Effects of noise on visual orienting

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EFFECTS OF NOISE ON VISUAL ORIENTING

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ABSTRACT

EFFECTS OF NOISE ON VISUAL ORIENTING

Martin Bramwell Howard Spencer

Eleven experiments are reported which examine the effects of 90 dB (A) white noise on the processes which govern orienting of attention in visual space. The selectivity hypothesis argues that noise alters the priorities which govern stimulus selection so that subjectively dominant aspects of the environment are attended to more fully than those which are non-dominant. The applicability of this hypothesis is examined with regard to attentional orienting.

Three experimental paradigms are used. The first involves a central cue presented immediately prior to target onset. In the absence of eye movements reaction times to expected targets are faster than to unexpected targets, but noise has no effects on performance. It is concluded that the power of the central alerting cue is focussing attention in a maximal fashion and noise has no further effect on policies of allocation.

A second task design involves the presentation of positional information prior to a block of trials. Under such conditions subjects fail to maintain orienting as trials continue. Noise enhances the ability to maintain orienting over time. This effect is discussed in the light of the selectivity hypothesis. It is argued that the inability to maintain orienting is not due to the inhibition which arises as a result of successive responding. Rather it is due to the difficulty involved in maintaining an active orientation.

The third paradigm involves orienting to specific locations on the basis of information stored in short-term memory. When recall of this information is aided by a visual warning signal occurring prior to target onset noise has no effect on performance. Without this signal, noise alters performance and these data are compared to predictions based upon the selectivity hypothesis.

These effects are discussed in terms of a noise-induced change in the strategy of performance, rather than an effect which is mechanistic.

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DECLARATION

I declare that the work presented in this thesis is entirely my own and has not be previously submitted for a degree at this or any other university.

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CHAPTER 1

SELECTIVE AND SUSTAINED ATTENTION

SUMMARY

This chapter examines the processes which govern how we are able to attend in both a selective and a sustained manner to environmental events. Particular emphasis is placed upon the ideas proposed by Posner. The mechanisms which govern the way in which attention can be covertly oriented under both conscious and automatic control are given special priority.

This aspect of attention is contrasted with more traditional studies of sustained attention within a vigilance paradigm. The way in which phasic and tonic elements of attention govern how we prepare for and select stimuli from a source of information is also discussed.

1.1 Introduction

The topic of attention has been considered to be of prime importance ever since the early history of experimental psychology, and increasingly over the years (e.g. Moray 1969a; Posner 1975) it has been recognised that it is not a single concept but rather the name of a complex field of study. This fact is reflected in the title of a recent book on the subject - "Varieties of Attention" (Parasuraman and Davies 1984).

This chapter will focus on two of these "varieties" in particular, those of selective and of sustained attention. The aim will be to relate each of these aspects of behaviour to the way in which we concentrate upon one location in visual space. This alignment of attention with a source of sensory input is defined by Posner (1980) as orienting.

Posner (1975) has also identified what he sees as three more general senses of the term attention. These are:

1) Selection, "of some information from the available signals for special treatment."
2) Effort, "a sense of attention related to the degree of conscious effort which a person invests."
3) Alertness, "an organismic state which affects general receptivity to input information."

According to these distinctions attention involves the following: a selective process whereby environmental information is analysed and perceived; an intensive process whereby the amount of a specific resource devoted to a particular source can be varied; and an alerting process, whereby the receptivity to input information can be heightened.

1.2 Selective Attention

Concerning the above three aspects of attention, the most consistent feature of all attentional research conducted over the years has been an interest in the selective processing of information (see Kinchla 1980). In the late 1950's and early 1960's several major theories were put forward in order to account for attentional selectivity (see Broadbent 1958a; Treisman 1964; Deutsch and Deutsch 1963). While there were important differences among them, these theories had in common the notion that at some point in the course of information processing there was a bottleneck. The main disagreement concerned the putative location of this bottleneck, i.e. whether it occurred at an early (perceptual) or late (response) stage.

Over the years there has been a search to find the "experimentum crucis" to decide between these early and late selection models. As Lambert (1985) points out, the degree of current disagreement that still exists in this respect can be illustrated by quoting from two recent papers which address the issue: "Evidence has piled up to show that such a view (i.e. late selection) is wrong"..."The popularity of late selection does not stem from any empirical evidence" (Broadbent 1982, p. 281). But according to Duncan (1980), "the evidence from the literature is consistent with late selection" (p. 296). As Lambert (1985) also argues, such differences as these exist in part because different authors have agreed that different types of experiment represent the truly acid test between early and late selection. Additionally it is true though that both early and late views of attention underestimate the flexibility of attentional mechanisms and processes, and neither can accommodate the evidence that attentional selectivity operates at both perceptual and semantic levels of analysis.

In more recent times various theoretical frameworks have offered a different account of attentional selectivity arguing that it is not fixed, limited or localised in an all or none fashion to one task at a time. For example Kahneman (1973) provided a model of attentional allocation which views attention as a limited resource which can be deployed in a flexible manner, and increasingly stage-analytic approaches to the study of attention are being abandoned in favour of such approaches. According to the type of resource allocation theory favoured by Navon and Gopher (1979) and Wickens (1980, 1984) attentional selectivity is conceived in terms of a number of pools of processing resources that may be allocated across the various components of a task depending upon their available supply and task demands.

In fact, as Posner (1982) argues, there need not necessarily be any incompatibility between the idea of such multiple capacity views of attention and a single channel view, if one allows that the latter structure performs a co-ordinating function with information from several separate more isolable systems. Posner (1978, 1980) has suggested that much processing is accomplished by such isolated processing systems and that co-ordination is achieved through a limited capacity system. Within such a framework as this, a fuller understanding of attention is achieved through a study of selective operations described in terms of the facilitation and inhibition of pathways. These arise as a result of the operation of a central general purpose decision making processor and more specialized satellite processing systems. Because they are of particular relevance to the way in which subjects are able to attend to specific locations in visual space, Posner's ideas and the assumptions which underlie them are addressed in the section which follows.

1.2.1 Posner's Concept of Automatic Activation and Conscious Processing

Posner (1978) describes selective operations in terms of the facilitation and inhibition of neural pathways and proposes there to be a central, general purpose decision making (active) attentional mechanism of limited capacity which interacts with a more isolated and specialized automatic processing system in the selection of environmental stimuli.

Ideas concerning these mechanisms were developed as a result of priming studies, particularly those of Posner and Snyder (1975a, b) where these authors developed their influential conceptual distinction between automatic processes and conscious attention. The essential design of these priming studies involved the presentation of a single priming item which was either a letter on half the trials or a plus sign on the other half. This prime was followed by a pair of letters, and the subjects' task was to decide whether the two letters were the same or not. The two experimental variables of greatest importance were the probability governing whether the letter prime would match the array pair, and the time delay between the prime and the array. For trials where the probability that the prime would match the letter pair was 80%, it was shown that reaction times in the expected condition (e.g. "A: AA") were faster than the control (e.g. "+: AA") which in turn were faster than unexpected trials (e.g. "B: AA"). However, on trials where the probability that the prime would match the letter pair was 20%, there was a processing advantage for the "match" condition (i.e. "A: AA") over the "mismatch" ("B: AA") and control conditions which were not in themselves different. Along the same lines as argued by Keele (1973), Posner and Snyder proposed that the priming stimulus would automatically activate its own representation in memory, resulting in a facilitation in performance irrespective of the particular probabilities governing stimulus occurrence. However, they attributed the first set of results above to the operation of both automatic and control processes - conscious responding to the probabilities of different events speeding up decision making when an expected event occurred, and slowing it down when an unexpected event happened.

Further to this, Posner and Snyder (1975a, b) argued that some additional specific properties of these two mechanisms were highlighted by an examination of the effect of the length of time between the prime and the letter array. This delay was varied between 10 and 500 msec, and the data obtained from this manipulation are displayed in Figure 1.1.

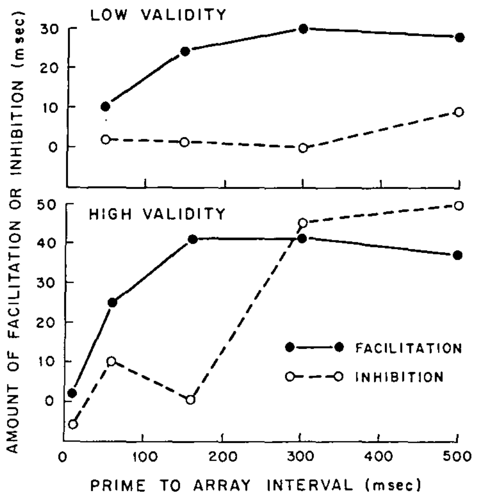


Figure 1.1

Facilitation (benefit) refers to the advantage in processing expected information (e.g. "A: AA") over the neutral condition, and inhibition (cost) to the negative effect of processing unexpected information. The noteworthy theoretical point is that facilitation of performance is due to conscious attention or automatic activation, whereas impairment of performance is due to the action of conscious attention alone. This was their explanation for the data shown here, where the effects caused entirely by conscious attention take longer to appear than those attributable to a combination of the two processes.

On the basis of such evidence, Posner and Snyder (1975a, b) have proposed three formal criteria for assessing automaticity and also three defining features of conscious attention:

Automatic processing:

1) Occurs without intention.
2) Does not give rise to conscious processing.
3) Does not necessarily interfere with other mental activity.

Conscious processing:

1) Is slow acting.
2) Cannot operate without conscious awareness.
3) Inhibits the retrieval of information from pathways that are not activated.

These two concepts have been highly influential in determining the course of attentional research in recent years. Examples of this can be seen in work on visual search (e.g. Shiffrin and Schneider 1977; Schneider and Shiffrin 1977), single-word priming studies (e.g. Neely 1977) and studies which have employed full sentence contexts (Stanovich and West 1978). As a result of such studies it has been widely agreed that the definitions above contain many of the features central to any concept of automatic and controlled processing, though it is also recognised that the proposed control/ automatic dichotomy is, like many such theoretical dichotomies, an oversimplification.

Broadbent (1982) argues in favour of caution over the distinction on two main counts. The first is that the concept of automatic processing does not differ from the proposed low level of analysis performed by filter theory, and the second is that contrary to the claim made by automatic processing theorists, under some circumstances practised processes can be stopped, a phenomenon which can also be accommodated by older theories of selection. In a far more critical article, Ryan (1983) examines the original distinction made between automatic and controlled processing and argues that the majority of means which are claimed to distinguish between the two processes do not in fact do so. One argument in particular centres around the question of whether controlled and automatic processes reflect qualitatively different processes (Shiffrin, Dumais and Schneider 1981) or form instead two ends of the same continuum (Hirst, Spelke, Reaves, Caharack and Neisser 1980). Part of this difficulty arises from the acknowledged fact that automatism and controlled processing are only theoretical states and that ultimately performance in all tasks will be carried out with a contribution from both processes, and the exact contribution from either source is difficult to measure. Shiffrin, Dumais and Schneider (1981) and Schneider, Dumais and Shiffrin (1984) acknowledge that a necessary and sufficient distinction between the two types of processing cannot be found, at least not one which holds up under all circumstances, and other than being able to list several of the general characteristics of the two processes, these authors finally appeal to the basic idea that automatic processes do not require resources or reduce capacity, whilst control processes do. In summary, the best view to take of this issue is that the controlled/automatic distinction does provide a useful way of organising much of the literature on attention, but at present it raises at least as many questions as it answers.

1.2.2 Orienting of Attention

Posner (1978) distinguishes between three internal mechanisms which he claims to be basic factors in the study of selective attention. These processes are alerting, detecting and orienting.

Orienting is defined by Posner (1980) as "the aligning of peripheral or central mechanisms with a source of sensory input or an internal semantic structure stored in memory" (p. 4), and detection is the "indication that a stimulus has reached a level of the nervous system at which it is possible for a subject to report its presence" (p. 4). The operation of these processes is closely associated with the attentional mechanisms discussed in the section above, as will be seen in Section 1.3. Of particular relevance to this thesis is the process of orienting, the study of which according to Posner (1980) is "capable of providing us both with important tests of the adequacy of general models of human cognition and with new insights into the role of attention in more complex human activity" (p. 4). The third mechanism, that of alerting, closely associated with the processes of orienting and detecting, refers to the overall level of activation, and this and the precise nature of the relationships between these processes are addressed more fully in Section 1.4.

Overt and Covert Orienting

The term overt orienting simply refers to changes in the alignment of attention that occur as a result of movements of the head and eyes, and covert orienting refers to those changes occurring as a result of changes in the alignment of the central processing system. With reference to the latter, psychologists have long believed that attention can be shifted from one object to another independently of any overt movement of the eyes or head. For example, Wundt (1912) wrote:

> "If...we practice letting our eyes wander over...different parts of the field of vision while keeping the same fixation point, it will soon become clear to us that the fixation-point of attention and the fixation-point of the field of vision are by no means identical" (p. 20).

Wundt's comments have been confirmed in a variety of controlled experiments in which subjects were required to move their attention independently of their eyes. For example, Sperling and Melchner (1978) presented subjects with sequences of arrays of alphanumeric characters, consisting of an inner array of 4 characters and an outer array of 16 characters. The task was to detect a target character occurring within one of these arrays, whilst maintaining visual fixation. In some blocks of trials the subject was instructed to give most of his attention to the inside characters, in other blocks to the outside characters, and in others to pay attention to both. Detection results clearly showed how subjects were able to follow the attentional instructions they had been given previously. A similar finding is reported by Jonides (1980) who presented subjects with an eight item circular array and instructed them to use an arrow which pointed to the likely position of a target within the array to guide the locus of their attention whilst maintaining their fixation. These are just two examples of many experiments where subjects have clearly demonstrated an ability to attend selectively to parts of visual displays in the absence of eye movements.

Of much interest is the exact nature of the relationship between such covert shifts in attention as these and changes in overt orienting of the head and eyes. Posner (1980) identifies what he sees as four different logical alternative forms of this relationship. These are:

1) That they are completely identical systems.

2) "Efference theory", i.e. that eye movements are facilitated by a prior movement in attention.

3) That they share a functional but not a physiological relationship.

4) That they are completely independent systems.

As discussed above, there is considerable behavioural evidence which shows that attention shifts do <u>not</u> depend upon overt movements. In addition Bushnell, Robinson and Goldberg (1978) have demonstrated how some single cells in the parietal lobe show a change in firing rate without movement of the eye. Von Hooris and Hillyard (1977) have found similar results with enhancements of evoked potentials. Thus attention and eye movements cannot be identical systems.

The second view was examined by Klein (1980). He tested the notion that whenever attention is moved to a given location, eye movements in that location are facilitated and that the <u>readiness</u> to move the eyes to the target improves detection. He gave subjects a cue instructing them to where to shift attention and then commanded them to either move their eyes or respond to a stimulus. His results showed that this detection task was totally unaffected by the direction in which the eyes were moved - showing that there are at least some conditions under which there is no relationship between attention and eye movements.

