in this section, the author alludes to other behavioural effects of noise, classified as 'social effects', citing as an example a series of field experiments which showed that people tend to be less helpful in noisy conditions.

The last section of the review details psychophysiological effects and their concomitant long-term health effects. It categorises the effects into short-term transient responses, persistent responses and long-term changes (health effects). It identifies a group of short-term responses which it groups under the category of an 'orienting reflex' (lowering of heart rate and blood pressure etc). The second category of short-term response is the startle reflex. Neither of these are regarded as having any consequences for long-term health. Longer-term cardiovascular and hormonal responses come into the category of persistent responses and a link can be hypothesised between these responses and long-term health effects. For example, persistent increases in blood pressure may result in hypertension (permanently raised blood pressure). The strongest support for this suggestion is derived from animal studies. There is some support from studies of human groups although the author states that 'there are several contradicting results'. Finally, brief reference is made to possible influences of noise on mental health although the author concludes that it is impossible to distinguish the effects of noise from those of other possible contributory factors.

Sutherland and Flin (1989) included noise as a possible factor in their review of working conditions in the offshore oil and fishing industries. The section relating to the oil industry refers
to impairment of communication but, apart from sleep loss, makes no reference to non-auditory effects, despite the fact that noise exposure offshore is, to some extent, virtually continuous albeit at lower levels in living accommodation. The coverage of noise in the fishing industry is limited to a report from a newspaper, including reference to an instance of noise from a hydraulic gear causing nausea and headaches amongst the crew. No details of noise levels or of possible confounding variables are reported.

Namba (1989) carried out a review of the general subjective impact of noise and its relationship with different physical characteristics of the noise. The main purpose was to provide a technique to allow the psychosocial impact of noise to be predicted from physical measurements when planning roads, airports etc. The review concentrated on annoyance rather than any aspect of performance decrement.

Triolo (1989) produced a two-part review of hazards affecting hospital nursing staff. Although reference was made to noise and to the fact that physical environmental stressors received the highest frequency of stress ratings in one cited study, no specific reference is made to non-auditory effects of noise.

8.4 Reproduction and Foetal Development

Hartikainen et al (1991) looked at the effect of experimental noise exposure on human pregnancy. A 15 minute exposure of 90dB(A) white noise was used to examine systolic, diastolic, mean arterial pressure, heart rate and stress hormones (ACTH, cortisol, prolactin, epinephrine and norepinephrine) in a total of 27 normotensive and hypertensive pregnant women. Fetal and uterine blood circulation was also examined. With the exception of fetal heart rate in normotensive pregnancy, there were no other significant changes in variables considered. Although the measurement techniques used in the study were appropriate to investigate the cited parameters, there were shortcomings within certain areas of the methodology. In addition to the relatively small sample size, the length of exposure period was too short to guarantee significant change in hormone output. The technique for measuring uterine blood flow is not likely to yield true values, rather it would be representative of actual values. In conclusion, although the study highlights negative effects of noise exposure on pregnancy, the overall conclusions are questionable and it has limited application for extrapolation to occupational environments.

Nurminen and Kurppa (1989) examined the possible relation of occupational noise exposure on adverse pregnancy outcomes. Threatened abortion (determined by vaginal bleeding), pregnancy induced hypertension, length of gestation and birth weight were examined in a case-referent study of 1190 mothers. Exposure noise levels were assessed both by maternal report and assessment by industrial hygienists. The problem of relying on recall for noise exposure criteria was highlighted by the finding that whilst 429 mothers reported their working noise levels a problem, independent assessors classified only 102 mothers as working in a noisy environment, defined as above 80dB(A). Very small groups were classified in the higher exposure categories (3% = 85dB(A) and 0.7% = 90dB(A)). Results of the study proposed that threatened abortion was not associated with noise alone, but when in combination with shiftwork the risk of spontaneous abortion was greatly increased. Similar results were found both with pregnancy induced hypertension and shorter duration of pregnancy, when noise exposure was considered in combination with shiftwork. Although there was no effect of noise alone on any of these three factors, noise did show an independent on the probability of low birth weight, (median birthweight of infants of mothers in noisy working environments = 355g, and for mothers working in quiet working environments, 370g). The authors conclude that threatened abortion, pregnancy induced hypertension and gestation were not related to noise alone. Examination of the confidence
intervals which often includes unity and the possibility of confounders which are not quantified means that results could not therefore be quoted with confidence.

Luke et al (1995) examined the association between occupational factors and preterm birth. A case-control study of 210 nurses whose infants were delivered prematurely (> 37 weeks = cases) and 1260 nurses whose infants were delivered at term (≥37 weeks = controls). In addition to questions regarding working conditions, an occupational fatigue score was constructed to address issues such as posture, physical exertion, mental stress and the working environment. Results of the study suggested that the risk of preterm birth was higher among nurses exposed to strenuous working conditions and long weekly hours in comparison with nurses working under less arduous conditions. The following factors were found to be significantly associated with preterm birth:-(1) Standing, especially when in excess of six hours, (2) A 24% attributable risk of preterm birth caused by occupational fatigue and, (3) Long hours of work. The authors suggested the following three preventative measures for pregnant women in work:- (1) Reduced working hours per week/shift, (2) Changing work areas, moving away from the more ‘acute’ working areas and, (3) Granting work leave during pregnancy, especially for women with pregnancy complications. The authors considered many confounding factors which resulted in a very strong study design. The main objective however, was not the independent impact of noise on preterm birth. The only data collected on this aspect was contained in one question which asked the respondent to rate the typical noise level which they worked in during pregnancy, ranging from quiet, moderate to loud. This type of self-reporting of noise is unreliable, and no quantitative exposure measurements were available. In general, the study is very helpful in identifying other work related factors associated with preterm birth, however there is not enough evidence to conclude a direct effect for noise alone.

The goal of the investigation by Hartikainen et al (1994) was to prospectively examine the effects of occupational noise during pregnancy. The exposed group (continuous A-weighted sound level \(L_{meas} > 78\text{dB(A)}\)) consisted of 111 pregnant women, and the reference group comprised 181 pregnant women with similar work conditions but without noise exposure. Age, obstetric history, social class, and occupational status were all examined as confounding factors within the statistical analysis. Attempts were also made to control for differences in working conditions, the noise exposed group had more inconveniences at work such as shiftwork, impulse noise, vibration and excesses of temperature. The contrast with the unexposed women was further evaluated in subgroups of exposed subjects defined by noise level (low noise exposure < 90 dB(A) \(L_{meas}\), and high dose = noise exposure ≥ 90 dB(A) \(L_{meas}\) and by presence or absence of impulse noise. Results relating to the 78dB(A)(\(L_{meas}\)) limit showed no chronic arterial hypertension, systolic or diastolic blood pressure in either group. No changes were observed in either blood pressure measurement when noise exposure rose to 90dB(A)(\(L_{meas}\)). However, slightly lower than average birthweights were detailed for this subgroup. These findings were more pronounced for women simultaneously exposed to a standing work position or shift work. The authors conclude that working in high noise exposure can be considered a risk factor during pregnancy. The study is notable however in regard to the lack of effect on blood pressure at the noise levels assessed. Unfortunately the other exposures such as vibration, and shiftwork weaken the strength of the findings in relation to noise and nearly two thirds of the nonexposed group were not in manual jobs. Accepting these limitations however, the study has obvious relevance for this review.

