

## Non-auditory effects of noise: Psychological Task Performance

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### ABSTRACT

The information processing interpretation of various aviation tasks emphasises the importance of attentional and cognitive processes. This review discusses the empirical evidence of one of the non auditory effects of noise viz., the effects on psychological task performance. Three main aviation relevant abilities are outlined: vigilance, serial responding, and memory and cognition. It is proposed that the seemingly equivocal evidence in this field can best be explained in dynamic environments within the conceptual framework of the multiple resources model. In this model, task variables (modality of inputs, type of coding operations, stages of processing and nature of responses) and subjective variables such as selective strategies are seen to be the prime determinants of quantitative and qualitative effects.

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Noise threatens the health, safety and well being of people connected with or exposed to aerospace as well as non-aerospace operations. It is one of the most extensively studied stressors because of its predominance in industrial and military settings. The effects of noise on man could be physiological or psychological. Exposure to excessive noise affects the auditory system and causes temporary or permanent threshold shift. These changes in physiologic mechanisms or functions attributable to noise are known as auditory effects. Effects other than these are called non-auditory ones.

Non-auditory effects can be divided into (i) general physiological responses including changes occurring in other sensory channels, changes during sleep and those related to health and (ii) psychological responses which comprise of effects of noise on task performance and well being which

relates to annoyance and social effects. These are discussed briefly here. Noise may directly interfere with the reception of auditory signals such as speech, however the effects of noise on communication are not discussed, as these predominantly are due to masking phenomena.

Noise also affects the attentional and cognitive processing of information received by both auditory and other modalities resulting in various types of effects on psychological task performance. General cognitive abilities are important to aviation personnel especially pilots and air

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traffic controllers (ATC) as their job performance draws heavily on these abilities. Pilots depend on a number of more general cognitive abilities that are, to varying extents, independent of specialised aviation knowledge. There are also certain underlying psychomotor processes involved, apart from the learned skill of 'stick and rudder' control. Human information processing takes place in a sequence of operations beginning with sensory storage and perception. The next stage, the decision making response selection phase, is dependant on attentional and memory processes, and the sequence ends with response execution. This review discusses in detail, the literature on the various effects of noise on important specific psychological processes.

### **General Physiological Responses**

The state of understanding is still unclear as to relationships between potential adverse physiological effects and general noise exposure, as well as significance to general health of changes that do occur.

A number of investigators have reported general and specific physiological responses to sound [1, 2]. The reported responses include effects on peripheral blood flow, respiration, GSR, skeletal muscle tension, gastro-intestinal motility, cardiac response, pupillary dilation, renal and glandular function. Since these are considered as measures of arousal they have also been studied as the 'orienting response' (OR) which habituate with continuous/repetitive stimulation.

Startle may be evoked by a wide variety of stimuli, but is particularly susceptible to sudden unexpected noises. Physiological aspects of the startle response include increased pulse, increased blood pressure and diversion of blood flow to the peripheral limbs and gross musculature. In the aerospace environment, potential adverse effects

of aerospace noise environment should be evaluated especially when they fall outside the conditions specified in existing standards and criteria for allowable noise exposures.

Some studies have concentrated on clinical syndromes such as hypertension, gastric ulcers, glandular atrophy and hypertrophy since long term or daily exposures might lead to chronic health problems [3, 4]. While there is evidence that this is so, the evidence is far from conclusive, since it is debatable whether causation of disease by exposure to noise has been established [5].

Adequate sleep is a biological necessity and there are two general kinds of sleep interference due to noise: actual arousal or wakening, and changes within the sleeping individual who does not awaken. Noise does influence sleep, awakenings by sound as reported in various studies indicate that the intensity, duration of the noise and stage of sleep are important factors. Additional subjective variables such as type of sleeper, age, sex, restedness and motivation to awake partly determine effects [6].

### **Effects of Noise on Well Being**

Noise annoyance or unwantedness of the sound is described as perceived noisiness (PN). This is dependant on a number of factors including the level of noise [7], the circumstances in which a given noise arises, individual expectation and attitudes, and the frequency content of the noise [8].

Social effects of noise include a range of effects associated with being in noisy neighbourhoods has been noted including high crime rate, truancy and a reduction of casual social interaction associated with noisy areas. The most widely studied social behaviour is that of helping.