However there are data arguing for a firmer link between attention and eye movements which discount the possibility that they are completely independent. A number of physiological studies (e.g. Goldberg and Wurtz 1972; Wurtz and Albano 1980; Fischer and Boch 1981) have suggested that the mechanisms responsible for saccades and shifts of attention are closely linked. Goldberg and Wurtz (1972) found an enhancement in the firing rate of cells in the monkey superior colliculus whose receptive field was to be the target for an eye movement. This enhancement occurred <u>before</u> the eyes began to move. Similarly, Remington (1980) showed that an attention movement precedes an eye movement to the same location by about 50-100 ms. He argued that human attentional movements were more closely tied to the onset of peripheral stimuli than to eye movements.

Such data as these lead to the conclusion that the relationship between the two is functional rather than necessarily physiological. Posner (1980) argues that in many ways the relationship between eye and attention movements resembles that which exists between eye and hand movements. The eye and hand function in close relationship together in many tasks, yet the physiological systems for their control are quite distinct. Posner and Cohen (1984) develop this concept further with reference to the covert attentional effects involved in reading. This is a particularly interesting situation where both overt and covert mechanisms interact. They discuss work by Chang (1981) who investigated the existence of a covert internal scan similar to the enlarged visual field to the right of fixation which occurs during the reading of English. He presented subjects with stories one or two words at a time, while they maintained central fixation. The words of the story were presented at this fixation point. Occasionally subjects were probed with an arrow to the right or to the left of fixation, and Chang measured the time taken to report the direction of this arrow. Results showed that arrows were processed better to the right of fixation while reading normal English, but when subjects read upside-down English, arrows were processed better to the left. These results suggest there to be an internal scanning process that goes from left to right, matching the overt change in visual field.

Internally Controlled Orienting

The term internally controlled orienting refers to the situation where attention is directed as a result of an internal decision (Posner 1980) and probably the most extensive work in this area has been conducted by Posner and colleagues over the past few years (e.g. Posner, Nissen and Ogden 1978; Posner, Snyder and Davidson 1980). It is mainly the paradigms and research methods developed by these investigators which have been adopted in this thesis (see Chapter 3).

Posner, Nissen and Ogden (1978) demonstrated some of the particular components of internally controlled orienting. Subjects had to respond to a stimulus "X" presented either to the left or to the right of fixation, and warning signals of three types were presented at one of six intervals preceding the target: 0, 50, 150, 300, 500 or 1000 msec. These warning signals were either an arrow which predicted subsequent target position with 80% reliability or plus signs which told subjects that the target was equally likely at either location. When the target occurred to the left of centre the subject had to press the left key as quickly as possible and likewise the right key when it appeared on the right. A "valid" trial was one on which target position corresponded with that indicated by the cue. An "invalid" trial occurred when the target appeared at the opposite location. A "neutral" trial was one on which the cue was a plus sign, i.e. where target location was unspecified. Results showed that reaction times to valid targets were faster than those for neutral targets, which were in turn faster than for invalid targets. Putting this another way, there was a "benefit" in processing a valid target over a neutral target, and a "cost" in processing an invalid target over a neutral target. These effects occurred when the cue preceded the stimulus by as little as 50 msec (see Figure 1.2 below).

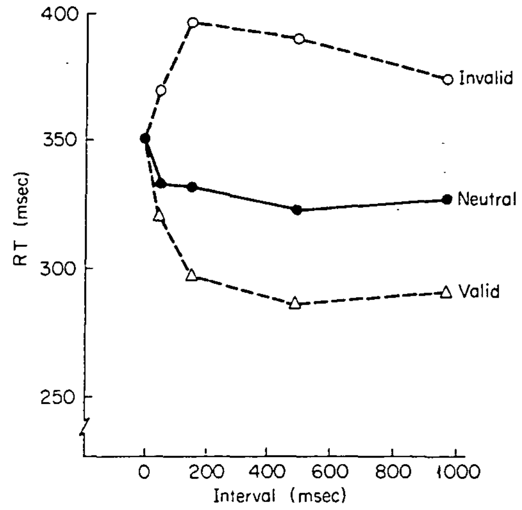


Figure 1.2

Posner et al also undertook an analysis of error data (i.e. when subjects made an incorrect response) and showed that if an unexpected stimulus followed the arrow by only 150 msec then performance approached chance. They discuss their results in terms of the development of "set" - by their definition simply the process involved in turning attention to a source of input signals - an operation which takes a clearly defined amount of time. During the first 150 msec or so while this active orienting is taking place subjects are highly susceptible to making errors if the wrong stimulus occurs.

The separation of the benefits due to the subjects' knowledge of where a stimulus might occur from the costs when it occurs at an unexpected location is an example of "cost-benefit analysis", originally developed by Posner and Snyder (1975a, b) in their interpretation of the data obtained from the letter matching studies discussed above. Since then cost-benefit analysis of reaction times has become a popular chronometric tool in the study of cognitive processes. It is true to say however that the unthoughtful application of the technique may sometimes have caused researchers to draw improper conclusions about the exact nature of the underlying mechanisms that produce the costs and benefits. Jonides and Mack (1984) point out that as this technique depends upon the same rationale as Donders' (1969) subtraction method, it is vital that both neutral and informative cues are identical with respect to all their effects, except with regard to information specific to the target. Jonides and Mack (1984) argue that for numerous reasons this is often not the case. For example neutral and informative cues differ physically and thus engage different processing demands, and especially in the case of sentence priming experiments, they may take longer to read and encode. Different reaction times can be obtained from neutral trials depending on whether they are intermixed with other trials or presented within blocks alone. Also differential attentiveness may be induced when neutral trials are presented with a different frequency to informative trials, and as Jonides and Mack rightly point out, all studies which employ cost-benefit analysis suffer from this problem. For such reasons they suggest that neutral trials are not included in experimental designs at all, and if they are, then they suggest that if possible converging measures are taken to verify the conclusions drawn from them. Even then they recommend that the data so obtained be treated with caution. Having acknowledged this warning, it must also be said that cost-benefit analysis has expanded the scope of mental chronometry in the study of preparatory effects, and is a technique that is used throughout this thesis. In addition to this it is vital in tracing the time course of the operation of the automatic and conscious attentional mechanisms postulated by Posner and Snyder (1975a, b).

As discussed above the letter-matching studies of Posner and Snyder (1975a, b) represent one experimental situation in which some of the time-dependent properties of limited capacity attentional processes have been demonstrated. Work by Shulman, Remington and McLean (1979) and Remington and Pierce (1984) addresses the related issue of time locked attentional movements. Shulman et al found that with the eyes kept in a fixed position a shift in attention in the visual field took place within 500 msec of a locational cue. They also showed how a probe stimulus located between the cue and the target was processed faster than the target itself, with a maximum advantage occurring when the prime to move attention and the probe detection stimulus were separated by 150 msec. From this result Shulman and colleagues argued that attention was moving through the visual field in an "analogue" fashion. Thus given three collinear points in visual space labelled A, B, and C, moving attention from point A to point C involves a hypothesised continuous movement such that attention must pass through the intermediate point B. Such data as these have caused the development of the frequently used metaphor that directed visual attention operates like a spatially restricted beam or spotlight.

Recent researchers have disputed the applicability of this analogy. LaBerge (1983) has shown that the exact spatial extent of the area receiving attention can vary according to task demands. Both Eriksen and Yu-Yeh (1985) and Hughes and Zimba (1985) have also shown that attention is capable of distribution over a large extent of the visual field, but that it cannot be split between separate locations. Lambert (1986) set out to explicitly test the spotlight analogy. Subjects were required to make speeded orientation judgements to alphanumeric characters that could appear at one of two locations. Letters were more probable at one location ($p = .8$) and numbers at the other, and alphanumeric category was also cued on each trial ($p = .8$). Thus both short and long term expectancies about target events were manipulated. As would be predicted, results showed that response times were faster for cued than uncued items, but critically for cued items subjects were faster when the item occurred at the likely location for that item. Similarly, for uncued items this was reversed. This meant that location selectivity reflected location probability for each category regardless of short-term expectancies. These data cannot be reconciled with the concept of a spotlight which produces a general improvement in perceptual efficiency over a specific area. Instead Lambert (1986) favours the view that multiple selectivity with respect to both category and location can be achieved directly within a single level of processing (see also Lambert and Hockey 1986). Despite data such as these the spotlight analogy remains influential in attention research, particularly when simple expectancies operate over two spatially distinct locations, as is the case in the experiments reported in this thesis.

A further feature of the central capacity attentional mechanism is its active nature. In the Posner, Nissen and Ogden (1978) study it was argued that the build up of "set" took a defined length of time, and in another group of experiments Posner, Snyder and Davidson (1980) explored this active nature of attentional orienting more fully. Instead of cueing subjects on each trial they made one of four spatial locations the most likely target position for a whole block of trials. They found no benefits for the "frequent" position in comparison with conditions in which all positions were equally likely, although there were still significant costs for targets occurring at the "infrequent" position. This point is returned to and developed more fully in Chapter 5. Posner et al (1980) argue that this result fits with the active nature of orienting, which does not involve a passive filter that can be set in place and left. Rather it is the active process of maintaining the orientation that is important, and subjects find this difficult to do without constantly being alerted to orient to a spatial location by the central cue. Posner, Cohen, Choate, Hockey and Maylor (1984) ran some similar experiments using a design where subjects received a cue at the start of a block of trials as opposed to every trial. Results again clearly showed that subjects became increasingly ineffective in maintaining selectivity over successive trials. They also showed how active orienting could be reduced or delayed further in this setting by requiring subjects to perform a secondary task (in this case, counting backwards). These data are also discussed more fully in Chapter 5.

Externally Controlled Orienting

In contrast to the definition of internally controlled orienting, Posner (1980) describes a process of externally controlled orienting as the drawing of attention by means of a peripheral stimulus. Engel (1971) was also aware of a similar distinction between the two types of mechanism when he referred to internally controlled orienting and externally controlled orienting as being governed by "subject factors" and "object factors" respectively (p. 563).

Also, both Remington (1980) and Flowers, Polansky and Kerl (1981) have reported a similar phenomenon where attention can be directed in what they term an "automatic" manner by a peripheral visual stimulus, but in recent years the most comprehensive work on externally controlled orienting has been conducted by Posner and Cohen (1980, 1984).

Posner and Cohen (1984) presented subjects with a screen showing a central box (to be fixated) and two peripheral boxes, one either side. Targets appeared in the central box with a probability of 60% and at each of the other locations with a probability of 10%. Catch trials accounted for the remaining 20% of trials. A trial would begin with a 150 msec brightening of one of the peripheral boxes, and the target would then follow at either 0, 50, 100, 200, 300, or 500 msec after brightening. Reaction time results showed there to be a clear advantage for the centre, as expected because of the high probability of target appearance there and also its foveal location. Peripheral targets occurring at cued locations showed an advantage over uncued ones in response time for the first 150 msec after box-brightening. However, as the cue-target interval increased, response times to the uncued targets were actually faster than those to cued ones, this effect becoming significant at SOAs of 300 msec and over. Posner and Cohen (1984) explained these effects as follows: There was an initial summoning of attention by the peripheral cue resulting in the initial reaction time advantage of the cued targets over the uncued ones. This effect was termed "facilitation" and was attributed to the action of central attentional mechanisms, primarily because it could be initiated by either a symbolic or a peripheral cue. The later effect was termed "inhibition". This the authors argued was not central in origin but arose instead without the need for any deliberate strategy on the part of the subject, and was sensory rather than attentional in origin. [N.B., the term "inhibition" here is used in a somewhat different manner to that referred to by Posner and Snyder (1975a, b). In the latter case pathway inhibition arises as a result of the activation of conscious attention, but here inhibition is said to arise as a result of a process which is primarily automatic]. Posner and Cohen's (1984) arguments as to the origin and nature of these effects were supported by a number of experiments which appeared to confirm their theoretical claims. One of these studies involved the simultaneous cueing of each of two peripheral target locations, followed by subsequent target presentation. They found that the use of this experimental technique resulted in a significant reduction in target facilitation, but no corresponding reduction in the inhibitory effect. They argued that this demonstrated that facilitation and inhibition did not both arise as a result of attentional orienting - impossible in this particular situation.

Posner and Cohen's claims have since been disputed by Maylor (1985) and Maylor and Hockey (1985). Maylor (1985) repeated the above-mentioned double cueing experiment and found a significant reduction in the processes of both facilitation and inhibition. This result is one of the most powerful arguments that has led her to the conclusion that inhibitory processes are in fact dependent upon orienting of attention, and act to delay further orienting to a location sampled immediately previously. This is an important finding and will be returned to in Chapter 5. Certainly it is true, as Maylor (1985) acknowledges, that the relationship which exists between the different components of attentional orienting is a complex one and requires further detailed study.

Shifts in attention such as those described by Posner and Cohen (1984) are said to occur "automatically", inasmuch as they occur without intention. Jonides (1981) actually set out to compare such effects with internally-controlled orienting. His primary task was the identification of an "L" or "R" that appeared among seven other letters spaced around an imaginary circle. There were two conditions in the experiment: In the "peripheral cue" condition each search display was preceded by an arrowhead that was placed near one of the letter positions. In the "central cue" condition an arrowhead was also used as a locational cue, but it was placed at the centre of the display where subjects were told to fixate. On 70% of trials the cues were "valid", the remaining 30% being "invalid", and subjects participated in each of the two conditions whilst holding a variable memory load. Cost-benefit analysis of the data revealed that the greater automaticity of the peripheral cue rendered it less vulnerable to interference by the memory task. The attention capturing power of the peripheral cue was relatively unaffected by increased demands made upon processing capacity. As Jonides concludes, this is exactly what one would predict if the peripheral cue were operating in a more automatic fashion than the central cue.

As mentioned above, Posner, Cohen, Choate, Hockey and Maylor (1984) conducted two experiments which bear directly upon the issues discussed above. The design of these studies has been adopted for some of the experiments reported in this thesis. They gave subjects small blocks of trials which were not individually pre-cued. Instead each block was preceded by a symbolic cue which indicated which of two possible target locations was to be the more probable (80%, 50% or 20%) for the sequence of trials to follow. Thus a target-target procedure was employed, in a manner similar to the blocked cueing studies conducted by Posner, Snyder and Davidson (1980). Experiment 1 used R-S intervals of approximately 2000 msec and Experiment 2 intervals of between 200 and 1000 msec. As previously found by Posner et al (1980), the effects of attention were rapidly shown to disappear as each block proceeded. Additionally it was found that for both experiments when successive targets occurred on the same side, reaction times were systematically longer than when they occurred on opposite sides. These effects were very tiny for Experiment 1 but quite pronounced in Experiment 2. This effect was similar to the results reported by Posner and Cohen (1980, 1984) where responses to targets at previously stimulated locations were inhibited by about 20-30 msec when compared to the previously unstimulated locations, and was indeed attributed to the operation of the same process of inhibition - or "negative sequential dependency" in this case. Posner and Cohen (1984) reported that the effect lasted about one to one and a half seconds, and the data from studies by Maylor (1985) and Maylor and Hockey (1985) report inhibitory effects which last for an approximately equal length of time (see Section 5.2.2). The significance of these experiments will be returned to in Chapter 5.