Griffiths et al (1994) examined noise induced hearing loss in fetal sheep. The problem of extrapolating results from animal studies to human were addressed by using sheep, which are a widely recognised animal model for human fetal physiology and development, however interspecies differences still need to be considered. The auditory brainstem response (ABR) was recorded from chronically instrumented fetal sheep prior to and following exposure of pregnant ewes to intense broadband noise (120dB SPL for 16 h). ABRs were elicited by clicks and tone
bursts delivered through a bone oscillator secured to the fetal skull. Results showed that exogenous sounds can penetrate the uterus and result in alterations of the fetal ABR. ABR thresholds were temporarily elevated by an average of 8dB following the noise exposure. Being a temporary phenomenon however, it is difficult to predict the effect of repeated similar episodes on potential for hearing loss.

Nurminen (1995) reviewed a number of studies to assess the effects of noise exposure and shift work on reproductive disturbances. With respect to the effect of noise on preterm birth of the five studies reviewed: one study showed an increased risk for preterm birth, three showed no such effect whilst the other was inconclusive. Of the six studies examining the effects of noise on low birth weight, four studies indicated that noise exposure might have a negative effect on birth weight whilst the remaining two showed no effect. There appeared to be more evidence for pregnancy effects as a result of shift work. A number of studies related to shift work in general. Rotating or changing schedules indicated a higher than average number of preterm births. Such schedules were also associated with decline of birth weight, low birth weight and intrauterine growth retardation. An elevated risk of spontaneous abortion was indicated for shift work, rotating/changing schedules and night work. Pregnancy loss was also associated with fixed evening and night work, rotating shift work however was not related to such loss. As this study was by nature a review of a number of research studies, the validity of the paper reviewed could not be evaluated. There was very little information available to assess methodological information such as size of population, exposure pattern and intensity and various confounding socioeconomic factors. In general however, it would appear that there is more evidence for a negative impact on pregnancy outcome due to the effect of shift work rather than noise.

Nietzow (1993) conducted a review of studies addressing fetal hearing loss, aircraft noise and animal studies. In terms of attempting to define safe exposure limits for the foetus two studies stated that a threshold exists at just above 90dB that is harmful for the developing human foetus. However, one of these authors, (Laland et al 1986) stated that an 8 hr time weighted average of 85dB(A) increased the risk of having a child with a high frequency hearing loss by a factor of three. None of the reported ‘noise and aircraft’ studies took socioeconomic status into account, other factors such as data on noise measurements, and control groups were not well documented. The reported animal studies were all based on rodents (mice and rats) data from which cannot be easily extrapolated to human fetal data. Other factors such as overcrowding and vibration were not considered in the analyses. The author concludes that female workers should avoid prenatal chronic noise exposure greater than 90dB(A).

Henriksen (1994) examined the relation between psychosocial job strain, preterm delivery and low birthweight for gestational age. 3503 subjects with participation based on working at least 30 hours per week in the first trimester, were asked to respond to two questionnaires. The first questionnaire was completed around the 16th week of gestation and the latter around the 30th week. In addition to collecting data concerning medical, obstetric and socioeconomic history, psychosocial (psychological distress, life events and social support) and work conditions data were also collected. After adjustments for confounders, results showed that women with relaxed/less demanding jobs had the lowest risk of small-for-gestational-age (SGA) and preterm delivery. There was a slight, but non-significant, increase in risk of preterm delivery among women with high-strain jobs (low control and high demands). A higher risk however, was found in women who still worked in high-strain and passive jobs in the 30th week of pregnancy. The author suggests that this could indicate that time of exposure during pregnancy or cumulative exposure are important factors. In general, all risks were increased in women with low job control. The risks were higher for preterm than for SGA deliveries, none of the findings however were statistically significant. Noise data, in terms of personal exposure, is poor, therefore a specific impact on pregnancy outcome due to noise effects could not be based on this study alone.
Meyer (1989) reviewed a number of research studies investigating the effects of noise on reproductive outcomes. Of the 13 papers, the first seven detailed findings of animal studies. Based predominantly on rodents, there are obvious interspecies differences and presentation of the data made it difficult to establish pattern of exposure and potential for confounders. The six human based studies, all bar one were based on the effects of aircraft noise on communities. Although slight effects were cited such as teratogenic outcomes, low birth weight and gestation length, the results could not be quoted with confidence due to methodological inadequacies. The author concludes by stating that the findings must be interpreted with caution.

Kurppa et al (1989) tested the hypothesis that exposure to noise during pregnancy is teratogenic. Of the 783 mothers who reported noise exposure in the first trimester, 370 had babies with deformities (cases) and 413 were referents. The study population being identical to that employed by Nurminen and Kurppa (1989), identified the small study numbers exposed to high noise levels, eg 7% of total population worked in environments at $>80\text{dB}(A)$ whilst very small sample sizes were classified into the higher exposure categories ($3\% = 85\text{dB}(A)$ and $0.7\% = 90\text{dB}(A)$). Teratogenic outcome was defined by orificial cleft or structural defect of the central nervous system, skeleton or heart and great vessels. Study data was collected in a special interview soon after delivery. Results of the study showed no relation between teratogenic outcome and noise exposure level. This may however have been to some extent due to the small portion of mothers exposed to noise.

Hepper and Shahidullah (1994) presented a critical review of literature specifically aimed at assessing the impact of noise on the foetus. The authors of this review would therefore suggest any interested readers refer to this publication for a more detailed examination of the findings. The findings of two specific areas, namely fetal hearing loss and pregnancy outcome, however relate directly to the aims of this review.

The authors confirm that little is known about the function of the auditory system in utero, but that it is inappropriate to make comparisons with the function of the system after birth. Over the course of pregnancy the abdominal environment in which sound travels to reach the ear also changes. These two factors interact to affect external sounds reaching the inner ear, and therefore this dynamic component must also be considered. In general the authors feel that existing studies in humans whilst suggestive of hearing loss resulting from prenatal noise exposure, cannot as yet be regarded as conclusive and feel that further studies are required.

For the foetus to respond to sound it requires both a functioning motor (response) system and a neural link between the sensory and motor system in order for the response to be emitted. It is therefore possible that the auditory system is able to sense stimulation before the motor system is able to respond. It is thought that the foetus responds to external auditory stimuli at 20 weeks gestation and possibly even earlier. Shahidullah (1993) found the foetus to respond to frequencies of $500\text{Hz}$ and $250\text{Hz}$ at around 24 weeks gestation, and to frequencies of $1000\text{Hz}$ and $3000\text{Hz}$ at 29-31 weeks of gestation. In late gestation sound of increasing intensity has also been shown to elicit a greater reaction, in terms of foetal heart rate or movement. Certainly in the last trimester it is likely that this response is mediated by the auditory system, as Hepper (1991) showed that newborns respond preferentially to auditory stimuli that have previously only been presented in utero.

There is evidence in newborn and adult animals that identical noise exposures in newborn and adult animals result in a much greater deficit in hearing in the newborn animal (Pujol and Bock, 1986). Animal studies suggest that noise exposure may influence both auditory thresholds and the developing structure of the inner ear. However comparisons between studies show equivocal results and no definite conclusions can be drawn from animal evidence. The authors again discuss
the likely existence of a critical period for hearing damage. This period corresponds with the time that the cochlea first exhibits evidence of adult-like functioning. This corresponds to the time in humans from six months gestation to the newborn period. It is likely that the most intense sounds experienced by the foetus will be those of low frequency due to the attenuation characteristics of the human abdomen.

Examination of the newborn also reveals, that compared to adult hearing range (20-20,000Hz), newborn hearing is concentrated at the lower end of the range, possibly <1000Hz. It is also likely that a broad band noise will stimulate all the developed areas of the cochlea. The paper by Lalande et al (1986) also suggests that for noise exposures having a large low frequency component, hearing loss increases with intensity of noise exposure. It is also likely that in young children who have yet to acquire language processing abilities, a small deficit in hearing threshold will produce a much larger effect on language skills.