A range of studies has shown that individuals exposed to noise above 80 dB(A) are less likely to grant interviews and less likely to offer various kinds of assistance. Noise appears to potentiate the expression of anger and the judgement of others also appears to change in noise [8].

### **Effects of Noise on Task Performance**

The fabled 'man in the street' believes that his efficiency at work is lowered by exposure to noise. Data generated by the 'man in the lab' do not unequivocally support this belief. There have been great many studies concerned with this question. No unequivocal simple generalisation about the effects of noise on behaviour may be drawn, leaving some to conclude that very many interacting factors, circumstances and the manner in which they interact is very complex and only partially known [5].

Noise is defined as an unwanted sound, unrelated to the structure of performance task being carried out. A differentiation may be drawn between intermittent noise and continuous noise. Since most noise encountered in practical working situations is a mixture of different frequencies and intensities (and different sounds), this review of its effect on performance considers primarily broad-band noise. Here, noise may be taken to mean continuous broad band sound with sound pressure level (SPL) over 80 dB. Exceptions are pointed out in the text.

### **Impulse and Intermittent Noise**

Unexpected bursts of noise produce masked but transient changes in the psychophysiological response. Three categories of response to unpredicted noise may be distinguished, startle response, OR and defense reflex [9]. The startle response is a potentially protective muscular

response (including eye closure, facial muscle contraction and head jerk) whereas the OR is a general alerting response and defense reflex is a response to intense sound stimuli that are interpreted as harmful. Effects on performance produced by sudden noises are probably related to this dramatic underlying change in bodily state and can be because of distraction.

The duration of the phase of reduced efficiency following exposure to a sudden noise was studied. On visual inspection and serial responding there was some impairment of performance following noise bursts, periods of reduced efficiency lasted upto 30s. Others have found dramatic impairments in pursuit tracking following a pistol shot (SPL 124 dB peak) lasting 2.3 s [10].

It clearly depends on characteristics of both noise and task and upon factors such as frequency of distraction and temporal structure of the activity. Some attempts have been made to establish the types of tasks that are more susceptible to such effects with generally equivocal results. Bursts of noise slow the speed of a simple motor response only when the burst arrives during the execution of the response rather than during the presentation of stimulus [11]. Several studies have shown that the intake of information and other mental tasks are disrupted by noise [12,13]. It appears that the elements of the task are susceptible to disruption by noise bursts are those that are 'data limited'. Activities of this kind include short perceptual or motor events in which compensatory effort on the part of the subject is not possible. Such perceptual/motor effects may be a reflection of the startle effect described above. Thus higher mental activity such as that involved in calculation is immune to the specific effects of infrequent bursts because of the way in which short term memory may compensate for such brief disruptions.

An important consideration is the extent to which these short term responses diminish with repeated presentation of the bursts. Although it is clear that elements of the physiological response, such as the OR are eliminated by habituation, the startle response may resist complete elimination. Even after long periods of exposure to impulsive noise, residual effects of the eye blink and head jerk response are found. Laboratory studies have confirmed that repetitive impulsive noise is still capable of disruptive performance of a skilled tracing task after many repetitions [10]. Performance in complex tasks is disrupted if uninterrupted vision and steady posture are necessary for the successful execution of the task.

Effects that extend to the order of 30s beyond the burst are likely to be the ones associated with strategic effects rather than arousing effects [14]. As the effect of startle becomes less pronounced, the subject may gain tactical advantage by anticipating the appearances of the noise burst and overcome its effects by compensatory effects.

A second type of arousing effect may be found because noise of variable/intermittent type may improve performance of tasks requiring vigilance after a period of long continued work. These tasks involve the detection of small changes in the flow of information arising from one or more sources over long unbroken periods of time. Typically the ability to detect such signals diminishes as the time at work increases. Varied and irrelevant auditory stimulation stems the decline usually found in quiet, at least when events, within the task, are presented at a low rate [15]. In long monotonous tasks variable noise may serve to raise the level of arousal and hence improve efficiency.

#### **Continuous Noise**

The majority of studies on the effects of

noise on performance are concerned with loud, continuous broad bandnoise. A large number of experiences have shown both positive and negative changes in task performance. Until about 1970, the emphasis was on tasks of long duration (vigilance/serial reaction tasks) in keeping with the belief that only this type of task was sensitive to noise effects. More recently, however, brief cognitive tasks have also proved sensitive to these effects, although the changes in performance are more subtle than originally thought.