This section has highlighted some of the internal mechanisms which relate to how we prepare for and select stimuli from visual space. Particular emphasis has been placed upon attentional orienting, its control and consequences, all of which are essentially short term phenomena. Of further interest are the processes that govern the ability to attend selectively over a prolonged period of time. This ability to maintain a focussed form of responding over time was recognised by Jerison (1977) to be a primary aspect of perceptual functioning. The section which follows examines the ability to maintain the focus of attention and remain alert in this way. This is the subject matter of vigilance research.

1.3 Sustained Attention

Head (1923) used the term vigilance to refer to a maximum level of physiological efficiency, but subsequently the term has come to refer to a state of the nervous system thought to underlie performance at so-called "vigilance tasks". Mackworth (1957) defined vigilance as "a state of readiness to detect and respond to certain small changes occurring at small time intervals in the environment" (p. 389). Origins of research in this area are rooted in the practical military problems involved in the performance of radar and sonar operators during the Second World War. Anti-submarine patrol radar operators were reported to be suffering from overstrain and were missing possible contacts. In response to this Mackworth (1948, 1950) designed a laboratory task which simulated the essentials of a watchkeeper's job (see Section 2.2.1 for details). The most widespread and consistent finding from this research and that which has been conducted in its wake is the phenomenon which has become known as the "vigilance decrement". This refers to a drop in the percentage of signals detected as time on the watch progresses. Similar decrements are reported by Adams (1956) and Bakan (1956). Also, when reaction time is the dependent variable it has been shown that the speed of response to critical signals declines over time on task (Davies and Parasuraman 1982). It is interesting to note however that under certain circumstances results which indicate a loss in alertness may in fact be attributable to a change in response criterion. This point has been made by Shaw (1984) who showed some fundamental differences between the detection of letters and of luminance increments as a function of display size. In other words the type of task may influence the exact nature of the performance effect.

Sustained Attention and Alertness

The notion of arousal has its origin in the idea of a general state which acts to potentiate all behaviour, in other words, a concept that all activity is driven by an internal energy, the availability of which corresponds to the arousal level of the organism.

Alertness refers to the level of receptivity to external signals, i.e. it is a specific aspect of arousal concerned with receptivity. Posner (1975, 1978) identifies two particular aspects of this concept. The first is that of tonic alertness, which refers to general changes in the state of the organism which occur slowly. These include diurnal rhythms, changes over life-cycle, whether a person is sober or intoxicated, sleepy or refreshed, and so on. Phasic alertness on the other hand is the term used to refer to a specific state of moment-to-moment preparedness; changes which occur at a rapid rate and are often under volitional control.

Tonic Alertness

Colquhoun (1971) reports how there is a marked change in many autonomic indicators of state over the course of a day, and a simple measure of these changes is oral temperature. Generally, body temperature rises throughout most of the day from early morning to late evening, and then falls again through the night. A number of investigators have shown how performance changes can follow a similar cycle, a good example of this being the study conducted by Blake (1971). He showed that scores in a letter-cancellation task mirrored the rise in body temperature throughout the day. Studies by Adams, Humes and Stenson (1962) and Mullin and Corcoran (1977) are just two examples of the evidence which shows that a similar pattern of results is obtained for vigilance tasks.

Thus it is clear that alterations in the level of tonic alertness can affect sustained attention performance, but it is important to note that such effects are restricted to tasks which emphasize a direct response to external stimulation only - Blake (1971) for example having shown how memory span actually declines with time of day. Davies and Parasuraman (1982) also point out that with vigilance tasks the precise attention requirements of the task and processing load are critical in determining whether or not tonic alertness effects on detection efficiency are obtained. As will be seen in Chapter 2, this latter point is of particular relevance to the issues addressed by this thesis.

Phasic Alertness

When preparing to process an incoming stimulus, a subject will show a predictable pattern of changes in E.E.G. (Lansing, Schwartz and Lindsley 1959; Walter 1964). This pattern of fast desynchronised activity and slow negative drift (contingent negative variation or C.N.V.) appears in every paradigm where subjects are told to get ready to attend closely to an external event. Related to these changes are a constellation of alterations in autonomic activity, many of which are related to the general state of sympathetic dominance that accompanies any difficult mental activity (Kahneman 1973). The exact pattern of these changes depends upon the type of mental processing involved, but the state of preparation for external signals is marked by cardiac deceleration, a reduction in blinking (Webb and Obrist 1970) and an inhibition of spinal reflexes (Requin 1969).

Many researchers have studied the effects of warning signals on subsequent responses to environmental events. Whether the response task involves reaction time (Bertelson 1969) or signal detection (Egan, Greenberg and Schulman 1961) results are similar, showing performance to be worse with no warning and improving as the warning interval increases to some optimal value. This value is usually in the range 200 to 500 msec (see Niemi and Naatanen 1981). As pointed out by these authors, optimal reaction will occur at various intervals following a warning signal depending on task requirements and structure, for example whether foreperiod is blocked or varied. Such an effect has become a commonly recognised feature of alerting signals, typically producing a U-shaped function as warning signal increases from a sub- to a post-optimal period. At this point reaction time increases, one argument for this being that subjects become less accurate at estimating the precise moment of target onset (Rabbitt 1981).

Posner and Boies (1971) have shown that such a change in rate of responding is not connected to any build up of stimulus information in the nervous system and that fluctuations in phasic alertness have a negligible effect upon such a process. They studied alertness by varying the time between a warning signal and a pair of letters which subjects were required to match, and separated this alertness from the process of selectivity by providing one of the two letters at a varying interval prior to the second. In a critical experiment they varied both "preparation" time and "encoding" time between 0 and 500 msec and showed how these processes were both contributing to an improvement in performance. From these data Posner and Boies (1971) claimed that alerting in itself is a non-selective process, though obviously it can have a separate effect leading to a specific form of preparation depending on whether the warning signal is "neutral" or informative.

It is also interesting to note that in Posner and Boies' (1971) study optimal encoding time for physical matches tended to be around 150 msec, whereas the optimal encoding time for more complex matches occurred between 250 and 500 msec. This finding, though not specifically identified as such at the time, provides evidence for the activity of both controlled and automatic processing systems. In a manner similar to that shown by Posner and Snyder's (1975a, b) studies, the point is that automatic activation facilitates the passage of messages that share the same pathway, and thus allows a rapid matching response, whereas the limited capacity system comes into operation more slowly for the matching of signals that do not share the same pathway.

1.4 The Relationship between Selective and Sustained Attention

As acknowledged in Section 1.1, the term attention is a concept with a great number of meanings applicable to a very wide range of phenomena, and because the topic of attention is a broad one, there is obviously much interdependence between the many theoretical subdivisions discussed thus far. As argued by Jerison (1977), the sustained and selective aspects of attention are clearly separate phenomena, and maintaining a general state of responding is different from maintaining a specific one. Nonetheless, as argued below, it is not the case that selective attention is totally synonymous with tonic alertness and sustained attention with phasic.

This fact is demonstrated in a study by Gostnell (1976). He measured reaction time as a function of foreperiod during early morning and late evening. Results showed a slight effect of time of day but it appeared that at intermediate foreperiods (where phasic alertness was highest) the difference between morning and evening performance disappeared. This result suggests that subjects may be able to compensate for low tonic alertness by high phasic alertness, and that phasic and tonic alerting effects operate at least in part through similar mechanisms.

Starting from a different approach and working within the automatic/controlled processing analysis framework of Schneider and Shiffrin (1977), Fisk and Schneider (1981) showed that under conditions in which attentional resources are likely to decline, only tasks which require controlled processing will show a decrement. They set subjects two versions of a detection task, one which emphasised automatic processing, where target and distractor stimuli were chosen from different sets, and another which emphasised control processing, where target and distractor stimuli were randomly chosen from the same set. They found that only the former version of the task resulted in the traditional vigilance decrement, and argued that maximizing automatic processing may reduce problems in vigilance performance.

Beatty (1982) measured the phasic pupillary dilation during performance on a 40 minute auditory vigilance task. There was the usual decrement in sensitivity over time which was accompanied by a fall in the amount of pupillary dilation. However the absolute pupillary size (an established indicator of tonic arousal level) did not change as would have been predicted, again providing evidence for the suggestion that the behavioural processes of both selective and sustained attention might share a common physiological basis (see also Parasuraman 1983).

Data such as these highlight the validity of Posner's (1975) caution against any overly strict division of attention into its supposed theoretical components. If a comprehensive study of this subject is to be achieved, then it is essential that we deepen our knowledge of the way in which these various aspects of attention are interrelated. The major aim of this thesis is to provide a detailed study of the various components of attentional mechanisms, and in particular to focus upon the way in which alterations in environmental state affect the way in which we prepare for and select stimuli. As Moray (1969b) pointed out:

> "It might well be, for example, that the relation between selective listening and arousal is such that arousal level acts as a parameter which will alter the over-all efficiency of selection and rejection as it varies. But, no systematic investigation has so far been carried out" (p. 85).

This thesis sets out to provide just such a systematic investigation with particular relevance to the mechanisms mediating orienting in visual space, further to Posner's (1980) claim already mentioned that such a study is:

"capable of providing us both with important tests of the adequacy of general models of human cognition and with new insights into the role of attention in more complex human activity" (p. 4).

CHAPTER 2

NOISE AND PERFORMANCE

SUMMARY

In the chapter which follows particular emphasis is placed upon the effects that continuous noise has upon information processing, and the state of responding it produces within the human subject. The effects of noise on performance on a number of different types of task are reported, all of which are relevant to the experimental issues examined in this thesis. It is shown how the data from a wide variety of sources point to a similar conclusion about the patterning of performance changes that noise produces. This is best summarised as an alteration in the balance of attentional priorities so that high priority aspects of a task are concentrated on at the expense of those of lower priority.

2.1 Introduction

Environmental variables will influence the processes involved with the preparation for and selection of external events discussed in Chapter 1. Such variables include noise, vibration, high or low temperatures, sensory deprivation and so on. They exert an effect on the general state of the observer, by altering his level of excitability or responsiveness, often termed arousal. The term "stress" is frequently used to refer to any unusual states or conditions induced in this way, or to the behaviour patterns associated with them. By far the most common experimental method of altering arousal level has been by means of exposure to loud white noise, the traditional agreement being that noise produces a state of heightened arousal. Although as will be seen later in this chapter this is a fairly simplistic view, evidence for this assertion is reported by Berlyne and Lewis (1963) who showed that moderate intensity white noise produces a significant drop in skin resistance. Also Frankenhaeuser and Lundberg (1977) found the level of urinary adrenaline to increase in noise.

Noise has been shown to have certain specific effects upon many aspects of performance, including the way we selectively attend to environmental events. However the aim of this chapter is not to review the whole range of these effects. Such a task goes well beyond the specific focus of this thesis, and detailed summaries can be found elsewhere, e.g. Berrien 1946; Kryter 1950; Broadbent 1971, 1978, 1981; Davies and

Parasuraman 1982; Davies and Jones 1985. These reviewers draw attention to many of the problems and theoretical issues concerning noise research, including problems of definition and measurement, the level and type of noise used by different researchers and effects specific to distracting noise bursts. In this chapter particular emphasis is placed on the interpretation of performance effects, especially those related to the experimental techniques used in this thesis. Except where otherwise stated the scope of the review is restricted to the effects of continuous noise. This is one of the most common kinds of noise experienced in the work situation and is the one used most often in research (see Hockey 1978a).

2.2 Noise and Selectivity

One of the most prevalent views concerning the effects of heightened arousal is that it has a substantial bearing upon attentional selectivity. The earliest clear exponent of this position is Easterbrook (1959) who argued that states of high emotionality, arousal and anxiety produce comparable effects on cue utilization. His hypothesis supposes that there is increased cue restriction with increased arousal; as arousal increases the processing of environmental information decreases, starting with peripheral or secondary sources and eventually restricting primary task information. Selectivity in this case can be defined as the extent to which subjects focus attention on a relatively small number of aspects of a task.

Despite the fact that the Easterbrook hypothesis has been successfully appealed to by a number of authors as an explanation for their data (e.g. Hockey 1970a, b), the model is inadequate in many respects. Eysenck (1983) criticises it by pointing out that Easterbrook (1959) regarded attentional selectivity as a somewhat passive consequence of arousal rather than as an active coping response. He argues that it is firstly an oversimplification of what is an often complicated patterning of responses to changes in arousal. He also cites data which indicate effects in the direction opposite to what the model would predict (e.g. Nottelman and Hill 1977; Deffenbacher 1978).

Another model that addresses the issue of arousal and attention deployment is that of Callaway and Stone (1963). On the basis of the effects of amphetamine on the Stroop effect these authors suggest that attentional limitation is strategic response to overload. They argue that environmental events are coded on a probabilistic basis and that this coding breaks down in a situation of high arousal, leading to attentional selectivity.

Broen and Storms (1961) suggest a different model again to explain the effects of arousal on performance. They argue that any situation defines a set of dominant and non-dominant responses. Behaviour tends towards dominant responses as arousal increases, leading to an eventual ceiling. After this point non-dominant responses continue to increase and dominate behaviour. Again, this model implies some kind of strategic change rather than an automatic response to arousal. As Fisher (1986) points out, no research has ever tested the model directly.

Wachtel (1967) criticises the "cue restriction" view of the relationship between attention and arousal. Instead he argues that attention at very high levels of arousal is best described as a beam of light with narrow width but which moves in a rapid and unstable way. This leads to a situation where the aroused person, although he has a great deal of material available, is concerned with disparate details which are poorly integrated.

In discussing responses to aversive stimuli in terms of compensatory reactions, Teichner (1968) makes a similar point. He argues that increases in activation level result in a decrease in the bandwidth of attention and proposes that with an increase in arousal or activation "the degree of regulatory activity in the tuned direction increases, and the degree of selectiveness of attention may also be expected to increase" (p. 274).

All of the above authors are describing a behavioural reaction to an increase in arousal level. With particular reference to the effects of noise on performance Broadbent (1978) details a scenario which he claims integrates the main features of the behavioural response to noise stimulation:

> "A more aroused person will select information from a smaller area of the environment. He will therefore pick up less fragmentary and doubtful information outside that area. Consequently he will rarely give qualified and doubtful judgements about, say, visual signals seen in peripheral attention; but

will give confident assertions and denials. This will be good for performance so long as the centre of attention is on the task; early in the work session this will be true most of the time. Any shift away from the task later on, may give rise to missed signals, or inefficiencies in continuous performance" (p. 1063).

The sections which follow examine the experimental evidence for this interpretation of the effects of noise on performance.

2.2.1 Vigilance

Much of the work mentioned in this chapter was part of a series of experiments developed at the Applied Psychology Unit, Cambridge in the post war years. A whole line of research has its origins in a group of studies conducted by Mackworth (1948, 1950). He simulated the task of watching for submarines from an aircraft using a radar screen by setting up a clock pointer which moved in a series of steps. The subject had to watch this pointer and report any occasions on which it gave a double step. A typical result was that the number of signals reported would decline after half an hour or so on the task. It was also noted that such a performance decrement could be removed by the provision of rest periods or knowledge of results, suggesting that the decrement may have been due to a fall in arousal or motivation. Although the exact task used by Mackworth has not always been adopted in vigilance studies its use has been widespread and it has formed the basis for the majority of studies of this type.