The authors conclude that for a broad band sound low frequencies (<250 Hz) pass relatively unattenuated into the abdomen, whereas higher frequencies are better attenuated. These findings are based on studies taken at the end of pregnancy, and therefore a degree of caution is required when interpreting these findings. Better prospective studies including actual measurements of noise at various times during pregnancy are also required.

With regard to pregnancy outcome, the majority of papers are based on either aircraft community studies or those relating to occupational exposure. With both types of studies confounding factors are not adequately controlled for producing conflicting results. The authors summarise by stating that although noise does not appear to be a teratogen, there is some evidence that noise exposure may influence prematurity and low birth weight. The methodological draw backs and conflicting results however render such a link as tentative. The authors conclude that any effects of noise on reproductive outcome may be mediated by stress induced in the mother rather than the effect of noise itself. As stress is known to exert an adverse effect on pregnancy, it is important to reduce the stress experienced by the mother in response to noise exposure rather than the absolute levels of noise experienced. Again the need for further studies was indicated.

Lalande et al (1986) undertook a cross-sectional study of children in Quebec, whose mothers had been exposed to industrial noise during pregnancy. The study was undertaken to determine whether the Occupational Health and Safety Administration permissible limit of 90dB(A)-8h, or equivalent noise exposure for pregnant women, was safe as far as the development of foetal hearing was concerned. The children were selected by the following criteria: a negative history of diseases associated with hearing loss; no middle ear problems, or recent noise exposure at the time of the hearing test; a mother who had worked outside the home for a minimum of one month during pregnancy. A total of 131 children were examined (63 boys, 68 girls) with uniform age distribution between four and seven years of age.

Industrial sectors were selected on the basis of noise exposure from 65-95dB(A), and who had women employed during pregnancy with children in the age range considered. Selected mothers represented 80% of the eligible candidates in the target population and were representative of a range of industry. Noise level measurements were taken at 75% of the participating industries. Records of recent noise assessments were available for the other 25%. These were combined with information from employees and union representatives on the noise levels prevailing at the time of the pregnancy. For each job held during pregnancy the daily noise dose was computed in terms of $L_{Aeq-8h}$ or $L_{eq-8h}$. Noise doses were then calculated for each week, trimester and 9-month pregnancy. Any day, or period of time, not worked during pregnancy was taken into account in the calculations. A validated occupational and health history questionnaire was used to assess work and other exposures during pregnancy including: socioeconomic status, details of pregnancy and the post-natal period, health status of the child and any noisy recreational activities.
The hearing tests were performed in a sound-proof room in compliance with American National Standards, and using a method appropriate for the age group. The individuals conducting the tests did not know the exposure level of the mother. Significant hearing loss was defined as: >10dB from 1-4kHz; >15dB at 0.5 and 6kHz; 20dB at 8kHz. In order to ascertain that the children were otherwise comparable in terms of risk factors for hearing loss, clusters of relevant variables were considered using one-way analysis of variance and chi-squared tests. The impact of low-frequency noise in the total noise dose was evaluated using a two way analysis of variance. The use of multiple regression techniques for adjustment of confounders would have been a more appropriate method for this study design.

There was a three-fold increase in the risk of having high frequency hearing loss in children whose mothers were exposed to noise in the range between 85 and 95dB, although due to limited data this did not reach statistical significance. There was however a significant increase in the risk of hearing loss at a frequency of 4kHz, when these exposures involved a strong component of low frequency noise. Although the population size limits the power of the study, there is reasonable consideration of confounding factors, and the results suggest that noise exposures over 85dBA, which include a significant low frequency component, have implications for the auditory system of the foetus. It is not possible on the basis of this data to establish a safe noise dose for pregnant women. Although this paper was published prior to 1988, it was not covered in earlier reviews, and provides useful data which is often referenced by other researchers in this field.

Pikus (1991) again discusses the concept of a critical period of heightened susceptibility to noise during the development of the inner ear in utero. This period varies widely dependent on the species considered, and therefore evidence from animal studies cannot be easily extrapolated to the human foetus. However it is hypothesised that the absence of noise-protective mechanisms within the cochlea during the last trimester of pregnancy as part of the normal development process may account for an increased susceptibility to noise at this ‘critical period’. This would suggest that infants born prematurely in the early part of the third trimester are more susceptible as they no longer have the additional protection of intrauterine attenuation. Further research is needed concerning the existence and nature of a possible human critical period for susceptibility to noise.

Campo et al (1989) review the effects of noise during pregnancy on foetal audition, and also describe the last three months of pregnancy as a critical period during which the cochlea seems particularly susceptible to noise. The authors suggest that prolonged exposure to noise levels less than 85dBA may result in foetal hearing loss. They suggest that abdominal and uterine structures can attenuate noise for the foetus up to 20 to 30dB for frequencies above 600Hz, but that frequencies below 500Hz are far less attenuated and therefore more harmful to the foetal cochlea. It is also concluded that the A weighting is not well adapted to estimate the harmfulness of prenatal noise exposure. Again it is reiterated that experimental and epidemiological data is sparse, and therefore it is at present not possible to accurately confirm or refute these findings, but urge erring on the side of caution when developing legislation and exposure standards in this area.

8.5 IMPULSE NOISE

Dodd et al (1990) reported the results of a study at the extreme range of non-auditory effects, that of damage to other organs by sound pressure waves from explosive charges. These are apparently distinct from the actual effects of the explosion itself and are relevant to military personnel and possibly civilians exposed to repeated explosions (eg during the manufacture and testing of explosives). The use of hearing protection means that individuals may remain exposed to potentially damaging pressure waves which can produce lesions in the upper respiratory tract, the
lungs or the gastrointestinal tract. Limits are proposed, based on studies on sheep, suggesting that as the sheep upper respiratory tract is apparently more susceptible to damage, a limit based upon trivial damage to the sheep should provide a conservative protection limit.

Brambilla (1991) reported briefly on the results of work under the 4th CEC joint research project on human responses to impulse noise. The paper related to comparisons between subjective and objective criteria for ‘impulse’ classification, annoyance and sound intensity. Reference is made to 64 different noise samples although only three (hammering wood, gun fire and road traffic) are named. Ratings of annoyance were shown to increase with perceived impulsivity and sound intensity although the effect of impulsivity diminished with increasing sound intensity effectively to zero at 70 dB (L_{Aeq}).

The work relates mainly to annoyance in relation to environmental noise rather than occupational exposure. Although the same principles may apply, other studies have shown that the perceived relevance or need for the noise modifies any subjective effect and therefore, where industrial noise is seen as ‘necessary’ by those working in the industry, the subjective impact of the noise will be diminished.

Rossi (1991) reported the results of a study carried out as part of a joint project on impulse noise with ISVR Southampton. Twenty four male and twenty four female students were divided into four groups of noise-sensitivity and non-noise sensitivity. They were exposed on different occasions to taped traffic noise or synthetic gunfire noise at 55 or 75 db L_{Aeq} for 15 minutes or 120 minutes. No significant differences were recorded between any of the four groups for any of the physiological responses recorded. These were brainstem evoked auditory potentials, blood pressure (described as maximum and minimum) and heart rate. The heart rate results did however show a progressive decrease throughout the experiment, probably due to the fact that the exposures were conducted lying down. As would be expected, subjective annoyance reports were greater amongst the noise sensitive groups, particularly the female group as were anxiety levels although no details are provided of these findings. The authors suggest that the failure to demonstrate any significant results were because the noise levels were not sufficiently high in relation to habitual exposure in Turin and that the gunshot impulses were too frequent (no detail is given as to their regularity). Consequently, the results of this study should be treated with some caution.