#### **(a) Attention and Vigilance**

Attentional processes in flight tasks include focussed and divided attention, and prioritisation. Vigilance tasks require consistent monitoring without lapses in attention. This can become a challenge in monotonous tasks. Vigilance has always been important in aviation, pilots need to be constantly aware of both instrument readings and surrounding airspace. Advances in flight deck automation have increasingly emphasised the pilots' role as a system monitor. ATC also requires high levels of vigilance.

#### **Attention During Prolonged Work**

Early in the history of noise research, effects of very intense noise were noted on tasks involving vigilance. The way in which the vigilance performance is influenced by noise has benefitted from the development of sophisticated theories of signal detection. These theories distinguish between effects on the efficiency of detection of response bias and perceptual sensitivity.

#### **Loud Noise Influences Response Bias**

If people are required to state the confidence of their judgement that an event is a signal, noise

tends to increase the tendency to use extreme categories of judgement at the expense of intermediate categories. They are more prepared to assert that they are sure that a signal is or is not there [16]. From what is known about vigilance of performance in quiet, we may predict what will happen in noise to the number of signals detected. When signals are very unlikely, people report the presence of the signal only when they have high confidence, and doubtful judgements that something is present do not produce a report. The increased certainty that results from noise then gives more correct reports. If signals are more probable, however, people report them unless they are certain that no signal was present. Doubtful judgements of the absence of a signal tend to get reported as positive detections. In that case, noise reduces the numbers of reports of signals. Impairment is likely only when signals are difficult to detect and the task situation encourages risky decision behaviour.

The prevailing level of confidence, in addition to its effects on the reporting of signals, will have effects on the way in which observers check on the state of a display. If several sources are involved, it is possible to chart the process of interrogation by offering the observer brief glimpses of a state of each display. Typically, some displays receive more attention than others, and this tendency is exacerbated in loud noise [17]. The action of noise in this case seems to be one of exaggerating those biases that already prevail about where significant events requiring action are more likely to occur. Effects have also been noted on another class of vigilance tasks that are sensitive to levels of noise as low as 80 dB (C), [18]. In this case the detection of signals places a very heavy reliance on memory, and the periods over which performance was assessed were relatively short. Because of these differences, the results may arise out of changes of the strategic type. Some experiments suggest that noise causes an increase in errors over time.

### **Time sharing**

Everyday tasks are made up of a range of different activities each with different priorities. The effects of noise on tasks of this sort is to swing resources away from elements of low priority and toward those that are seen to be subjectively more important [19]. Some variation will be observed in the patterning of response in tasks involving different elements, this is to be expected in view of the different demands made by tasks and by type of instructions given for their execution.

### **Task difficulty**

Noise of a very high intensity (114dB) impaired arousal detection using three sources of signals or using a single source having three times the signal rate [16]. Multiple source tasks are more readily affected by noise whatever the signal discriminability or instructions about caution. Where relation between task components can be clearly specified, spatial selection and subjects expectation of spatial events influenced secondary task performance. Noise causes an increased tendency to sample dominant or probable sources of information. This effect was only found when the rate of sampling is limited by pacing and the probability of a fault is quite high.

These procedures encourages the use of selective strategies. The idea of a strategy suggests a person may on different occasions perform the same task by using different mental operations. Noise does not cause a straightforward reduction in efficiency but rather causes some activities to be favoured and others not. The analysis of performance may reveal that the effects of noise that are originally thought to be mechanical and involuntary are in fact of the strategic type. Verbal memory experiments have shown that it is not the deficiency in the way the

material is stored that is changed in noise, rather it is the choice of a way to recall the material. This effect occurs only if the individual has a variety of means at disposal to perform the task. The extent of this effect depends also on the nature of the list to be remembered.

Once a strategy is adopted noise tends to increase the likelihood of its continued adoption even when circumstances might suggest otherwise. Moreover rapid alteration between different types of tasks has been particularly damaging to performance in noise. The reluctance to abandon a strategy in noise is shown by studies examining the effects of noise on the speed of response to subtle changes in the features of a task. When signals in a task are not equi-probable, noise produces faster reactions to rare signals. If without warning the signals become equi-probable in noise, the pattern of responding previously established tends to be carried over [8].

#### **(b) Serial Responding**

One of the characteristic effects of noise is the tendency for the speed of work to increase at the expense of accuracy. Sometimes, it takes the form of an increase in speed only, sometimes an increase in errors only, and sometimes both effects are found. In one study, 100 dB noise increased the number of erroneous responses made when one of five signals occurred without affecting the average rate of work, later this effect was found only in an increase in the number of slow reactions, or gaps. All these effects of noise increase in severity with time spent on a particular task [20].