Several studies exist in the literature which suggest that noise has no effect on such (simple) vigilance tasks. A typical experiment of this type was conducted by Jerison (1957) who required subjects to detect an occasional double jump of a pointer moving around a dial. He compared performance on this test in noise of 113 dB (note 1) and 79 dB over a session lasting nearly two hours and found that neither detection rate nor the extent of the vigilance decrement was affected by noise. Similarly Blackwell and Belt (1971) examined the effect of 50, 70 and 90 dB noise on a 40 minute visual display task where subjects had to detect aperiodic deflections in the position of a dot of light and found that the intensity level of the noise had no significant effect upon any aspect of vigilance performance.

Such results as these have led several recent reviewers (e.g. Davies and Parasuraman 1982; Davies and Jones 1985) to conclude that noise will exert a negligible effect on performance at single-source monitoring tasks. However, as argued in the paragraphs that follow, other reviewers (e.g. Mirabella and Goldstein 1967; Hockey 1978a) show that although this may be the case, under certain conditions noise will in fact result in an alteration in performance on a simple task. The variables which induce such changes will now be examined in turn.

Time on Task

It is important to note that changes in performance due to noise in tasks such as these usually take the form of a reduction in the vigilance decrement with prolonged work. This has been shown to be the case in a number of studies. Davies and Hockey (1966) found that performance on a 32 minute visual cancellation task was improved by 95 dB noise towards the end of the work period. Tarriere and Wisner (1962) also showed that although noise did not affect overall vigilance performance, it did exert an influence towards the end of an hour and a half of testing by reducing the extent of the characteristic vigilance decrement. Similarly McBain (1961) found a reduction in the number of errors in a monotonous printing task when subjects were presented with a tape of speech played backwards.

It is particularly interesting to consider these effects of noise on vigilance performance in terms of noise serving to maintain alertness and general arousal level. This can be either through an increase in the intensity or the variety of the noise (see Mirabella and Goldstein 1967). In fact McGrath (1960) showed that the visual detection efficiency of subjects working in steady noise at 72 dB was poorer than that of subjects receiving a mixture of different noises at the same sound pressure level. In terms of the distinction drawn between tonic and phasic alertness in Chapter 1 an alteration in environmental stimulation of this type is more likely to exert an effect on the former process.

Thus such effects are more common as time on task increases (see also Section 2.2.2).

However it is not always the case that environmental stimulation resulting from noise will enhance performance. Broadbent and Gregory (1965) identify two further aspects of tasks, namely the signal rate and the number of sources of signals to be monitored, as being the major variables which will determine the exact characteristics of the effects of noise. The importance of these two factors will now be considered in turn.

Signal Rate

Noise has been found to affect the confidence with which detection responses are made in single source monitoring tasks. The proportion of doubtful responses tends to fall while the proportion of confident ones rises (Broadbent and Gregory 1963, 1965; Poulton and Edwards 1974). In noise subjects are much more likely to report that a signal definitely did or did not occur. Under normal circumstances when signals are very unlikely, people only report the presence of a signal when they have high confidence, and doubtful judgements that something is there do not produce a report. The increased certainty that results from noise will give more correct responses. On the other hand, if signals are probable, under normal conditions people report them unless they are _certain_ that there has been no signal. Doubtful judgements on the absence of a signal tend to get reported as positive detections, and because noise reduces doubt, it will also reduce the number of reports of this type. Broadbent and Gregory (1963) conducted an experiment where subjects had to report every occasion when they thought a signal might be present. They had to judge their level of confidence about each decision by one of four levels: 1) Sure; 2) Not quite sure; 3) Uncertain; 4) Not quite sure not. It was found that noise reduced reports at the intermediate levels of confidence suggesting that in noise the range over which sensory evidence is considered becomes narrower, with risky and cautious criteria becoming closer. Broadbent and Gregory (1965) confirmed this tendency in a task where regular flashes of light were required to be monitored for the occurrence of an occasional brighter flash. The task lasted for 70 minutes and two levels of signal frequency were used. Under the high signal frequency condition the number of correct detections was greater in noise than in quiet, while in the low signal frequency condition it was slightly lower. In addition to this, subjects were required to register the confidence of each response as "sure yes", "sure no" or "unsure". In noise at both levels of signal frequency it was shown that subjects were more confident about the correctness of their response.

This tendency for noise to increase confidence about the adequacy of a decision was also shown by Hockey (1973). Using Holland's (1959) observing response technique, Hockey looked at the way in which subjects inquired into the state of one of three displays in noise. The current state of each display was made briefly available when subjects pressed the appropriate button. He found two interesting trends in his data. Firstly, noise exaggerated the tendency for high probability sources to be sampled. Secondly, as the experiment proceeded, in quiet there was a rise in the number of faults reported after a second confirmatory observation ("unsure hits"), and in noise this was reduced. These two findings reflect a trend towards a diminution in uncertain responses and a bias towards sources likely to give signals. A similar bias towards making risky decisions is also reported by Dardano (1962), and Schulz (1981).

Another experiment which demonstrates the importance of signal rate and which suggests that situations which encourage a high incidence of false reporting are more likely to show an overall reduction in efficiency in noise is that of Davies and Hockey (1966). They showed that the facilitatory effect of noise on visual checking mentioned above was more pronounced for a low signal rate (24 per hour) than for a high signal rate (48 per hour). Similarly McGrath and Hatcher (1961) required subjects to monitor a flashing light for periodic increases in flash brightness and showed that auditory stimulation improved performance for the low flash rate but impaired it when the rate was high. In addition to this, as mentioned above, McGrath (1963) has shown similar results for an increase in event rate (rather than signal rate). He found that varied auditory stimulation facilitated detection of an occasional increase in the brightness of a light when it came on for 1 second and off for 2, but not when it came on for 1/3 and off for 2/3 of a second.

Despite the differences which exist between the types of tasks discussed above, they all indicate the critical nature of the information processing demands of a task in determining the precise form of the effects of changes in the noise environment. Put simply, McGrath (1963) argued that on an easy task arousing conditions will generally improve performance, and on a difficult task they will generally have a detrimental effect on performance. Sometimes effects are difficult to classify in terms of straightforward efficiency (e.g Broadbent and Gregory 1965), but such effects are illustrative of the type of fundamental reaction brought about by environmental stress, and fit well with the map of the noise state outlined by Broadbent (1978).

As far as the specific focus of this thesis is concerned, the above reported data are of particular relevance. Typically in orienting tasks (e.g. Posner, Nissen and Ogden 1978) targets occur at rates much faster than in the majority of vigilance studies. For example Davies and Hockey (1966) used a "fast" rate of only 48 per hour, whereas orienting tasks often involve the presentation of signals at rates of several hundred per hour. Obviously the two settings are not strictly comparable, but even so as situations involving a high signal rate are more likely to show a reduction in efficiency in noise then the question is raised as to whether orienting tasks will also be susceptible to similar effects.

Number of Sources

As discussed above, Jerison (1957) compared performance on Mackworth's clock test in 113 dB and 79 dB noise and found no differences in performance. However, Jerison (1959) and Jerison and Wallis (1957) showed that when three such clocks were monitored simultaneously there was a clear detrimental effect of noise upon the number of correct detections made, the effect becoming worse as time at work continued. Jerison suggested that in the three-clock situation the subject had to scan rapidly from display to display and this demanded a high degree of flexibility of attention on the part of the operator. It was further suggested that noise will impair the flexibility of attention and therefore that increasing the number of signal sources to be monitored makes it more likely that noise will impair performance.

Broadbent (1954) reports the details of another complex monitoring task where noise also had an effect on vigilance performance. This situation was the "20 dials test" in which subjects were required to watch for critical signals on 20 steam pressure gauges spaced around three sides of a room. The quality of the display was deliberately poor and the frequency of signals low (15 signals in 90 minutes). Noise at 100 dB had the effect of impairing the time taken to detect a signal, and similar results to these have also been found by Loeb and Jantheau (1958) using a closely related task. It is interesting to note that when Broadbent (1954) improved the detectability of his signals by using lights instead of dials, the adverse effect of noise on overall detection performance was removed. However an analysis of signals in terms of whether they appeared in the periphery or the middle of vision showed that there was still an increase in the speed of detection for signals in the central part of the display in noise.

Taking these two important sets of findings together Broadbent (1958a) concludes that noise is only likely to affect tasks in which attention must be shifted regularly from one source to another, and clearly one possible interpretation of the effects of noise on tasks of this type is that it produces a change in the way in which attention is allocated to the different components of a multi-component task - performance is more likely to be impaired when attention has to be divided over a number of sources of information. Putting this another way, when task demands are higher and subjects are being "strained" in their capacity to perform a task, be that due to high signal rate or a high number of potential sources to monitor, then the effects of noise may well become apparent.

Section 2.3 discusses further the complicated nature of this theory of noise effects, but in the meantime it is useful to think in terms of whether tasks actually strain an operator's capacity or not. As was shown by Stevens (1972), many simple and basic functions are undisturbed by noise. Undemanding tests of card sorting, manual skill and perceptual judgement for example are unlikely to be affected. This is because noise will result in a worker attending more closely to a task, and where the task is simple, there will be no decrement. As Craik (1946) argued, man is a very efficient "self-regulating" device and thus attentional resources can be readily concentrated more tightly upon a task, resulting in a maintenance of performance or even its improvement. This is only the case though if the experimental situation is likely to benefit from a narrow span of awareness, and not if information load is high or if attention needs to be distributed over a number of sources. Thus even with a single source of information, as a work period goes on it becomes increasingly unlikely that attention can be held in the same place with optimal efficiency. The sections which follow examine situations which impose a considerable cognitive load upon the observer, and which thus provide more appropriate experimental conditions for the study of the effects of noise on performance.

2.2.2 Serial Reaction and Speeded Responding

The serial choice reaction or 5-choice task, originally developed by Leonard (1959), has perhaps been the most widely used experimental setting to investigate the effects of stressors on performance. In this task a subject must react as quickly as he can to a series of possible light signals, each one coming on as soon as the last has been reacted to. Such a task is a good laboratory simulation of a number of real-life situations which call for rapid organised sequences of actions (e.g. switchboard operation, air traffic control, etc.).

Broadbent (1953) was the first to investigate the effects of noise on this task, which because of its nature allowed for the measurement of both incorrect responses (errors) and long responses (gaps) in performance. When it has been carried out, the duration has generally ranged from 25 to 40 minutes and performance scores are usually obtained for 5-10 minute time blocks through a session to assess effects of time. Broadbent (1953) showed that loud noise at 100 dB increased the number of errors on this task, the effect becoming evident as performance continued. Several other studies have replicated this general result (Broadbent 1957; Hartley 1973; Hartley 1974 Experiment 1; Hartley and Carpenter 1974; Jones 1983a; Wilkinson 1963 Experiment 1). In some studies there has also been a reliable increase in the number of gaps made in task execution (Hartley 1973, 1974 Experiment 2; Hartley and Carpenter 1974).

Broadbent (1958a) originally concluded that the reported increase in errors in noise on this task could be explained in terms of a distraction hypothesis. He explained the occurrence of the majority of errors towards the end of a session in noise by the fact that a practised subject would attempt to respond according to his own subjective probability of the likely next signal. This would continue when his attention had been diverted away from the task by the presence of the noise. Unpractised subjects would have no basis on which such uncontrolled motor performance could operate, and this would explain the common finding that under normal work conditions slow reactions tend to increase with time on task (e.g. Broadbent 1953).

However this interpretation in terms of inattention was shown to be inadequate by the results of studies by Pepler (1959) and Wilkinson (1959), who showed that loss of sleep increased gaps in responding on the task, but not errors. Sleep loss should surely induce a state of inattentiveness similar to that hypothesized by distraction theory and thus any idea that errors and slow reactions could both be signs of distracted attention, but that errors happened to be the exact form in which distraction revealed itself in practised subjects, was untenable.

Instead, Broadbent (1971) argues that the effects of noise on the 5-choice task could be better explained in terms of an increased inefficiency due to over-arousal. It was argued above (Section 2.2.1) that noise could affect task performance by reducing the likelihood of doubtful or uncertain responses, and on the serial reaction task the setting of a cautious response criterion would result in slow but accurate responding; the setting of a risky one in fast and inaccurate responding. Thus elevated arousal due to noise could increase biases in favour of a reaction when evidence for one is insufficient, but if this tendency were primarily a *response* bias then it would be difficult to account for the increases in the number of gaps (i.e. slow responses) which as mentioned above also sometimes occur in noise. But Broadbent (1971) argues instead that noise will induce a bias in the selection of *stimuli* rather than the selection of *responses*, and he cites a number of studies which demonstrate perceptual selection in noise in situations where an explanation in terms of response bias cannot be appealed to. He argues that noise induces a difficulty in selecting one of a number of stimuli present for reaction and ignoring another by cutting down the intake of information. A subject performing the 5-choice task in noise could thus demonstrate an increase in inefficiency of responding as measured by errors or gaps due to a reduction in his intake of information. Broadbent (1971) is able to reconcile such an argument with the results from the Pepler and Wilkinson (1959) studies mentioned above. In these experiments there was a dissociation between errors and gaps (sleep loss affecting gaps), but as Broadbent (1971) points out, the particular change in performance which is manifested may be dependent on the precise extent of the stress involved. For example a mild stress might produce an increase in slow reactions, and a more severe stress a compensatory effort which would result instead in errors. Such an account would also explain why some researchers have found noise only to affect errors while others have reported effects on both errors and gaps: The level of stress induced by the noise in the different cases might not have been identical.

This interpretation of the effects of noise upon the 5-choice task is also useful when considering the way in which other tasks involving reaction to signals are affected by environmental stimulation. Broadbent (1979) argues that if a target is not difficult to detect or if the experimental situation in which it is presented does not encourage risky behaviour, then noise will have little or no effect on reaction time. Studies by Cassel and Dallenbach (1918), Miles (1953) and Stevens (1972) all show that if a person is told to press a key as fast as possible when a visual signal is seen, and if a warning signal is presented clearly and unmistakably before the main signal, reaction time will be unaffected by noise. Such a situation is directly comparable to the conditions set up by simple monitoring tasks discussed in Section 2.2.1 above. When a subject is not strained by the constraints of the task, noise may even exert a beneficial effect on response times. Such effects have been shown by Reiter (1963) and Fisher (1983) in choice reaction time tasks and by Hockey (1969) in a 40 minute vigilance task.

Conversely, when an operator is faced with a more complex task or a demanding situation where, for example, signals may appear without any warning, noise is likely to exert a detrimental effect on performance. Where six possible target sources had to be monitored as the secondary component in a dual task situation, both Hockey (1970b) and Fisher (1984a) have shown that noise can increase overall detection latency. A similar slowing of response speed to unpredictable signals has been shown by Franszczuk (1973) and Theologus, Wheaton and Fleishman (1974), the latter experiment using intermittent noise as the source of environmental stimulation.