The relationship between the impulse nature of noise and its annoyance was studied by Flindell et al (1991). The main emphasis of the work was on environmental noise in a domestic context although the main findings are undoubtedly transferable to the occupational setting. Pilot experiments studying annoyance and subjective impulsivity showed that, although these did appear to be related, other factors (e.g. signal to background noise ratio) raised doubts as to whether this was a real effect and not an experimental artefact. The results also showed that annoyance was significantly related to the duration of the noise and not its shape (positively or negatively skewed) whereas, for impulsivity, the situation was reversed.

A subsequent ‘main’ study examined annoyance and impulsivity in more detail, this time using ‘real’ sounds rather than simulated noises. The results showed that there appeared to be no simple causal relationship between annoyance and subjective impulsivity. It would appear that the degree of annoyance likely to be caused by noise cannot be predicted solely from physical measurements and that the psychological content must also be considered, a finding reported extensively elsewhere.

Parrot et al (1992) reported the results of a laboratory-based experiment in which they studied the effects of various noises on cardiac parameters and the influence on those effects of gender,
age and level of anxiety (Cattell). Four different noises were used, synthetic gunfire noise, pile-driver noise, road traffic noise and intermittent pink noise. Each were presented to give an equivalent continuous sound level ($L_{eq}$) of 75dB, over a 15 minute period. Male and female subjects were subdivided into 'older' and 'younger' groups and, for a further set of younger subjects, into 'anxious' and 'anxiety-free' groups. Each of the members of the eight sub-groups were exposed to each of the four noises in a random sequence designed to balance out any order effects. Measures were obtained of a variety of physiological parameters although only those relating to heart rate and cardiac reactivity were reported in this particular paper. Subjective ratings of impulsivity, annoyance and difficulties in coping with the noise were also obtained but not reported. There were no significant differences in pre-test heart rates between either the young and old groups or the anxious/not anxious groups, or between males and females in either pairs of groups. Across all eight sub-groups, noise evoked an increase in mean heart rate which was largest for the traffic and pile-driver noises. Males demonstrated larger responses than females and the older females were least reactive. However, no statistical analyses are reported for these data which are only presented graphically. All subsequent results and statistical analyses are reported in terms of computed 'index of cardiac reactivity' scores (CRI) described as 'a deviation from the linear slow trend of the cardiac parameter'. The mathematical derivation of this score is not given or referenced. It appears to be derived in some way from the pre- and post-exposure mean values and therefore approximate to a change in score derived from the varying pre- to post-baseline. Most comparisons are made within two sets of sub-groups, one addressing gender and age, the other anxiety and gender. For the first set, gender differences are statistically significant but age differences are not. Type of noise however has a significant effect on CRI with noises ranked in the order: traffic (most effect), pile-driving, gunshot and pink noise (least effect). In the second set, anxiety was not a significant source of variation but gender and type of noise were. In this case, pile-driver noise and traffic noise were reversed in the sequence.

It is interesting to note firstly that the mean physiological responses recorded were very small, with almost all mean increases being less than 3 beats min$^{-1}$, even amongst anxious subjects and that neither the pre-experimental means nor the experimentally-induced changes differentiated between anxious and non-anxious subjects. The results do appear to indicate that the physiological consequences of noise exposure, although statistically significant, are of little practical significance.

### 8.6 Noise and Performance

Hétu et al (1990) undertook a review of the literature pertaining to problems of noise in school settings. As a review document, the methodological quality of the cited studies cannot be assessed, rather the intention is to state the general findings.

The first aspect the author considers is that of interference with speech intelligibility in classrooms. Quoting from official standard documents on speech intelligibility, the author indicates that, for optional speech intelligibility, the average background noise level should not exceed 30dB(A) with a sound to noise ratio of +20dB(A) and reverbation time (RT) limited to 0.4 secs. One of the studies cited indicated that in all the classrooms visited, the background levels well exceeded this limit. Studies based on attention and learning trends in noise, indicate that when background noise levels in a room rise to levels higher than those favourable to speech, there is a statically significant drop in children's performance. In contrast, when reductions in background noise levels are achieved, significant improvements in attention and participatory behaviour have been observed. A number of studies have considered the influence of air traffic noise on the academic performance of school children. Due to the nature of these studies, there were numerous confounding factors to consider. However the author states that after controlling for these, statistically significant correlations between exposure to noise and indices of academic
performance (namely slowness in learning to read, less sustained attention and more frequent ‘learned helplessness’ behaviour in relation to complex tasks) were identified. It is noted that in all the studies indicating a correlation between low academic performance and exposure to noise, the upper sound levels exceed the threshold at which interference with speech begins.

In terms of general health and wellbeing, studies indicate that pupils exposed to aircraft traffic noise reported significantly more annoyance problems due to noise, as well as problems in understanding the teacher.

One study which was reported in full was based on assessing the importance of the problem of noise in Québec school settings. Largely descriptive and based on questionnaire data, supplementary information was obtained through direct observation and acoustic measurements. Respondents in all cases were members of teachers unions. Results found were that 61% of respondents reported sound levels that were ‘uncomfortable’ or detrimental to their work. In addition, these were reported to be either a frequent or a permanent feature of their workplace. Of 257 teachers, 72% reported that noise at work was an ‘average’, ‘important’ or ‘very important’ source of problems for them. The following problems were reported as significantly severe: (1) difficulties in communicating; (2) voice problems; (3) less patience; (4) less availability; (5) less effectiveness than they would like, and (6) stress malaises. These symptoms however are indicative of teaching in general which has recently been cited as one of the highest stress-related occupational sections. The schools chosen in this survey, with the exception of one, served lower socio-economic group populations which may influence teachers’ perceptions of workplace stressors.

In general however this review provides a good summary document with which to support the findings from other papers. Although reported noise levels are generally low in relation to the industrial setting, these findings could be translated to effects in office environments such as concentration and attention.

Kjellberg and Sköldström (1991) reported the results of a series of experiments in which subjects performed a variety of different tasks. The main focus was on the annoyance effects of noise on the different tasks.

In the first experiment, three tasks (proof-reading; finger dexterity and colour-word association) were performed against a background of 46 or 69dB(A) broad band noise. Noise had only a minimal effect on task performance, adversely affecting one aspect of the proof reading. However, this effect disappeared when the test was repeated. Higher noise exposure significantly increased subjective annoyance and perceived effort. Effort did not vary between tasks and, although there was a tendency towards higher annoyance in the colour-word task than the others, this was not significant. It had been expected that annoyance would have been highest in the proof-reading task as this utilises verbal cues which have been suggested as being susceptible to noise. However, ratings of annoyance were actually lowest with this task (although not significant). One interesting feature however is that subjects thought that their performance was significantly more affected by noise in the proof-reading task rather than the other two tasks. A second experiment increased noise levels and introduced a machine-paced version of the proof-reading task (omitting dexterity). The intensity of noise in the high noise condition was raised to 80dB(A). In this second experiment, noise had a significant and more enduring effect on performance in the proof-reading task but otherwise had no significant effects on performance. Noise had a significant effect however on annoyance and effort. The significant effect on annoyance was not task-dependent. However, effort was significantly higher during proof-reading (machine or self-paced) than during the colour-word test. Once again, perceived performance was significantly lower in proof-reading.
Finally, a further manipulation of experimental conditions was conducted before a third set of experiments. A speech-based noise was introduced (65dB(A)) with the high level of broad band noise returned to the same level (and adjusted to give a similar overall frequency composition to speech). A simple reaction time task was introduced and a more difficult verbal reasoning task (grammatical reasoning). These changes were introduced to increase the range of difficulty of the tasks and to test the suggestion that speech is more disturbing or distracting than noise. No significant effects of noise on performance were recorded. However, low noise was significantly less annoying than high noise or speech but noise had no significant effect on rated effort. There was a significant noise x task interaction indicating that different types of noise had different effects on different types of task.