#### **(c) Memory and Cognition**

Memory functions are very important in aviation to be able to use clearances, call signs,

adversaries, briefings and so forth. Any compromising of this short term working memory function would be likely to render a pilot's performance inefficient / dangerous. Impairment of working memory has the potential to affect visuo-spatial processes, among them orientation in three dimensional space - a function critical to many aspects of situational awareness.

The tendency for noise to bias selection toward dominant aspects of the stimuli has been observed quite systematically in the incidental learning paradigm. Ordered recall was marginally improved in 85dB noise (versus 55 dB) [21] but recall of location was markedly impaired. In another study, verbal recall was unaffected by 95dB noise, whereas the content of pictures of social scenes presented alongside the syllables was poorly recalled in noise [22]. The effect is one of the most robust in empirical literature on noise.

A number of studies have examined the effect of noise on short and long term memory. The general conclusion from these studies is that noise during learning facilitates recall after a delay (typically an hour or more) but impairs immediate retrieval of the material [23]. What is learned appears to be affected in addition to how much, thus semantic information may be lost while sequential information may be enhanced [24, 25].

There appears to be good evidence that noise reduces that effectiveness of short term memory in tasks requiring mental working space for the manipulation of task information. Intellectual tasks such as problem solving, reasoning, computation, comprehension, and reading have been shown to depend, in part on the efficient use of short term memory systems for both the temporary holding of current information and the control of information processing operations. One study showed that the effect of noise on a problem solving task involving transformations of alphabet

sequences depended critically on the degree to which working memory was involved. As the demands made on the working memory system increase with the longer sequence of letters, the effect of noise changes from being facilitatory (with single letters) to being markedly inhibitory [30].

There more recent studies have reported that the effects of noise on aviation flight tasks affect memory in the decision process. In a recent study on effects of 72 dB(A) noise on pilot judgement in a MIDIS simulator [26], the failure to perform a secondary task rapidly and accurately produced an annoying tone. This manipulation resulted in significantly poorer flight decision making, especially in decisions requiring spatial skills. Another study [27] found significant decrements in performance on working memory and spatial tasks as tested in an aviation relevant test battery. The third study [28] measured the effect of 90 dB(A) white noise on dual tasks of tracking and memory search. Tracking accuracy was impaired by about 15% and the amount of time spent "off target" increased by about 20%.

#### **After-effects of Exposure to Noise :**

A number of studies have focused on the effects of exposure to noises when the noise source is no longer present. Studies were reviewed [29] and the general result is that exposure to noise for a period of 20-30 min impairs subsequent performance (in quiet) on problem solving tasks, perceptual classification or serial reaction. At least part of these after-effects and direct effects are due to the individual's interpretation of the physical environment and the threat it poses.

#### **Conclusion**

Intermittent and impulse noise is generally more disruptive than continuous noise at the same

level, resulting in reduced task efficiency between 2-30 sec following exposure to sudden noise and task factors determine the exact nature of effects. In these situations the type of processing (parallel or automatic) appears to be the most important factor [30].

Continuous noise while carrying out a single task with specific meaning may not generally impair performance below 90 dB(A). In vigilance tasks, complexity/difficulty influences signal detection rates. Decision about task events become more extreme in noise. Multiple source tasks are more affected, as selective strategies assume more importance. Spatial ability is compromised and noise promotes a lack of flexibility when strategies need to be changed. In serial responding noise tends to increase errors and variability rather than directly affect work rate.

On memory tasks, noise biases selection during incidental learning. There is good evidence that noise reduces the effectiveness of STM in tasks requiring working memory. More recent evidence on simulated flight tasks showed that noise can give rise to significant decrements in performance on working memory and spatial tasks provoking poorer flight decision making.

It is observed that noise affects the above three aviation relevant abilities i.e. vigilance, serial responding, and memory and cognition in different ways. It is proposed that the seemingly equivocal evidence in this field can best be explained in dynamic aviation environments within the conceptual framework of the multiple resources model [31]. In this model, task variables (modality of inputs, type of coding operations, stages of processing and nature of responses) and subjective variables such as selective strategies are seen to be the prime determinants of these differing quantitative and qualitative effects.

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