Any task that requires rapid continuous output, such as serial reaction and cancellation tasks for instance, will often exhibit speed/accuracy trade off patterns (see Rabbitt 1981). Von Wright and Nurmi (1979) found that noise affected performance on a speeded classification task in adults and children in different ways. For adults, errors were unaffected whilst classification time was slowed, and for children errors increased and sorting times got faster. This suggests a clear but different effect of noise on the speed/accuracy trade off in children and adults, with children sacrificing accuracy for speed and adults maintaining accuracy at the expense of speed. Data presented by Blake (1971) and Davies and Davies (1975) suggest that noise can speed up processing under certain conditions. As will be discussed in Section 2.2.4, Hamilton, Hockey and Rejman (1977) have demonstrated how noise speeded processing on a letter transformation task at the expense of reducing short-term storage capacity. However Bailey, Patchett and Whissell (1978) found that noise had no effect on performance on a cancellation task very similar to that of Davies and Davies (1975) and Warner and Heimstra (1971, 1972, 1973) argue that there is no consistent relationship between speed of performance and noise.

Therefore it cannot be said that noise will necessarily result in an increase in speed - it depends upon a variety of task factors and in particular, as Hockey (1979) argues, on the precise balance between the operations required by a given task. In certain circumstances noise can shift the balance of mental operations and as proposed by Davies and Jones (1985), it can influence the way in which the speed of responding is regulated and controlled by the system responsible for selecting appropriate responses to environmental stimuli.

Such data as those discussed above are consistent with the view that noise produces an especially focussed or concentrated form of behaviour which facilitates performance on many tasks when attention is actually concentrated on them but may result in impairment when attentional resources are divided.

The specific implication that noise is more likely to impair performance when subjects have to divide their attention over a number of sources of information is now addressed in the section which follows. The discussion will examine data from a variety of experimental situations involving a hierarchy of task demands, i.e. situations which involve the efficient allocation of attention over a number of different components.

2.2.3 Multi-Component Tasks

Bursill (1958) required subjects to perform a (primary) pursuit tracking task while reacting at the same time to an array of six light sources stretching to the periphery of vision - the secondary element of the task. He used this experimental situation to study the effects of heat on performance and showed that the effect of a rise in temperature was to impair detection of the peripheral lights more than in central vision, whilst tracking performance remained unaffected. Hockey (1970a) investigated the effects of noise on the same task, with instructions given to subjects emphasizing that the tracking task was of high priority, meaning that they should attempt to maximize performance on that component. Results indicated that the primary task was dealt with more efficiently in noise than in quiet. Efficiency was maintained in noise but showed a decrement over time in quiet. On the secondary task detection of centrally located signals was slightly improved, whereas signals appearing in the more peripheral locations were detected less efficiently. Thus the effect was not simply one of an improvement in tracking and a decrement in detection. Instead there seemed to be a within-task increase in selectivity as well as the between-task effect. Hockey (1970b) argued that there were two possible reasons for this effect:

1) Because attention was biased to the primary task in noise, the central sources on the secondary task happened to benefit in an incidental manner.

2) There was a greater subjective probability that signals would occur centrally - a sufficient basis for re-deployment of attention in noise.

Hockey (1970b) repeated his earlier (1970a) study, but in one condition ensured that objective and subjective probability of signal occurrence were identical (the "unbiased" condition). He compared performance on this version of the task with a "biased" version of the task where signals were more likely to occur centrally. Results showed that in the unbiased case there was a straightforward improvement in tracking and a decrement in monitoring as found in the previous (1970a) study. However on the biased version of the task noise decreased reaction times to central signals and increased reaction time to peripheral signals, whilst also producing a general overall facilitation on the tracking task. Thus he showed this effect not just to be a result of the spatial location of the peripheral lights, as argued by Bursill (1958), who attributed his effects to a narrowing of the visual field. Hockey (1969) also demonstrated how when the peripheral signals were themselves given a high priority, the effect of noise was to improve their detection. From these data it was concluded that an observer working in noise would devote a higher proportion of his time to the intake of information from dominant sources and relatively less to minor ones.

The picture is then that noise can increase the stronger of two concurrent activities. In terms of

Easterbrook's (1959) theoretical analysis of environmental effects upon performance, noise is associated with an increasing neglect of environmental cues, beginning with those that are least important. There is widespread additional evidence for such a view. Glass and Singer (1972) have shown that subjects performing a primary tracking task in noise show a performance decrement on a secondary digit repetition task. Finkelman and Glass (1970) found that when subjects were given a primary tracking task and a subsidiary delayed digit recall task errors occurred exclusively in the latter in noise. Bell (1978) also used pursuit-tracking as his main task, but his secondary one required subjects to indicate whether each in a series of two-digit numbers was less than or greater than the preceding number. White noise did not alter the amount of time on target in tracking but produced more errors on the number task. Hockey, Dornic and Hamilton (1975) showed that subjects in noise were better able to selectively attend to one of two interleaved messages in a selective reading task. Finkelman, Zeitlin, Filippi and Friend (1977) have presented data of a similar type showing how noise increases errors on delayed digit recall whilst subjects are also performing a primary driving task. More recently Smith (1985) has shown how noise produces an effect of attentional selectivity which depends upon signal probability rather than the spatial location of the signal per se, as found by Hockey (1970b). He demonstrated that on a four-choice serial reaction task using biased signal probabilities, noise decreased response times to signals with high probabilities but increased latencies for those which occurred less frequently. The simplest interpretation of these findings is that the increase in selectivity in noise is best described as an enhancement of attention paid to sources already being given priority with a resulting withdrawal of attention from low priority sources.

There have also been a series of attempted replications of the original Hockey (1970a, b) findings. Some of these have proved successful (e.g. Hartley 1981) and others have not (e.g. Forster and Grierson 1978; Loeb and Jones 1978). At the time these studies seriously challenged the reliability of Hockey's findings and suggested that attentional selectivity in noise is perhaps more than a simple mechanistic or automatic response to stress but involves a number of other factors. Such discrepancies led Hockey (1978b) to propose a more general version of the selectivity hypothesis, according to which at least three different patterns of results are all indicative of increased selectivity:

1) Improved main task performance with no effect on subsidiary task performance.
2) Improved main task performance with an impairment of subsidiary task performance.
3) No effect on main task performance with an impairment of subsidiary task performance.

Results from a number of studies which have required division of attentional resources across a number of task elements provide support for the above concepts of attentional selectivity. Hockey and Hamilton (1970) compared the effect of 80 versus 55 dB noise on the recall of order information on an incidental learning task. They presented their subjects with slides containing words, the position of which varied between four possible locations. This was an "irrelevant" aspect of the task but subjects were later asked to recall this positional information. It was found that in noise performance on the so-called irrelevant part of the task was impaired. O'Malley and Poplawsky (1971) have presented data of a similar kind, setting their subjects a serial anticipation task along with irrelevant peripheral stimuli. They too found a narrowing of attention at high noise levels (85 and 100 dB).

Such findings are not restricted to laboratory based studies alone. For example Matthews and Canon (1975) showed that subjects exposed to 85 dB noise were less likely to help someone pick up accidentally dropped materials than those exposed to 65 dB. In addition to this a subtle cue suggesting the legitimacy of and need for assistance - a cast on the victim's arm - increased helping behaviour in quiet only. Similarly Page (1977) has shown how the presence of construction noise decreases the likelihood of granting small favours. A similar increase in the selectivity of attention was found by Cohen and Lezak (1977) using a combination of nonsense syllables with photographs portraying a range of social settings. As in Hockey and Hamilton's (1970) study, a test of memory for incidental material was unexpectedly applied after recalling the syllables and it was found that noise depressed performance on this aspect of the task while leaving syllable recall unaffected.

One dual task study which is of particular interest and relevance to the question of attentional selectivity is that performed by Boggs and Simon (1968). Their primary task was a reaction time study that was either simple or complex, and the subsidiary involved listening for odd-even-odd sequences of digits. They showed that unpredictable bursts of white noise had no effect on the main task but increased errors on the secondary. In addition to this, the detrimental effect of noise on the secondary task was greater when a more complex (and thus more attention demanding) version of the primary task was used.

In considering these data M. W. Eysenck (1982) argues that people exposed to intense noise are only able to maintain an adequate level of performance in most primary tasks by utilizing more of their processing resources than would be needed in quiet conditions. Dornic (1977) provides evidence for a similar point of view. He found that noise had no effect upon one version of a closed-system thinking task, though self-reported effort was greater. A more complex version of the same task resulted in a performance decrement in noise, but no change in self-reported effort.

Thus there is a great deal of evidence from a wide variety of multi-component tasks that noise produces a change in the information structuring process of the subject, biasing attention resources towards high priority aspects of stimuli.

When applied to a situation of attentional orienting this fact is of particular interest, especially when considered alongside the evidence discussed in Section 2.2.2 above. Here it was argued that reaction time is less likely to be affected by noise in a situation which lacks ambiguity, but how does this fact relate to a situation which encourages the heavy commitment of attentional resources in a highly specific manner - i.e. a situation which is likely to result in noise effects? The experiments in this thesis offer an interesting test-bench by which to find an answer to this question.

The next section assesses the extent to which a noise-induced predisposition towards certain forms of mental activity and away from others is applicable to tasks involving a memory component. This issue is of direct relevance to the experiments in Chapter 6 which incorporate a memory load in their design but also bears upon the more general consideration of the way in which information load renders a task more or less susceptible to the effects of noise.

2.2.4 Noise and Memory

Reviews of the effects of noise on memory tasks have revealed a complex pattern of data. The aim of this section is not to reproduce a summary of their findings, as such an overview would be inappropriate to the thrust of this thesis. Instead the reader is referred to articles by Wilding and Mohindra (1980) and Davies and Jones (1985) for recent summaries. For a specific discussion on the relationship between arousal and short term memory, the reader is referred to an account in Fisher (1984b). This section will deal with the data which indicate how the view of the effect of noise on attentional selectivity discussed above is relevant to other spheres of mental activity.

One of the best-known studies investigating the relationship between memory for paired associates and arousal is that of Kleinsmith and Kaplan (1963). They showed that low-arousal items were better recalled than high-arousal items at short retention intervals, with the reverse being true at longer retention intervals. This result was attributed to the reverberation of the memory trace which led to greater long term recall but poor short-term availability. Despite subsequent replication, interpretation of this result is equivocal and Hamilton, Hockey and Quinn (1972) make some suggestions relevant to this problem. They conducted an experiment using four groups of subjects. Each was required to learn a set of ten paired associates either in noise or in quiet. The list pairs were either kept in a constant order from trial to trial or were randomized. It was found that noise impaired recall when the order was changed but improved it when the order remained the same. This result was taken to suggest that in noise the order of the pairs as well as the appropriate response was being learned, i.e. that the presence of the stressor was structuring attention to the list more than the quiet condition. On its own however this experiment fails to prove conclusively that this is the case, because the results are equally open to the interpretation that noise is enabling subjects to use more cues to structure information in memory rather than less.

On the basis of results from performance on a tracking and simultaneous memory task in noise and quiet, Dornic (1975) makes a suggestion which is relevant to the first interpretation of the above findings, i.e. that noise may induce subjects to rely on a more primitive type of learning strategy. Noise was associated with reasonable retention of order information but with poor item retention, and the use of a more rudimentary storing mechanism in noise would account for this. One possible explanation is that noise is leading to a reduction in the capacity of the central processor that is available for task performance and increased reliance on the relatively undemanding component of the memory system, i.e. the articulatory loop. Wilding and Mohindra (1980) have presented evidence which suggests this is the case. They tested the effect of white noise on the serial recall of acoustically confusable or non-confusable consonants and found that noise improved performance on the acoustically similar stimuli. They argued that noise not only increased the use of the articulatory loop but improved the quality of information in it.

Evidence for the suggestion that noise also reduces central processing capacity comes from the study testing memory span by Hamilton, Hockey and Rejman (1977) already referred to in Section 2.2.2. They presented subjects with a set of items of indeterminate length, and when this was interrupted, subjects had to recall as many items as possible in the correct order. Noise was found to reduce the length of running memory span. In a further study using a letter transformation task, Hamilton et al (1977) showed how intense noise improved performance when the demands on working memory were low, i.e. when only a few letters required transformation, but as these demands increased, performance was impaired considerably. Such a result would go a long way to explain the complex pattern of the effects of noise often found on memory tasks (see Davies and Jones 1985) because certain results will be obtained when one component is used and others when it is not used or is used to a lesser extent.

If noise has a tendency to increase reliance upon the articulatory loop and decrease the use of the central processor then it might be expected that it will reduce the amount of complex processing of semantic information. Hormann and Osterkamp (1966) reported that noise reduced category clustering in free recall, suggesting an interference with semantic processing. Daee and Wilding (1977) make a similar point, having found that noise produced more fragmented clustering in a memory task.

M. W. Eysenck (1975) found that noise produced a greater difference between the speeds of retrieval of "dominant" and "non dominant" memory items. These were typical and non-typical examples of a particular category paired with the category name e.g. "Fruit: Apple" (typical) vs. "Fruit: Avocado" (non-typical). He interpreted this result as indicating that arousal affected the probability of sampling from dominant sources, and as Broadbent (1978) argues, a tempting speculation is that noise produces changes of salience in retrieval from memory as well as perceptual situations. Thus retrieval of dominant items is emphasized at the expense of less dominant ones. In the light of this it is interesting to consider the results of Von Wright and Vaurus (1980) and Millar (1979a). The former also found that noise improved retrieval for good instances and impaired it for poor instances of categories. Millar found that noise speeded the recognition of blurred words, but only when the presentation of the word was preceded by a word frequently associated with it in everyday use. The feature these studies have in common is that when subjects are presented with a range of possible activities noise will tend to swing resources towards one activity and away from others. As Broadbent (1971) argues, noise is more likely to show its effects in such circumstances when items compete for attention but not when the items are present in isolation.

However it would be inappropriate to conclude from the results of these studies that noise will inevitably lead to a more primitive form of processing. Returning to Eysenck's (1975) findings that noise will enhance the processing of conceptually dominant features of the environment, Smith and Broadbent (1982) showed how such results were highly sensitive to procedural details. On the basis of four experiments they suggest that the effects of noise can depend on the retrieval strategy being employed by the subject. They argue that the effect of noise is not always to favour dominant over non-dominant associations but rather to favour the aspect of a task which is of the highest perceived priority. This conclusion is supported by a result obtained by Smith (1982), who found that noise would benefit recall of either words or locations depending on which was given priority in the instructions.

Smith (1983a) develops this position further, arguing for an interpretation of the effect of noise in terms of a strategy change. Certainly there is some evidence to substantiate the validity of his position, for example, Smith, Jones and Broadbent (1981) showing that in noise subjects may adopt different recall strategies to subjects in quiet depending on particular features of the task. The argument is that in order to compensate for an overall reduction in the availability of resources, noise will cause a shift away from low priority task components and a concentration on those with higher priority. This characteristic of exposure to noise will manifest itself in similar patterns of performance on memory as well as attention tasks.

Such a viewpoint clearly allows for many different effects of noise on performance, but also suffers from the disadvantage that we have no way of predicting exactly what the processing strategies that will be selected in noise are. This point will be returned to in Section 2.3. In general, on the basis of data obtained from studies investigating the effects of noise on memory, it is fair to conclude that the state induced by noise does seem to be one of a particularly concentrated form of activity, which produces a predisposition towards dominant, high priority forms of mental activity and away from those that are less dominant or are of lower priority.