Few of the experimental presentations used in this series of studies showed any significant effect of noise on performance, the main effects being when a louder noise was used (although, at 80dB(A), even this is not particularly loud). This may, in part be due to the use of presented noise in the low noise condition rather than a background noise as, despite its low intensity, this may have had some effect. Psychological effects (perceived annoyance, effort and performance) were adversely affected although even these did not always demonstrate the anticipated differential effects relating to type of noise and type of task. Thus, although some of the findings support the suggestion of the importance of the type of noise and of the type of task the results do not provide the clear substantiation of theories concerning these factors.

Rentzsch (1990) presented the results of a series of studies mixing industrial tasks with laboratory-based simulations of essentially the same tasks. The experimental work is presented against the background of a general mathematical equation describing the reaction to noise exposure. Unfortunately, the model is so general as to be of little practical benefit, particularly as the results are not then used to develop the model. Field studies involved various tasks representing stages in the assembly and testing of electronic switching circuits. Details are given of sound pressure levels utilised in the tests but no indication is provided as to how noise levels were manipulated in the field studies. Three tasks were utilised: assembly, process monitoring and process supervising. In a fourth experiment, the effects of repeated exposure was examined, performing a printed circuit bond insertion on each of four consecutive days. The effects of exposure to various noise levels were monitored through measures of performance, physiological responses and subjective ratings. Interestingly, all results (from tests involving between six and nine subjects per group) were analysed using non parametric statistics although no reasons for this are given. The number of circuits assembled was higher at 70dB(A) than at 65 or 75dB(A). However, the percentage of failures increased significantly with noise level. The failure rate also increased during the period of study although no statistical analysis was reported. The results for subjective rating of various indices of well-being are unclear as they appear to be presented twice (with different scores on each occasion). The legends to the graphical presentations indicate statistical significance, with the text referring to differences between 65 and 75dB(A). No physiological measures were reported for this study. In the laboratory simulation of the same task, sound pressure levels of 60, 70 and 80dB(A) were used. On this occasion, the number of circuits assembled deteriorated progressively with increasing noise level but error rate was essentially unaffected. A significant difference was reported in the level of hand tremor at 80dB(A) vs a control although no details of the control group were given. This was the only physiological parameter recorded for this study.

In the second (process monitoring) task, significantly impaired performance was reported at a sound pressure level of 90dB(A) compared to those at 50dB(A) and 70 dB(A). However, apparently only one of four performance measures yielded any significant effects. Hand tremor differed significantly between each level of exposure (increasing with increasing noise level) and heart rate (reported as ‘duration of heart period’) increased with increasing noise exposure although these changes were apparently minor and failed to achieve statistical significance. A
single (unspecified) measure of subjective evaluation of 'the noise situation' also differed significantly between all three noise levels. The third experiment (process supervising) utilised sound pressure levels of 65 and 75 dB(A). Two tasks, each apparently yielding three performance measures were performed. However, the results are unclear and no statistical analyses are reported. On this occasion, heart rate dropped during the tests, although the reduction was lowest for the most demanding task at the highest noise level. Again, no statistical analyses are reported. Finally, although a full range of subjective ratings was apparently obtained, results for only one parameter are reported which show an increase with the higher noise level. This is described in the text as significant although no probability level is reported. No results for the physiological parameters recorded (heart rate and skin resistance) were reported.

Reporting of the final experiment is incomplete, seemingly due to a publication error. No performance effects were apparent for this element of the study. Physiological changes show an increase in heart rate for work at 90 dB(A) compared to 60 dB(A) which appears to increase with successive days of the test, attaining statistical significance particularly on the last day. However, as the test period was only 50 minutes per day, extrapolation of this to occupational settings should be treated with caution. Certainly there does not appear to be any indication of habituation of the response. Changes in skin resistance are also reported and these also give no indication of habituation either across an experimental session or between the four sessions. However, these do not achieve statistical significance. No reference is made to collection of psychological indicators as part of this experiment.

In summary, although there are shortcomings in aspects of the presentation of the results they do demonstrate some important issues. The first of these is the complexity of any performance effects demonstrated by the fact that some performance measures showed an effect due to noise and other did not. Associated with this was the fact that it was possible to show performance effects of noise in real field situations, although the measures were only obtained over a limited duration. A third factor was that, in some experiments, effects were demonstrated at noise levels well below 85-90 dB(A) and therefore at levels which may well be encountered in industrial workplaces.

Bhattacharya et al (1991) reported the results of a study of the effects of heat and noise on physiological variables and a battery of various psychomotor tasks. Two levels of white noise (70 dB(A): quiet and 100dB(A): noisy) were used, based upon measures at textile factories. Similarly, two levels of environmental temperature were used: 28°C (deemed comfortable by Indian standards) and 35°C (hot). In both cases, air velocity was 0.25cm sec⁻¹ and relative humidity 50%. Psychomotor tasks covered tweezer dexterity, memory and search (letter cancellation) two hand co-ordination (tracing) and reaction time. All bar the memory task had two levels of difficulty, this task having three. Subjects each worked in one hot and one comfortable condition and were with or without noise on both occasions. Thus temperature effects were primarily within subjects whilst noise effects were between subject. Noise caused a significant deterioration in performance in both levels of difficulty of the tweezer task and both levels of the reaction time task. Reaction time responses also showed a significant interaction with heat at the highest level of difficulty. Noise had no significant main effect on memory and search although it had a significant interaction with heat at the intermediate level of difficulty. Finally two hand co-ordination was significantly worse in noise at the lower level of difficulty but not at the higher but, at the higher level only, there was a significant noise and heat interaction.

The consistent significant effects are fairly straightforward, but the latter effect at the lower level of difficulty only is less easily explained. The authors suggest that noise acted as a dearousing stressor causing performance to deteriorate. However with the more difficult form of the task, noise and heat combine to increase arousal. This explanation does not however accord with the earlier observations that noise significantly increases heart rate thereby indicating an increase in
physiological arousal. Alternative explanations could relate to changes in attitude to the harder task eg. a narrowing of attention. Whatever the explanation it emphasises the unpredictability of some noise effects.

The heart rate change referred to above was the only significant main effect of noise amongst the physiological variables of heart rate, blood pressure, or body temperature. As well as the significant effect of heat on heart rate and body temperature there were significant interaction effects of noise and heat on systolic (but not diastolic) blood pressure and body temperature. However, the detail of the systolic blood pressure response is contradicted in the text which describes the combined effect of heat and noise as either depressing blood pressure or increasing blood pressure. In conclusion, the results show that noise can have some (normally deleterious) effects on various aspects of psychomotor performance as well as apparently increasing physiological arousal.

Smith (1989) produced an extensive review of the effects of noise on human performance. Brief reference is made to the direct (auditory) effects of noise where auditory information is masked. The main emphasis of the review is on the non-auditory effects of moderate noise, having stated that many of the earlier studies had used loud noise. The effects are described as highly dependent upon the nature of the task. It is suggested that continuous loud noise over 95dB impairs monitoring performance provided that the period of exposure (length of watch) is long; the signals are hard to see; and the situation does not encourage caution. The author also suggests that the performance effects are characterised by normal performance interspersed with momentary lapses. To support this the author cites studies which have shown an increase in errors (eg. missed signals) but no effect on average response rate. Other authors have explained this in terms of a change of working strategy towards a less cautious approach.

The author suggests that one reason for the apparent failure of many earlier studies to demonstrate effects of noise at lower intensities could be the general use of white noise. The review then examines various characteristics of sound, starting with irrelevant speech. No details of the experimental evidence is cited but it is stated that the effect of irrelevant speech is independent of intensity across the range 55-95dB(A) and also of meaning (foreign languages, nonsense material and backward speech being equally effective). It is also suggested that the effect of speech is mediated via memory rather than perception. The effect of speech also apparently extends to music where vocal music is more disruptive than instrumental music. Finally, Smith comments on the practical implications of these findings, particularly their independence of intensity.

The review then examines the differential effects of varying other characteristics of the noise, including both physical characteristics (intermittency, duration and frequency) and psychological elements (predictability of perceived control). Intermittent noise has been shown to be potentially more disturbing that continuous noise although the effects are dependant to some extent on the temporal relationship between the noise and the task components. For example, noise disrupts mental arithmetic performance when it coincides with the data acquisition but not the processing. Duration of noise is also regarded as important and the review cites a study indicating noise exposure for at least 30 minutes. However, many other papers have described effects of noise with much shorter exposures suggesting that the duration effect may be task specific. Finally, high frequency noise has been shown in early studies to be more disruptive than low frequencies although in the study cited, only at the highest intensity (100dB). Turning to the psychological elements it was suggested (although only a few studies were cited to support the contention) that both predictability and perceived control reduced the adverse effects on task performance of noise exposure.

The review next examines the question of long-term noise exposure, drawing upon a limited
amount of information from field rather than laboratory studies. Work is cited which indicates a positive relationship between the incidence of accidents and noise exposure although it is acknowledged that the risks of the jobs performed may have varied. To counter this, reference is made to a study showing a reduction of accidents following the introduction of hearing protection, allegedly suggesting an intensity-related phenomenon. However, wearing hearing defenders is often regarded as increasing social isolation and it is plausible that a degree of narrowing of attention occurs as a consequence of this. Additional work is briefly cited relating neighbourhood noise exposure to everyday errors, particularly amongst those who considered themselves to be noise-sensitive, and of effects on children.

The next main section describes studies which have examined individual differences in noise susceptibility. As well as age (conflicting results) and gender (conflicting results) reference is made to extroversion-introversion and neuroticism and anxiety. Extroversion/introversion studies have shown a variable pattern of results whereas the studies of neuroticism and anxiety appear to show a detrimental effect on both traits although this may be a function of relatively few studies having been performed. It is interesting to note that the author discounts the concept of noise sensitivity; a construct studied in a number of papers reviewed elsewhere in this report.

Temporal factors in exposure are next examined, specifically time-of-day and night work. The author states that, although some theoretical approaches do predict the existence of a time-of-day effect a previously published review ‘found little evidence’ to support this view. Although some evidence for a time-of-day and gender interaction was presented, the author cited other research which failed to replicate this effect (although the noise used was of a lower intensity) and the weak indications of an effect were considered to be unreliable. Similar conclusions were reached with night work where the effects of noise and night work were considered to be independent.

The bulk of the remainder of the review addresses the question of theoretical modelling of explanations for the perceived effects of noise which are considered to be beyond the remit of this review.

Duchon and Hudock (1989) reported the results of a review of the effects of environmental stressors on vigilance performance. The review was interesting because it was very strongly orientated towards the practical implications of research, being part of an exercise by the US Bureau of Mines aimed at reducing mining accidents. Although the emphasis of the title was on vigilance, the work reported was not necessarily restricted to this type of activity. The reviewers examined four environmental stressors: heat, noise, vibration and light. They concluded that there was little research evidence relating to the latter two (although both can obviously have direct effects on task performance including vigilance tasks). For noise and heat it was concluded that both could affect performance but that the magnitude and direction of any effect was highly dependent on the specific nature of the task, particularly for noise, where the physical and subjective characteristics of the noise were also important. Two studies were cited which reported a positive relationship between noise and accidents although the citations did not refer to the possible variations in hazard associated with variations in noise level. The authors identify change in response strategy as the most consistent reason for a change in performance, with moves towards a more risky strategy in noise. This can have conflicting results in, for example, decreasing response time but increasing false responses.

Belosevic et al (1992) reported the effects of noise (30dB(A), quiet; 55dB(A) moderate and 75dB(A) high) on a series of cognitive tasks. The moderate and high conditions used recorded motorway noise as being familiar to all subjects. Forty five subjects were selected, equally distributed between three groups designated as tolerant, moderate or sensitive to noise according to a subjective noise sensitivity test. They were also reportedly equally distributed according to
gender although this cannot have quite been entirely successful. In addition to the noise sensitivity scale, subjects completed a battery of questionnaires comprising an attitudinal scale relating to environmental noise; a scale on the annoyance of the test noise; the Eysenck Personality Inventory (EPI); attitudes to the tasks; and a self-rating scale on ability in mental calculation. All subjects performed four tasks examining short-term memory; search and memory; hidden figures detection; and mental arithmetic.

In the short-term memory tasks, noise had no significant effect on the number of missed letters, even in the noise-sensitive group, although this group was significantly affected by noise exposure in word recall. However, this should be interpreted with caution as, on all bar the six comparisons (word recall in the quiet) the sensitive group were significantly worse than one or both of the other groups. The search and memory, and hidden figures task results did not differentiate between any of the three groups under any of the noise conditions. In the mental arithmetic task, only the strictest criterion (totally correct to two decimal places) differentiated between groups, where the sensitive group showed significantly worse performance than the noise tolerant group at moderate noise levels. At the 0.05 significance level, one significant finding across multiple comparisons could well have been a chance occurrence. Generally speaking therefore, most of the test results seemed remarkably unaffected by noise, even in supposedly noise sensitive subjects. In an attempt to explain this, the authors presented the results from the battery of questionnaires. The main factor appeared to be the attitude towards the task, where what were regarded by the authors as the more difficult tasks (hidden figures and mental arithmetic) showed a positive correlation with interest in the task (but no differential effect attributable to noise). Other than this, although an array of over 100 correlation coefficients did show some significant results, few of these showed any consistent effect of noise. For example, annoyance with the test noise showed significant correlations with task performance in a number of instances but the results were seldom consistent with variations in noise level. For example, noise annoyance at the moderate (55dB(A)) noise level showed a highly significant correlation with the missed letters score on the short term memory task and correct mental arithmetic scores (p < .001) but a non-significant correlation at 75dB(A) on both tests. Similarly, extroversion showed a significant correlation with short term memory (missed words) in the quiet (p < .05) a highly significant result in moderate noise (p < .001) and no significance in high noise. Although the authors do discuss possible explanations for the general failure to identify effects the overall outcome can probably be summarised as a clear indication of the complexity and task specificity of noise effects.

Becker et al (1995) reported the effects of jet engine noise and performance feedback on performance and perceived workload in a monitoring task. Three noise conditions were used: quiet (not specified), low intensity (70dB(A)_max) and high intensity (95dB(A)_max) with intermittent noise episodes simulating a plane passing the listeners. Noise produced the expected effect on perceptual sensitivity but not on vigilance decrement (the derivation of these two measures is not clearly explained). However, the effect of noise was only significant with high intensity noise and was complicated by the presence of an interaction with feedback. When feedback was provided, noise had a negative effect. However, when no feedback was available, the already low performance was not lowered further. It was suggested that this was an artefact of the experiment representing a 'floor-effect' rather than a genuine interaction. As would be expected noise also increased perceived workload although, as with performance, this was only significant with high intensity noise. A breakdown of the mental workload parameter indicated that the perceived load was largely derived from the frustration and mental workload dimensions although these were not separately influenced by the noise.

Hartley et al (1989) reviewed the effects of various stressors on skilled performance. The section on noise and skill is almost entirely derived from laboratory studies of which no practical detail
is included. For example, nothing is said of the nature and intensity of noise apart from an opening comment that most (earlier) studies have used 95-100dB(A) white noise but recent memory studies have tended to use 85dBA. ‘Control’ has usually been 70dB(A) white noise. No detail is given to allow validity of findings to be evaluated.