2.2.5 Selectivity and Other Environmental Variables

As seen in the above discussion of the effects of noise on performance, the crucial assumption that high arousal produces attentional narrowing has been tested most clearly by using a paradigm which includes a hierarchy of task priorities. Easterbrook (1959) concluded that stress affected performance by narrowing the range of cues used by the stressed person. The view that the effects of noise on selectivity are mediated by arousal is supported by the knowledge that other factors which are associated with high arousal have similar effects on performance.

For example, Weltman and Egstrom (1966) reported perceptual narrowing in novice divers induced by a situation of perceived danger. Callaway and Stone (1960) found similar effects arising from the use of stimulant drugs, as have Zaffy and Bruning (1966) as a result of anxiety. H. J. Eysenck (1967) suggested that introverts are more cortically aroused than extroverts (see also Broadbent 1958b), and Amelang, Wendt and Frundt (1977) have shown how introverts perform worse on a visual reaction time task when paired with a primary memory task. Bursill's (1958) finding already reported in Section 2.2.3 and subsequently replicated by Poulton and Kerslake (1965) demonstrates that arousing heat can have a similar effect on performance. Bacon (1974) found that electric shocks impaired performance on a secondary auditory detection task when paired with a primary pursuit tracking task. Finally, in a detailed analysis of the effects of various stressors on dual-task performance, M. W. Eysenck (1982) concludes that well over half the relevant published studies produce results in line with the hypothesis that heightened arousal can induce a state of selective intake of information where one aspect of a task is given enhanced priority at the expense of another.

In the light of the above-expressed view that the activity which suffers most from stress is the one which is given less attentional priority by instructions or task demands, it is interesting to note the effects reported by Hockey (1970c). He investigated the effect of one night's sleep loss on the tracking and signal detection task described in Section 2.2.3. Results showed that impairment was evident over the task as a whole, but was particularly pronounced on the tracking component and less so on the detection of peripheral signals. Such data as these, and the related finding by Hockey (1973) that sleep loss resulted in a reduction of sampling of a source associated with high probability, indicate that loss of sleep results in a levelling of allocation priorities. Although Sanders and Reitsma (1982) present data which argue against this particular interpretaion, there is plenty of evidence from a variety of sources that environmental stress will bring about an alteration in patterns of attention.

2.2.6 Does Noise Impair by Masking?

Before continuing to an examination of the interpretation of noise effects, it is important to consider the arguments proposed by Poulton (1977a, 1979) concerning the effects of noise on masking. For an overview of this controversial area of debate in the literature the reader is referred to summaries by Eysenck (1982) and Fisher (1986).

Whilst acknowledging that noise can lead to a state of increased arousal and a corresponding improvement in task performance (see Poulton 1977b), Poulton (1979) claims that performance decrements in noise are caused by the masking of a) acoustic feedback and b) inner speech. He disputes interpretations of the effects of noise on selectivity in multi-component and serial reaction tasks by pointing out that the apparatus used in such tasks often produces an audible click which is masked by noise. Poulton and Edwards

(1974) report the results of an experiment which support this view. They found that a reduction in the frequency (and thus the masking qualities) of noise removed noise effects in a 5-choice task. Evidence against this view comes not only from a strong theoretical defence by Broadbent (1978) but also from empirical studies where deterioration of performance on one part of a task is accompanied by improvement on another in spite of the fact that acoustic cues are the same in both cases (e.g. Boggs and Simon 1968; Hockey 1970b; Smith 1985). Jones (1983a) also provides strong evidence against the masking hypothesis by finding a typical (see Section 2.2.2) effect of noise on a silent version of the serial reaction task.

As stated above Poulton (1979) also argues that noise will interfere with inner speech, thus inhibiting rehearsal loops and impairing short-term memory. He claims that noise will interfere with the duration of storage items leading to a need for more frequent rehearsal. This in turn can lead to a reduction in remaining capacity and a slowing in the rate of additional processing. Poulton's hypothesis can be tested quite simply by assuming that if noise masks inner speech then it should have the same effect as articulatory suppression. Millar (1979b) reports results which contrast with this prediction: Whether rehearsal was prevented or not, serial order information was better preserved in noise. In addition, acoustic confusions and omission errors were reduced in all conditions, arguing against masking.

Although Millar himself acknowledges that his findings "do not necessarily refute the masking hypothesis" (p. 574), they certainly cast doubt upon it as an exclusive explanation of noise effects on memory. In fact the greatest contribution that Poulton's model makes to the area is that it allows for a number of independently driven effects to influence performance. Such a mature view seems essential if our understanding of noise effects is to progress (see Chapter 7).

2.3 The Interpretation of Noise Effects

Yerkes and Dodson (1908) proposed that the optimal level of arousal is inversely related to the degree of difficulty of a task, such that more difficult ones will be impaired at arousal levels lower than those found to produce impairment in easier tasks. Such data as those discussed in the section above have often been interpreted in terms of the existence of a monotonic relation between the degree of arousal and level of selectivity. However, although a number of patterns of stress combinations do appear to fit the arousal theory (see Hockey 1984), especially studies which have investigated the effects of a number of stressors on one task, the current view is that such effects only represent part of the complex pattern of changes which occur under stress. Hockey (1979, 1984) argues that there will be a certain pattern of effects which will characterise any state of high or low arousal. Changes in performance cannot easily be described in terms of increments or decrements and many inconsistencies emerge from any attempt to map these effects onto any single dimension of arousal. Hockey and Hamilton (1983) and Hockey (1984) appeal to the usefulness of the type of analysis of the behavioural states of young infants outlined by Prechtl (1974) who described behaviour in terms of constellations of well-defined patterns. This is the way in which they wish to classify cognitive state and their adoption of this approach for analysing effects of stressors on performance, especially noise, enables a description of the total pattern of changes occurring under task performance in noise.

Hockey (1979) argues that noise makes some kind of resources more readily available and other kinds less so i.e. that noise has differential effects on the various component processes involved in cognitive functioning. Such a concept of the processes involved takes into account both the mental operations ("structural" variables) involved in task execution and also the kind of "strategic" variables discussed in Section 2.2.4 (Smith 1983a). Hockey and Hamilton (1983) distinguish between the effects of stress on these two fundamentally different aspects of performance. In a similar fashion to Fisher (1986) they point out that any such distinction between strategies of resource management and capacities of the available resources themselves is difficult to sustain, and that noise will exert an effect on both these features of behaviour.

The relationship between task demands and the way they are perceived and acted upon is obviously a complex and subtle one. Thus it is inappropriate to presume that just because a task contains more than one element performance on it will alter one way or another in noise. Hence data such as that presented by Pearson and Lane (1984) which fail to show any effect of noise in dual task performance (see also Loeb and Jones (1978) and Forster and Grierson (1978)) are not the result of any mechanistic effect of noise on performance. If it is the case, as Smith (1983a), Hockey and Hamilton (1983) and Jones (1984) all argue, that noise effects are sensitive to the particular strategies adopted by the subject and the precise nature of task demands, then until more is known about the way in which multi-component tasks are performed, our knowledge of noise will correspondingly be impoverished.

The most useful framework for the interpretation of noise effects is thus similar in flavour to that proposed by Teichner (1968), i.e. that the stressor will induce a response state which is essentially compensatory in nature. Under certain experimental circumstances which stretch capacity, noise may be shown to influence attentional selectivity, decrease the use of working memory, speed some aspects of mental processing and decrease subjective uncertainty. When a task is simple and does not impose a great information processing demand on the individual, it may benefit from the presence of noise due to the consequences of selection of information from a smaller area of the environment. But a situation which introduces factors of ambiguity or memory load, or which places a number of extra demands on the system is more likely to produce a selective change in the components of performance. Thus the compensatory effects of exposure to noise can be discussed in terms of "making life easier" for the individual concerned, in a manner similar to homeostasis. Hence the intolerance of ambiguity and specific effects on decision strategy (discussed in Section 2.2.1), and the concentration of attentional mechanisms on dominant or salient features of the environment in an attempt to maintain performance on what are perceived as high priority task components (Section 2.2.3).

The final section of this chapter goes on to discuss the relevance of some of the above issues to the questions addressed in the experimental chapters of this thesis.

2.4 Specific Issues Addressed by the Thesis

The use of the Posner-type paradigm in measuring the orienting of attention provides a potentially sophisticated and sensitive technique for the study of many of the features of the noise state. It is clear from the preceding sections of this chapter that loud noise may have a specific effect upon the organisation of an individual's behaviour, an effect which is likely to demonstrate itself in a variety of different task situations. Such manifestations are typically seen in terms of a reduction in the tolerance of ambiguity, a bias in the intake of information from dominant or high priority sources, and generally a tendency to direct activities towards what are perceived as the dominant aspects of an overall goal. Noise produces an especially concentrated or focussed form of behaviour, a state whose features are characterised quite accurately by Broadbent's (1978) general scenario (see Section 2.2).

Thus one critical question addressed by this thesis is: Will noise affect attentional orienting? If so, then in what way, and what does this tell us about the general nature of the effects of noise on performance? It was pointed out in Section 2.3 that just because a task contained a diversity of elements it did not mean that it would be sensitive to the effects of noise. Hence it is an interesting question whether attentional orienting will manifest any features of an alteration in the selectivity of attending. If the selectivity hypothesis is a tenable one then it is possible that the presence of noise will result in additional activation of the information presented in each positional cue, leading to an even greater quickening of responses to expected targets, and an opposite effect to unexpected ones, i.e. a greater slowing.

There are several reasons for choosing the paradigm of orienting to examine the effects of noise on attentional mechanisms. The first is that it provides a potential experimental setting in which to distinguish between the effects of noise on "strategic" or "structural" variables discussed in Section 2.3. For example orienting might be rather different to giving a priority to certain elements of a multisource task. Orienting is probably less affected by subjects' strategies than is a situation which allows differential sampling of environmental input. If noise does influence performance in terms of a "direct hit" on processing resources (Fisher 1986) then it will be more likely to influence a setting of this type.

As discussed in Chapter 1, the presentation of a directional warning signal immediately prior to onset of a target is a powerful means of causing subjects to commit their attention to a particular location in visual space, whilst still allowing for the possibility that a target will occur elsewhere. Thus this experimental paradigm offers an intriguing alternative to the types of dual task situation which have frequently shown how noise alters the balance of attentional priorities (see Section 2.2.3). It provides the opportunity to examine the attentional priority hypothesis in a particularly pure form. Instead of creating a hierarchy of demands across separate components of a display, in this task the differences in priority are contained within a single experimental structure.

Of particular relevance to this point is that in the experiments which follow any increase in selectivity caused by noise can only manifest itself in terms of an alteration in reaction time. Only a few experiments which have studied patterns of attentional allocation due to variations in target probability have used reaction time as their dependent variable. Hockey

(1970b) showed that responses to high priority central stimuli were speeded up and reactions to low probability peripheral stimuli were slowed down by noise, and Hartley (1981) in a replication of the experiment reported a similar result. In addition to this Smith (1985) showed that in a serial reaction task using a biased probability of target occurrence, noise decreased response latencies for high probability signals but increased latencies for signals which occurred less frequently. Hence there is previous evidence that noise can have a selective effect on the speed of responding to high and low priority events. However it was shown in Section 2.2.2 that when subjects are specifically alerted by a clear unambiguous signal in a relatively simple task situation, noise is unlikely to exert any influence on performance. In terms of the distinction drawn between tonic and phasic alertness in Chapter 1, this is broadly because noise will affect tonic alertness levels rather than those processes which are mediated by phasic alerting mechanisms. Generally speaking Sections 2.2.2 and 2.2.3 have also shown how noise is likely to affect performance in situations of complexity and ambiguity. Thus the Posner-type paradigm poses an interesting question: Will the alerting effect of centrally presented cues create a task situation which is sensitive to the effects of noise, or will the technique of cueing present a situational context where subjects are relatively free from ambiguity so that the balance of their behaviour will not be biased in any way? To this end Experiments 1, 2 and 3 in Chapter 4 provide important baseline studies for examining the effects of noise on a task similar to that used by Posner, Nissen and Ogden (1978) and described fully in Chapter 1.

Experiments 4-8 in Chapter 5 remove the specific state of preparation caused by the phasic alerting mechanisms used in the first three studies. This is in order to examine changes in attentional priorities which are free from activation caused by cueing. The precise experimental technique used is similar to that used by Posner, Cohen, Choate, Hockey and Maylor (1984) where subjects were informed as to which of two locations would be the most probable for a target to occur over a series of 10 trials.

In discussing the effects of noise on vigilance it was shown in Section 2.2.1 how important was the variable of time on task. The typical vigilance decrement described by Mackworth (1948), and shown by many studies to be removed by the breaking up of a period of monotonous monitoring with periods of rest or other activity (e.g. Wallis and Samuel 1961; Fox 1977), is also affected by noise especially towards the end of a task. This is because of the positive effect of the increase in (tonic) alertness brought about by the noise. Typically, orienting tasks are dissimilar to such sustained vigilance situations, often containing blocks of trials separated by frequent rest periods. Experiment 3 was specifically designed to remove this difference. Subjects were presented with a task containing long intertrial intervals and no rest periods - a situation thus far more similar to a traditional vigilance task and allowing for the study of the effects of noise on orienting over time.

If noise does create a state within the individual where ambiguity will be tolerated less than under quiet conditions, then a task which imposes a heavy processing load on the subject is more likely to stretch resources and result in some kind of compensatory change in performance. Hockey (1984) argues that one would expect coping with noise to be more of a problem with tasks that place heavy demands on memory as noise produces state changes whereby effort is required to maintain optimal performance. Thus the introduction of the factor of additional processing demands by means of memory load is a logical extension of the examination of orienting in noise which is considered in Experiments 1-8. In Chapter 6 details of three experiments are reported which present information concerning a series of 5 or 6 forthcoming target locations and discuss whether or not information presented in this way can be used efficiently to govern attentional orienting. In addition to this, these studies offer a rich and sensitive task structure within which are built varying levels of priority, thus again creating a novel task situation within which to study the effects of noise on the maintenance of task priorities, with the added cognitive complexity of memory load.

In addition to the these details about the content of the thesis, Chapter 3 contains information about the methodology common to all the experiments reported in Chapters 4-6, and finally Chapter 7 contains a discussion of the effects observed, their relevance to other work and some suggestions for future investigation.

Note 1: It should be noted that only a small number of studies actually give information about the weighting scale on which noise levels are measured. Although it is acknowledged along with Broadbent (1978) that this is a serious point, only general dB levels are reported in this review as none of the arguments presented here depend upon a critical measurement of the sound level for their validity.

CHAPTER 3

GENERAL METHODS

SUMMARY

This chapter contains a description of the overall methodology of experimentation adopted in the thesis. This includes apparatus, procedure, stimuli, subject details, the timing of responses and the presentation and analysis of data. Reasons concerning choice of experimental design and the controls used to counteract erroneous theorising are also given.

3.1 Introduction

All the experiments reported in this thesis share the same apparatus and similar stimuli, and so to avoid unnecessary repetition, this chapter provides a description of the basic methods used.