Significant performance-related statements are:-

i) noise accelerates the deterioration in detection rate with long-term vigilance e.g. watchkeeping.

ii) noise modifies decision criteria, increasing false alarms in a signal detection analysis.

iii) noise increases arousal and can therefore improve performance where underload is a problem (e.g. monotonous vigilance tasks)

iv) noise ‘narrows attention’ and may therefore improve vigilance and tracking although secondary task performance may deteriorate.

v) noise can increase errors of commission (wrong signal response) and omission (missed response)

vi) response time may improve, probably due to narrowing of attention.

vii) noise improves memory of order of words but increases confusion with similar sounding words. More recent items are recalled better but earlier items are more poorly recalled.

viii) noise affects attention strategies, e.g. spatial recall less good. As a result, information in noise should be written not pictured.

Moore and Von Gierke (1991) reported a wide-ranging review of noise and its possible effects on military personnel and their performance. It included direct hearing damage and interference with communication as well as possible non-auditory effects on task performance and physiological responses. No new work is reported. After briefly reviewing contradictory papers on physiological impact, some of which had apparent methodological deficiencies such as equating hearing loss with noise exposure, the authors suggest that an important mediating factor may be the attitudes to the noise (i.e. the degree of perceived annoyance) rather than the noise itself and they cite two studies to support this argument.

The conclusions regarding effects on task performance are derived from two sources: Broadbent (1979 and 1983) and Hockey (1986). It is concluded that noise is most likely to have a negative effect on performance when signals are difficult to detect and risky decision behaviour is encouraged (possibly an example of attention narrowing). It is also suggested that multiple signal sources are more likely to result in performance decrement in noise (attention narrowing) and that, under noisy conditions, speed of response may be increased at the expense of accuracy.

Davidson et al (1990) examined the effects of short bursts (totalling 207 secs in 23 mins) of very loud ‘red’ noise (100-108dB(A)) on a series of performance tasks (proof reading, encoding and a ‘frustration measure’). The tests showed the expected decrement in performance both during and after noise exposure. The main purpose of the study was to examine possible mechanisms for such effects by administering an opioid antagonist (naloxone). It was anticipated that if after-effects were attributable to the release of endogenous opioids during noise exposure then the use of naloxone would block this and counteract the post-exposure decrement. This did not occur,
thereby failing to support this proposed mechanism.

Loewen and Suedfeld (1992) report the result of a study which demonstrates the importance of the subjective content of the noise. Students performed a number of tasks in one of three conditions: no-noise; office noise; or offensive noise masked by white noise. The best performance was achieved in the latter condition despite the fact that, at 59-61dB(A), this condition was some 5dB(A) louder than the office noise. Performance was also better than that in the no-noise condition, possibly demonstrating the narrowing of attention previously reported. The duration of the experiment was not reported but appears to be approximately 20 minutes. As a result, the authors recommendation to use white noise in offices should be treated with some caution.

Dwivedi (1992) used a sample population of 160 male schoolboys in a study of the effects of noise on short and long-term recall of word pairs. Pairs were either formed from one of three semantic categories or three acoustic categories. The study also varied the task in that half the subjects took an immediate recall test followed a day later by a delayed recall test whilst the other half were given only the delayed recall test. In addition, only half the subjects were informed that they would be required to take a delayed recall test (investigating whether knowledge of test influenced learning strategy and subsequent performance). This complex experiment resulted in 16 groups of 10 subjects in a 2x2x4 factorial design. Two noise levels were used (65 and 85 dB(C) white noise).

The complexities of the results are too detailed to explain here. In summary however, the results showed a number of significant effects due to noise, together with interactions between noise and other factors. For example, the direction of these (significant) effects of noise on delayed recall performance depended upon whether or not an immediate recall test was taken; whether the pairing was semantic (meaning) or acoustic (sound); and whether learning for the delayed tested was intentional (pre-warning) or incidental (no pre-warning). The authors refer briefly to the theories relating performance in noise to the type of learning strategy adopted, citing earlier works as being supported by this. The paper does add to the pool of knowledge regarding the complexities of the effects of noise on performance but the schoolboy population studied may restrict the applicability to a more general working population.

Bhattacharya et al (1989) studied the combined effects of noise (70 or 100dB) and illumination (50-150 lux) on four standard laboratory tasks. These comprised a letter cancellation test together with tests of manual precision, coordination and dexterity. Level of illumination, but not noise, had a significant effect on coordination and dexterity. There were no main effects of noise or illumination level on precision although there was a significant interactive effect on accuracy and precision (p=.05) as well as a highly significant (p=.01) three-way interaction (including subject group).

Task accuracy and precision deteriorated in the highest illumination level, an effect which was enhanced by noise. This deterioration was attributed to the design of the equipment causing visual disturbance. Noise had a significant (p=.05) (beneficial) effect on speed and efficiency of letter cancellation, with increasing illumination significantly improving speed but not accuracy or efficiency. There was a highly significant (p=.01) interactive effect of noise and illumination on accuracy. The authors suggested that increases in illumination raised arousal levels whereas noise acted as a de-arouser. A better explanation may be over-arousal.

Albery (1989) reports the results of an experiment studying the effects of acceleration and noise on task performance. Pink Noise (40dB(A), 50dB(A) or 100dB(A)) increased stress (as measured by the Subjective Workload Assessment Technique) and improved secondary task performance.
(reaction time) but had no effect on primary task performance (tracking) or a battery of physiological measures including visual evoked responses, EOG, ECG, EMG, and mean blood pressure. However, trials only lasted for 24-60 seconds and always included a degree of accelerative loading ranging from 1.4G to 3.75G (at or near the relaxed, unprotected tolerance). This factor seriously diminished the general applicability of this study.

Britton and Delay (1989) reported the results of a laboratory study investigating the effects of noise on a light-cancelling task. They utilised white noise presented in three different patterns, continuous, 1Hz pulse rate and 10Hz pulse rate, at five different intensities (50, 60, 70, 80 and 90dB(A)). Performance in continuous and 1Hz cycle noise showed a shallow inverted U curve relationship with peaks at 70dB(A) (continuous) or 80dB(A) (1Hz). Performance fell with increasing intensity during 10Hz pulse exposure. The trial consisted of 20 signals (5 in each of 4 locations) and lasted between 200 and 480 seconds preceded by a 60 second 'habituation' to the noise. 15 male and 15 female undergraduates participated in a latin square design which saw each subject perform each of the intensities of one type of noise. Each type was therefore only tested by 5 males and 5 females. An ANOVA examined gender, type of noise and intensity of noise as factors as well as signal location. This revealed a significant (p < .001) effect due to intensity as well as intensity x type of noise and location x type of noise interactions.

The authors suggest that the effects due to noise intensity and type can be explained by arousal theory with 10Hz cycle noise already exceeding the optimum at the lowest intensity. The interaction with signal location is explained by the theory relating to narrowing of attention, with detection of the more peripheral signals deteriorating under the more intrusive 10Hz cycle noise.

Jubis (1990) reported the results of a study of which the main focus was the effects of alcohol although 85dB white noise was included as a second variable. The noise was presented in 12, randomly presented 2 second bursts during the one minute in which words were presented on a VDU screen. The study also examined the effects of the experimental treatments (noise and alcohol) on arousal, using the Activation-Deactivation Adjective Checklist (ADACL). Within each experimental session, three trials were conducted. The first two required the recall of the words presented to them on the screen. The last one involved an additional task for which they had received no prior warning, namely that of the position of the words on the VDU screen (termed incidentally learned). Noise made subjects significantly less calm and placid (as determined by the ADACL). However, it had no significant main effect on task performance (unlike alcohol), possibly because of a significant alcohol x noise x word order interaction. This element of the study is not well explained but appears to relate to whether or not the second presentation of the word list is made in the same sequence as the first (fixed order) or a different sequence (random order). In this part of the experiment, noise had relatively little effect on performance in Trial 2 with a fixed word order for those subjects given either the placebo or the low alcohol treatment, but produced a marked reduction in performance with the moderate alcohol treatment. However, with the random word order the effect was reversed with poorer performance in the quiet. Noise had no effect on performance in the incidental task, that of location recall. The authors explain the results in terms of arousal, with noise counteracting the alcohol induced impairment of performance when the work order is 'random' (re different from Trial 1 to Trial 2). However, this requires the acceptance that subjects do not concentrate so hard in the fixed word order task as an explanation for the effect not occurring in this trial, despite the fact that only 20 words are presented within one minute, which does not allow much time to recognise that the order is the same. It also is not supported by parallel effects with the ADACL measures of arousal.

Harazin et al (1990) reported the results of an experimental study in which they studied visual function during and after a one or two hour period of exposure to 'broad-band' noise of various
intensities. The authors measured visual acuity (far point) and accommodation (near point) by subjective report of clarity of visual field. Unfortunately, no no-noise condition was included. The results showed a progressive decrease in acuity and increase in accommodation resulting in a decrease in the width of the visual field. Expressed as a percentage of the starting value this amounted to a 4-6% decrease over one hour. The change appeared to be limiting in that there was little difference in effect between the higher noise levels and two hours exposure did not result in substantially greater decrement. Curiously however, the two hour exposure did not result in a levelling off after one hour. The effect gradually diminishes after the cessation of exposure, returning to basal levels after 40-60 minutes. Neither shift is linear with most of the effect occurring sooner rather than later. No physiological explanations are offered for this phenomenon although it may relate to changes in output of stress hormones (eg adrenaline) affecting pupillary mechanisms.

Linden (1991) reported the results of a series of laboratory studies set up to examine different aspects of experimental design relating to mental arithmetic tasks. Noise featured in two of these. The first showed that noise did not significantly impair task performance, or blood pressure or heart rate responses. Variable real-life noise did however significantly increase perceived stressfulness over a no-noise condition. Steady real-life noise or variable meaningless noise did not have a significant effect. In a second study, using a different mental arithmetic task, similar effects were obtained with no significant effect on task performance but increased perceived stressfulness (with real-life variable noise again most distressing). On this occasion however, noise did affect cardiovascular responses with significant increases in systolic pressure and heart rate. In this instance, the variable meaningless noise had the most effect. The authors suggest that the use of visually presented arithmetic, rather than the totally mental counting backwards tasks used previously, accounted for the different effects with those carrying out the latter task somehow able to ‘tune out’ the noise. The distraction with the visual task resulted in greater cardiovascular activation. It is interesting to note little systematic difference between the real-life and meaningless variable noises. However, care should be taken in interpreting this as although each of the noise components used were real noises, their assembly into a noise montage was far from realistic.

Bhatia et al (1991) report the results of a study which, as well as examining the effects of the intensity and variability of noise on mental performance, also took noise sensitivity into account. Fifty students designated as ‘low noise sensitivity’ and fifty with ‘high noise sensitivity’ (using a Hindi version of a published scale) were involved. They carried out a task described solely as a multiplication-subtraction task (no further details were provided). The results showed that those who were classified as noise sensitive performed best in no-noise (somewhat improbably described as 0dB) whereas those who were not noise sensitive performed best in the low intensity (40dB) noise, presumably because of attention narrowing. The intermittent corridor noise tended to have more effect than the steady factory noise although this was not always significant. The authors also recorded forearm skin resistance (GSR) which, curiously, they refer to as a measure of physiological energy expenditure. Skin resistance decreased (higher energy expenditure) in the expected fashion. As would be predicted, the low sensitivity group were much less affected with only the 110Db treatment producing significantly different changes. The high sensitivity group were significantly affected by the variable 40Db corridor noise as well as the two 110dB conditions.

Baker & Holding (1993) report the results of test involving a battery of different tasks with varying demands on short and long-term memory. Four different types of task were used (simple card sorting, complex card sorting, anagrams and random letter sequence generation) as well as five different noise conditions quiet 55dB(A); white noise 90dB(A); machine noise 90dB(A); speech 85dB(A); and reversed speech 85dB(A). The experimental design also allowed for the
examination of effects due to time of day and gender. In general terms, the results demonstrated the complexity of the issues involved, with different noises showing different influences on different tasks and with some results also affected by general and time of day effects or interactions. For example, in the anagram test, machine noise produced the worst score whilst normal, forward speech the best. In random letter sequence generation, the best performance occurred in white noise and machine noise, which did not differ significantly from one another. Quiet noise produced the worst performance.

The authors suggest that meaningfulness and intermittency, previously cited as the main predictors of noise effects are not entirely effective. They propose that the familiarity of the sound is also relevant. The results also indicate that the effect of these factors can be greater than that for the intensity of the noise, resulting in the result referred to above where the quiet condition produced the worst performance. The introduction of the time of day and gender as further influential variables confuses the picture even further. Thus, with random letter generation males produced their worst performance with machine noise in the afternoon. Females however produced an intermediate performance with machine noise in the morning and their worst performance with the same noise in the afternoon. Although the authors draw specific conclusions about their own particular experimental paradigms, the general conclusion would seem to be that it is difficult to predict accurately the effects of any particular noise in any particular performance measure. What can be predicted is that it will have an effect.

### 8.7 Interaction Effects

Smith and Broadbent briefly report the findings from studies on physical agents (vibration, illumination, heat) as well as other agents (sleep-loss, alcohol, other drugs, workload, night work). Many topics are represented by only one paper and no critical evaluations of the validity of the studies are presented. Some of the findings can be accounted for by reference to theories of physiological arousal or activation where results are mediated by concurrent effects on arousal brought about by both agents. One such example, referred to by Smith and Broadbent, is the established relationship between sleep-loss and noise, summarised in lay terms as noise keeps you awake when you are tired. Others however, do appear to indicate some form of interactive relationship. For example, noise and vibration appear to demonstrate an inter-relationship which extends beyond that which can be explained in terms of variations in arousal. However, the reported relationships are not always consistent. For example, Seidel et al. (1989) reported that increased noise exposure (86 vs 65dB) caused high estimates of vibration intensity whereas Zeichart et al. (1994) found that vibration caused less annoyance in conjunction with simultaneous high noise levels. In contrast, Sato (1990) found an increase in noise annoyance with an increase in vibration. These different findings are probably due, at least in part, to variations in the test criteria adopted and the nature of the studies. Meloni and Krueger (1990) for example, refer to different effects when studying vibration perception thresholds than those obtained from annoyance studies. In addition, the first study cited (Seidel et al., 1989) utilised controlled laboratory presentations in a systematic experimental manipulation whilst the others reported the findings of surveys of environmental noise and vibration exposures.

Individual papers were identified which reported results apparently contradicting some of the conclusions expressed by Smith and Broadbent. For example, these authors concluded that mental performance was not generally significantly altered by variations of noise and vibration exposure. Yoshida and Sakata (1987) however reported that vibration exposure appeared to eliminate the detrimental effects of exposure to 79dB(A) noise on a paired associates learning task. However, the present review has demonstrated the complexity of the non-auditory effects of noise and the use of randomly intermittent noise in this paper could have had a bearing on the results.
Collectively the papers identified as relating to the interactive or combined effects of noise and other agents confirm the complexity of the relationships. Manipulation of detailed noise characteristics (both physical and psychological) can produce apparently contradictory effects and superimposing the effects of other agents will undoubtedly complicate any relationships still further. Relatively few papers have been published dealing with such relationships and the variety of potential combinations, even with just two agents, makes comparisons or extrapolations difficult.