3.2 Subjects

The subjects were all undergraduates, postgraduates and staff at the University of Durham or personal friends of the author, themselves recent graduates. These subjects were recruited as a result of advertising campaigns throughout the University or on the basis of a personal request by the author. No attempt was made to balance sex differences, though these data are given for each experiment in this thesis. Several subjects participated in more than one of the experiments reported in the chapters that follow. All reported normal or corrected-to-normal vision and were paid for their participation at a rate of £1 per each experimental session of a length up to half an hour, and £2 for any session lasting up to one hour. Subjects were screened for normal hearing in a sound damped room on a Grason-Stadler 1702 audiometer and all those who took part in the experiments demonstrated less than 30 dB hearing loss on either ear at any of ten test frequencies covering the audible range.

3.3 Noise

The levels of noise used in the experiments were 90 dB (A) (loud condition) and 50 dB (A) (control condition), with equal levels per octave (+ or - 1.5 dB) from 25 to 24000 Hz. The noise was recorded from a Dawe Instruments white noise generator (Type 419C) onto a TEAC A-3440 tape deck. It was then amplified and played to subjects through a pair of Telephonics TDH-50 headphones. Noise levels were measured by a Dawe Instruments transistor sound level meter (Type 1400E) using a GR 1560-P83 earphone coupler.

The noise was administered through headphones because of the practical considerations involved and its advantages over free field noise: The experimental room was not sound proof and there was no group testing of subjects. It is generally clear from the literature that headphone noise causes similar alteration in task performance to free field noise, with perhaps only minor differences in the nature of their effects (see Hartley and Carpenter 1974).

In a review of the evidence, Broadbent (1979) argues that noise levels much below 95 dB are unlikely to produce changes in task performance, and in another review (1981) he suggests that levels of 85 dB and above are suitable for noise research. Certainly this seems the lower limit for the majority of noise effects reported in the literature. Broadbent (1981) also raises the ethical point that exposure to unnecessarily high levels of noise can be needlessly unpleasant, leaving aside the risks involved and the danger of damage to hearing. For these reasons and on the basis of recommended maximum noise exposure levels (Truax 1978) the level of 90 dB (A) was settled on for the loud condition, as it falls well within guidelines for safety. 50 dB (A) was chosen as the "quiet" condition as it provided a good contrast to the "noise" condition, was easily produced from the same equipment with a minimum of adjustments and was approximately equivalent to the level of background noise present in the laboratory during testing.

There are three networks (A, B and C) for the measurement of sound (see Jones 1983b), but only the A and C scales are used in practice. The C-weighting provides a straightforward pressure measurement with equal contribution from all frequencies. The A-weighted scale has the same weighting for high frequencies as does the C-weighting but attenuates low frequencies markedly in a manner similar to the human ear. Thus the A-weighting corresponds to the tendency of the ear to discriminate against low frequency sounds, and this is the rationale for using it here.

3.4 Apparatus

Presentation of stimuli, timing and the recording of responses were controlled by a Hewlett-Packard Series 200 9816 microcomputer. The space bar on the computer keyboard was the response key used to record reaction time which was measured to the nearest millisecond. The timing software for this was written by the author. A chin rest placed 50 centimetres in front of the computer screen ensured that viewing distance and visual angles remained constant. The room was illuminated completely artificially by a strip light positioned behind the subject.

3.5 Procedure

Each subject carried out the same experimental task in both noise and quiet. Half the subjects were tested in the order noise-quiet and half in the order quiet-noise. The two experimental sessions were usually on separate days approximately a week apart.

The subject was seated in front of the computer as in Figure 3.1 and the heights of the chin rest and computer were adjusted so that the subject was seated comfortably with his eyes level with the centre of the screen. Instructions were given informally by the experimenter and any queries regarding the subject's task were answered. A copy of these instructions is provided in Appendix 1. Subjects were then given the headphones the size of which was again adjusted for comfort. The noise was turned on prior to the beginning of the experiment, and for the noise condition the intensity was increased gradually over a period of a few seconds up to the pre-set maximum.

Except for Experiment 3, experimental sessions were run in blocks of trials of varying lengths, each block being preceded by the presentation on the screen of information relevant to the forthcoming block. In addition to this there was a reminder that the eyes were to remain on a central fixation point during the

Figure 3.1 : Set up for the experiments

block, i.e.: "Remember to keep looking at the central spot." A key press by the subject caused these instructions to disappear, and if this was the onset of the experiment, a number of practice trials would begin. If not, then the key press would initiate the experimental trials.

3.6 Stimuli

In all the experiments to be reported three square boxes with a fixation point inside the middle box were generated by the computer and displayed on the screen throughout a block of trials. The positions and visual angles of the boxes are shown in Figure 3.2. These are not drawn to scale. The cues were arrows and crosses occupying 0.6 degrees of visual angle both horizontally and vertically. Targets were filled squares occupying 0.25 degrees of visual angle and appeared at the centre of either the left or the right box. These stimuli are also illustrated in Figure 3.2.

3.7 Recording and Presentation of Data

It was decided to use the space bar on the computer keyboard to record responses: In other words to present subjects with a simple reaction time task. The reasons for this were twofold. Firstly Posner (1980), in considering differences between the response characteristics obtained from using choice and simple reaction time tasks within the orienting paradigm, shows the only significant difference between the two designs to be response speed. In addition to this there

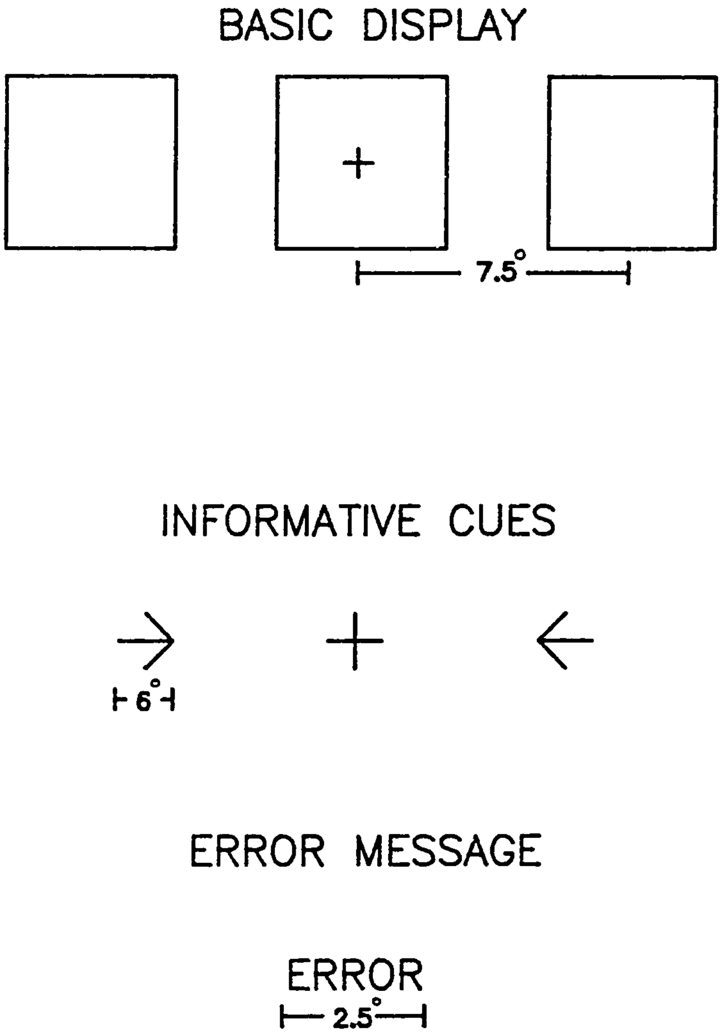


Figure 3.2 : Experimental stimuli

are several published studies where the two designs are used interchangeably (see for e.g. Maylor and Hockey 1987).

In all of the experiments to be reported the measure of central tendency of reaction time is given by the median. This is because the median is a more appropriate description of reaction time data than the mean given the positively-skewed nature of reaction time distributions (Ashby 1982). Responses which exceeded 1000 msec in latency or were less than 180 msec were treated as either missed signals or anticipations respectively and were discarded from subsequent analysis.

It is acknowledged that in certain reaction time tasks long responses might well be more frequent in noise (see Broadbent 1971 for a discussion). This is an argument for presenting the data for responses which did exceed the top cut-off point. However, as stated in Section 2.4, the main aim of this thesis was an examination of the applicability of the selectivity hypothesis to the paradigm of visual orienting. In that regard, the main area of interest of response times centres around possible differential reactions to valid and invalid targets rather than long response times per se. As will be seen in the discussion of individual experiments, error rates are very low. This indicates that the frequency of long responses is also low and therefore the median will not be affected.

The lower cut-off point of 180 msec is somewhat high for a reaction time study. It is acknowledged that as a result it is not possible to distinguish genuine anticipations from what are very fast responses. The figure of 180 msec was decided upon on the basis of data obtained from studies on visual orienting conducted at the University of Durham and reported by Hola (personal communication).

In the case of anticipations a visual "ERROR" message subtending 2.5 degrees of visual angle was presented above the central box for 2 seconds, after which the experiment continued. This was the case for all experiments. The purpose of including this error message was to reduce the number of anticipatory responses, as was the inclusion of catch trials in certain experiments (see Section 4.2.2). It is acknowledged that the provision of such information could induce a specific state of responding within the subject, leading to a sequential effect on the responses which follow (see Hale 1969; Fisher 1984b). However, as will be seen in the discussion of the reaction time data, the overall error rates for each experiment were very low so that the number of trials affected in such a way is likely to be minimal. (N.B. Responses which occurred immediately after an error were discarded from the analysis of inhibitory effects discussed in Chapter 5. They were not discarded from the overall analyses, but again, due to the low rate of errors, this point is not deemed important.)

Concerning the analyses of variance reported in the experimental chapters, main effects and interactions which did not reach significance are not usually reported. Two-tailed tests are always used. Standard deviations can be found in Appendix 2. Separate ANOVAs are usually performed both upon raw RT data and the derived measures of costs and benefits. This is because the two different presentations of the data are useful as tools for investigating the various properties of attentional orienting (see Posner 1978). Because this strategy has been planned a priori and does not involve any post-hoc "fishing" for results, it is considered justified.

3.8 Eye Movements

It is obviously important to ensure that in experiments on covert orienting of attention, performance measures are not in fact a reflection of overt movements of the eyes or head. Because of the technical difficulties involved and the inconvenience caused to the subject, eye movements were not recorded. Every experiment required subjects to fixate on a central point and instructions were clearly given as to the importance of this. Additionally, further reminders were given throughout the experiments prior to the commencement of each new block. After the experiments were completed subjects often reported that the maintenance of fixation had not been difficult, and on the basis of experiments similar to the ones reported here, Posner (1980) reports that "if subjects are told they can move their eyes on each individual trial if they wish after a few trials they give up doing so." (p. 9). Posner, Nissen and Ogden's (1978) study used similar techniques to many of the experiments in this thesis, including the overall design of the task as a luminance detection experiment, the spatial layout of the display and the range of warning signal intervals used. They found that eye movements occurred on less than 4% of trials, and that the inclusion of these trials in subsequent data analysis did not change the overall pattern of results. On the basis of this fact Posner, Snyder and Davidson (1980) did not maintain careful monitoring of eye position, justifying the procedure similarly adopted in the experiments which follow.

Having said this, it is acknowledged that there are some features of experimental design which may alter performance and encourage the use of eye movements. The first of these is the presence of loud noise. Kryter (1970) argues that loud noise may affect eye movements, but admits that such effects are more likely to be the result of vibration from low-frequency noise affecting the resonant frequency of the eyeball. The 90 dB(A) used here is unlikely to produce such effects, especially as the lower limit of the bandwidth was 25 Hz (see Section 3.3) and according to Kryter (1970) the eyeball resonates only at about 5Hz.

The use of blocked cueing designs (Experiments 4-7) might encourage eye movements, especially if one target location is known to be the likely source for a target over several trials. However, Posner, Snyder and Davidson (1980) did not monitor eye movements in their blocked cueing study, and in a recent study by Maylor and Hockey (1987) using successive runs of targets at the same location, eye movement recording was also neglected. It appears from the literature that eye movements are presumed to be unlikely even in these settings.

3.9 Experimental Design

Poulton (1982) provides an influential case for the use of between-group designs in noise experiments. He argues that for within-subjects designs, asymmetric transfer effects can sometimes occur because of the influence of a strategy learned in one condition and used inappropriately subsequently. These effects can occur because learning in the condition paired with the stress is different from learning when the stress is not present. An equally powerful argument for using within-subject designs in stress research is the sheer number of variables known to affect performance. Many authors (e.g. Broadbent 1983; Jones 1984; Fisher 1986) make this point, and therefore to keep variability due to subject factors down to a minimum, a within-subject design was favoured here. In addition to this, where noise exerted an effect on performance, the influence of the order-of-noise factor was examined. In each case the author was satisfied that the effects of noise were unlikely to be attributable to this factor. It is interesting to note that even noise effects of this type can be explained under the umbrella term of "strategy change" under noise - this point is discussed in Chapter 7.

CHAPTER 4

CENTRAL CUEING

SUMMARY

This chapter reports the results of three studies which examine the effects of noise on internally controlled covert orienting. In all three attention was directed to one of two possible target locations by a central warning signal. Using a broad range of SOAs and a blocked design, Experiment 1 showed task performance to be generally stable in noise. However there was evidence to suggest that noise was having a specific alerting effect at the shortest SOA, an effect which was specifically examined and shown to be non-generalizable in Experiment 2. Experiment 3 was a longer and more demanding orienting task and allowed an examination of the possible effects of noise over time on a task structurally more akin to those used in more traditional vigilance paradigms. Performance proved to be remarkably stable in noise, though there were some specific effects of time on task upon orienting. These data led to the conclusion that the highly alerting effects of central cueing prevent any further alteration in attention allocation arising as a result of exposure to noise.

4.1 Introduction

As explained in Chapter 1, Posner, Nissen and Ogden (1978) used differences in reaction time to targets at expected and unexpected locations in the visual field as a measure of the alignment of attention towards an expected target location. Their experimental technique is described in Section 1.2.2, and as was shown one of the most important aspects of their work was the introduction of cost-benefit analysis.

The experiments reported in this chapter use this technique of cost-benefit analysis to separately assess the processing benefit (neutral RT minus valid RT) of knowing the likely location of a target from the costs (invalid RT minus neutral RT) incurred when the target appears at an unexpected location. Experiment 1 was designed to investigate the possibility of a change in allocation of attention occurring as a result of an alteration in use of cue information under loud noise. Such a change in attention allocation could demonstrate itself as a greater commitment of processing resources to one location at the expense of another. This would arise as a result of a change in alertness level producing an alteration in the operation of the limited capacity attentional system.

Because of a suggestion from Experiment 1 that noise affects attention allocation at short SOA intervals only, Experiment 2 considers the consequences of performance on the same task with a reduction in the range of SOA intervals. Finally Experiment 3 investigates performance on a longer and more demanding version of Experiment 1 so that many of the experimental features characteristic of more traditional vigilance studies can be incorporated into task design.

It was seen in Chapter 2 that noise tends to produce a selective state of responding in the observer whereby a higher proportion of effort and time is devoted to the intake of information from dominant sources, and relatively less to minor ones. In terms of Easterbrook's (1959) analysis, noise is associated with an increasing neglect of environmental cues, beginning with those that are least important. The widespread occurrence of this phenomenon, especially in multi-component task situations, was discussed in Section 2.2. There are several ways in which a noise-induced alteration in the balance of attentional resources could be manifested in the experiments reported in this chapter. In response to the central directional cue, attention is likely to be aligned with one particular location. Both automatic activation and consciously directed attention (see Chapter 1) may be involved in this. If noise enhances the degree of commitment of processing resources in this situation, then one would expect to see a further decrease in response times to valid targets and/or a further increase in response times to invalid targets. In addition, the SOA between cue and target would allow for the investigation of whether such effects operate mainly on the limited capacity attentional mechanism or the more automatic spreading-activation process.

On the other hand, the cues used in these studies are alerting as well as being informative. As was discussed in Section 2.2.2 of Chapter 2, experimental situations where subjects are alerted to the occurrence of an unambiguous environmental event and which do not place a great demand on processing resources tend to be resistant to the effects of noise, or show an improvement with time-on-task. Thus another alternative pattern of results from the direct cueing situation is that noise will have no selective effects on reaction times to different trial types, as a result of the maximal alerting effects of the cues involved.

4.2 Experiment 1

4.2.1 Introduction

The main aim of Experiment 1 was to establish a baseline for measuring the effects of noise on a symbolic cueing task. Attention was marshalled for each trial by the presentation of the informative cue which predicted the likelihood of forthcoming target location with a probability of either 80% or 50%. This procedure is similar to that adopted in a number of other studies of spatial attentional orienting (e.g. Shulman, Remington and McLean 1979), and is specifically modelled on the work of Posner, Nissen and Ogden (1978) - see Section 1.2.2 of Chapter 1. This design was chosen because the results usually obtained from it are consistent (e.g. Spencer 1983; Maylor 1983) and clearly defined. The most straightforward prediction from the attentional selectivity hypothesis would be that noise would affect orienting to produce greater commitment of attentional resources to valid targets, resulting in a speeding of responding, and an opposite effect on invalid trials.

4.2.2 Method

Subjects

Fourteen subjects (8M,6F) participated in each of two experimental sessions in both noise and quiet. These sessions lasted approximately 45 minutes, were conducted on separate days and were counterbalanced as described in Section 3.5.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

The general procedure was as described in Section 3.5. Each experimental session consisted of 20 blocks of trials arranged into 5 equal sets of 4 blocks. Cues preceded targets by one of four SOAs: 100, 250, 500 or 1000 msec, and trials at each SOA were blocked together. Thus each SOA occurred once within each set of four blocks, presented in a random order.

The distribution of trials for this experiment is shown in Figure 4.1. There were 720 trials in total and each block contained 36 trials of which 10 were neutral. For these trials the target occurred on one side of the fixation point on 5 occasions and 5 times on the opposite side. There were 20 arrow cued trials, 10 pointing to one side and 10 to the other. The direction of the cue was valid on 8 trials and invalid on 2 in each direction. In addition to these there were 6 catch trials when just the locational cue but no target occurred. Of these 2 were neutral trials and 4 were arrows. Subjects were required to withold from responding on such trials. The aim of including these trials was to prevent anticipatory responses, to which subjects were particularly susceptible due to the blocked design.

SUMMARY OF CONDITIONS IN EXPERIMENT 1

5 Identical sets, each containing 4 blocks
Each block contains one of 4 SOAs

36 trials within each block

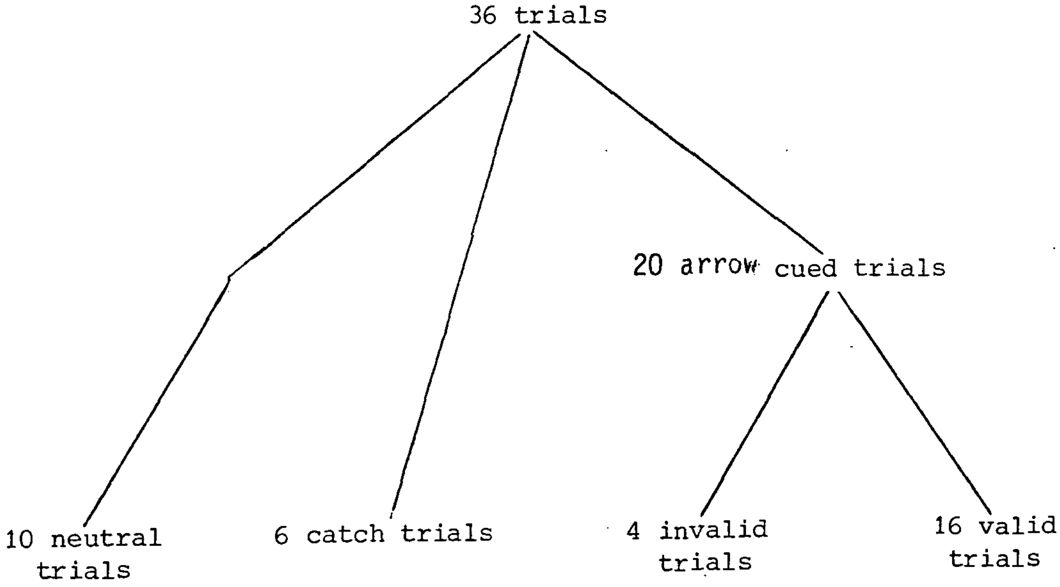


Figure 4.1

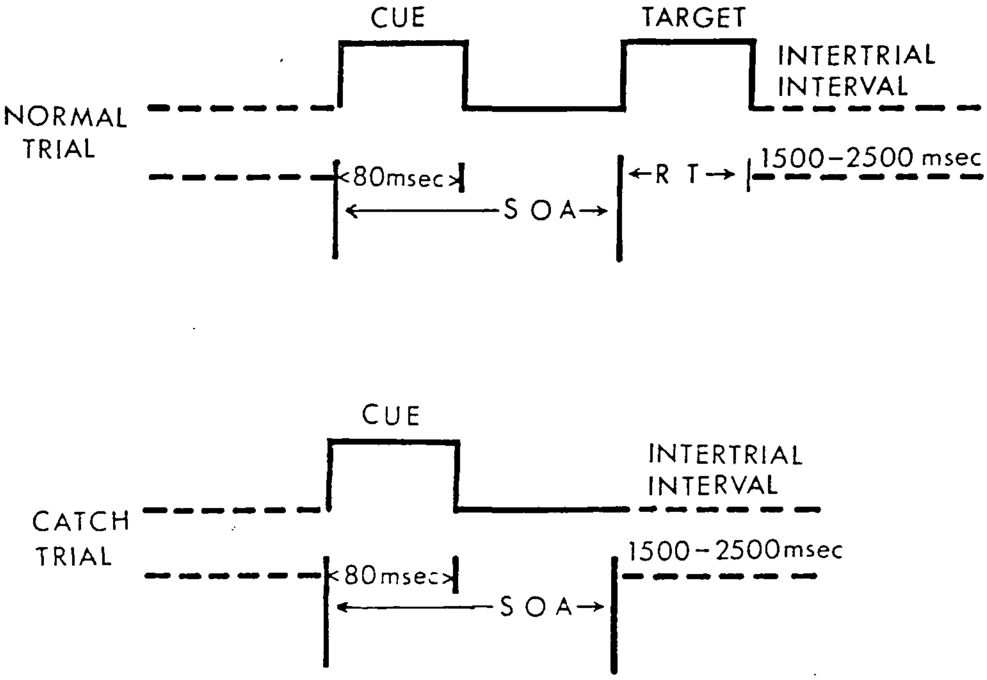


Figure 4.2 : Timing of trials in Experiment 1

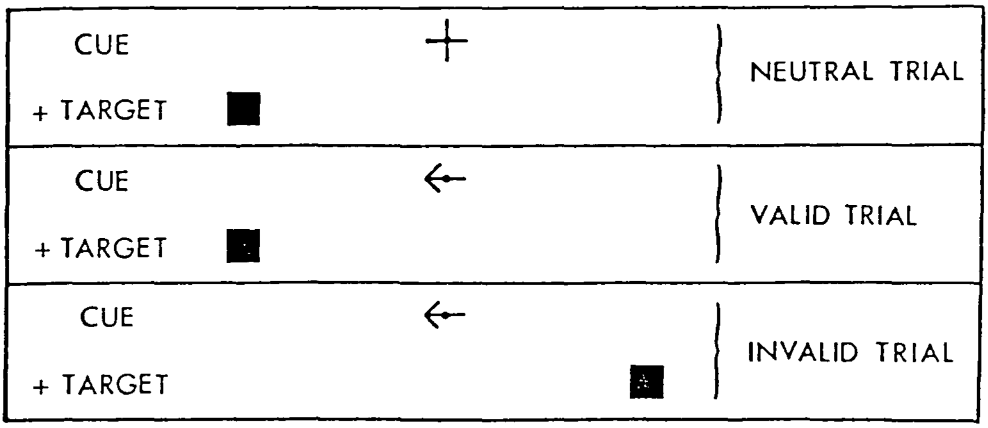


Figure 4.3 : Coding of trials in Experiments 1 - 3

If on any trial subjects did anticipate and respond during the SOA, then an anticipation was recorded and the trial deleted from subsequent analysis along with excessively short or long responses as detailed in Section 3.7. At the end of a block the total number of anticipations made in that block was presented to subjects, again in an effort to reduce such responses.

The blocks differed only in the length of the SOA operating for that group of 36 trials. Prior to the commencement of a block subjects were reminded to maintain central fixation and told of the length of the next SOA (e.g. "The delay in this block is 0.5 seconds") and a key press initiated 6 practice trials at the new SOA before the experimental trials began.

The timing of an individual trial is summarized in Figure 4.2. At the start of the trial one of the three possible symbolic cues appeared for 80 msec and was followed after the SOA on 30 out of 36 trials by the target which disappeared when a simple detection response had been made by the subject, or after 8 seconds if no response was made. An intertrial interval randomly chosen from the range 1500 to 2500 msec occurred prior to the onset of the next trial. On catch trials no target was presented and the next trial sequence began, again after the SOA and the intertrial interval had elapsed. The coding of the trials is shown in Figure 4.3.

4.2.3 Results and Discussion

General Effects

For each subject the median reaction times were taken for each type of trial for the four SOAs in both noise and quiet. Figure 4.4 shows the means of these medians for all fourteen subjects, from performance in both noise and quiet. Error rates were 2.98% (quiet) and 2.77% (noise).

The first thing to note about these data is that they replicate the general kind of result found by other researchers using a similar technique (e.g. Posner 1980). Quite clearly there is a difference between reaction times to the three different trial types, expressed (in Figure 4.5) as a benefit from knowing where a target will appear in the visual field, and a cost when it appears at a location other than the expected one. These derived measures were obtained by applying the technique described in Section 4.1 on the median RT for each subject. The means of the data so produced are plotted here. This is the technique used for obtaining the cost/benefit measure throughout this thesis.

Looking at the overall data there is a sharp decrease in reaction time followed by a slight increase as SOA increases from 100 to 1000 msec for all types of trial. This effect arises from the temporal warning properties of the cue and is typical of the alerting effect described by others in the literature (e.g. Posner and Boies 1971; Posner and Snyder 1975a, b; Niemi and Naatanen 1981). When cues are used in simple

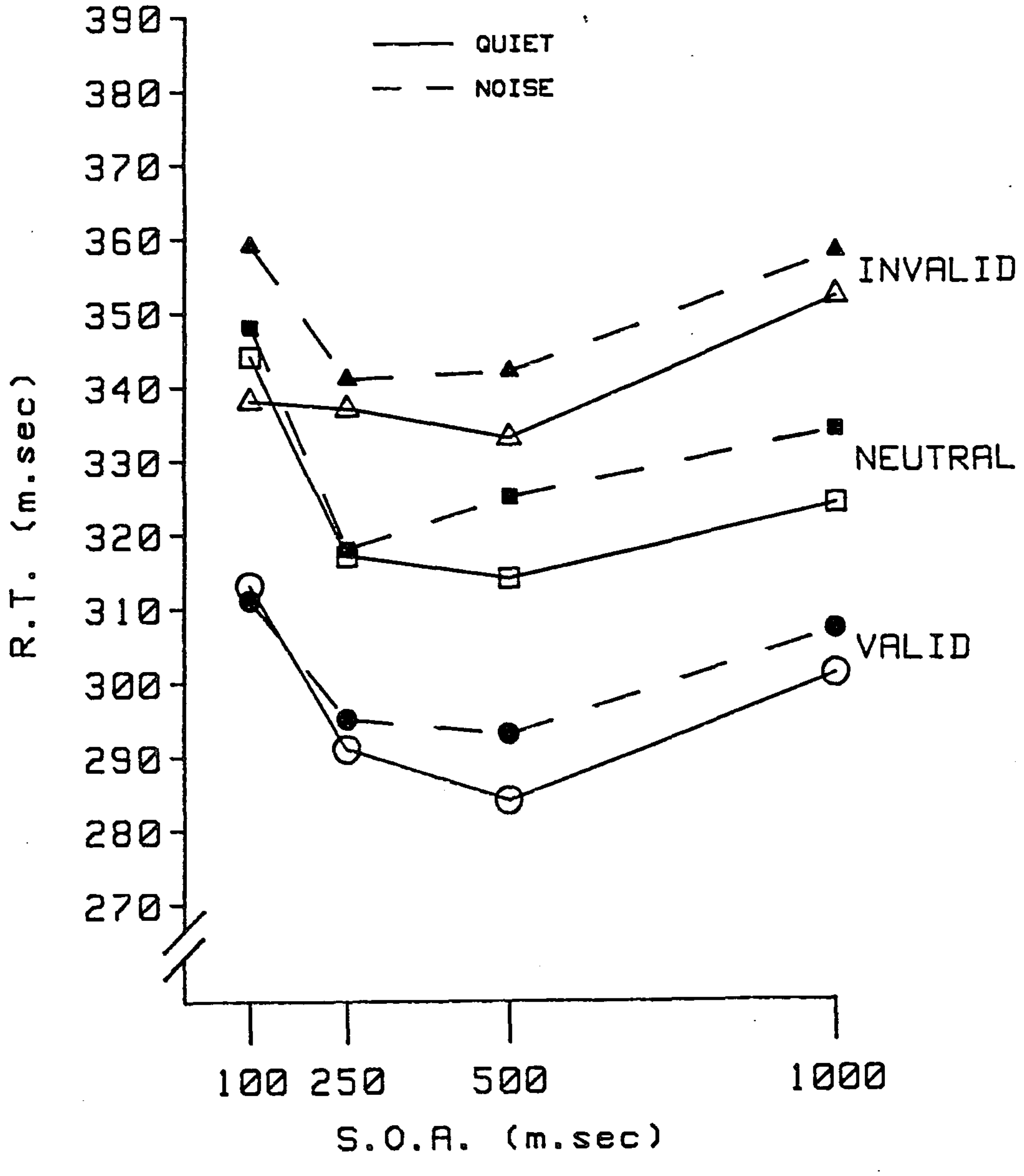


Figure 4.4 : Results from Experiment 1 - Reaction times

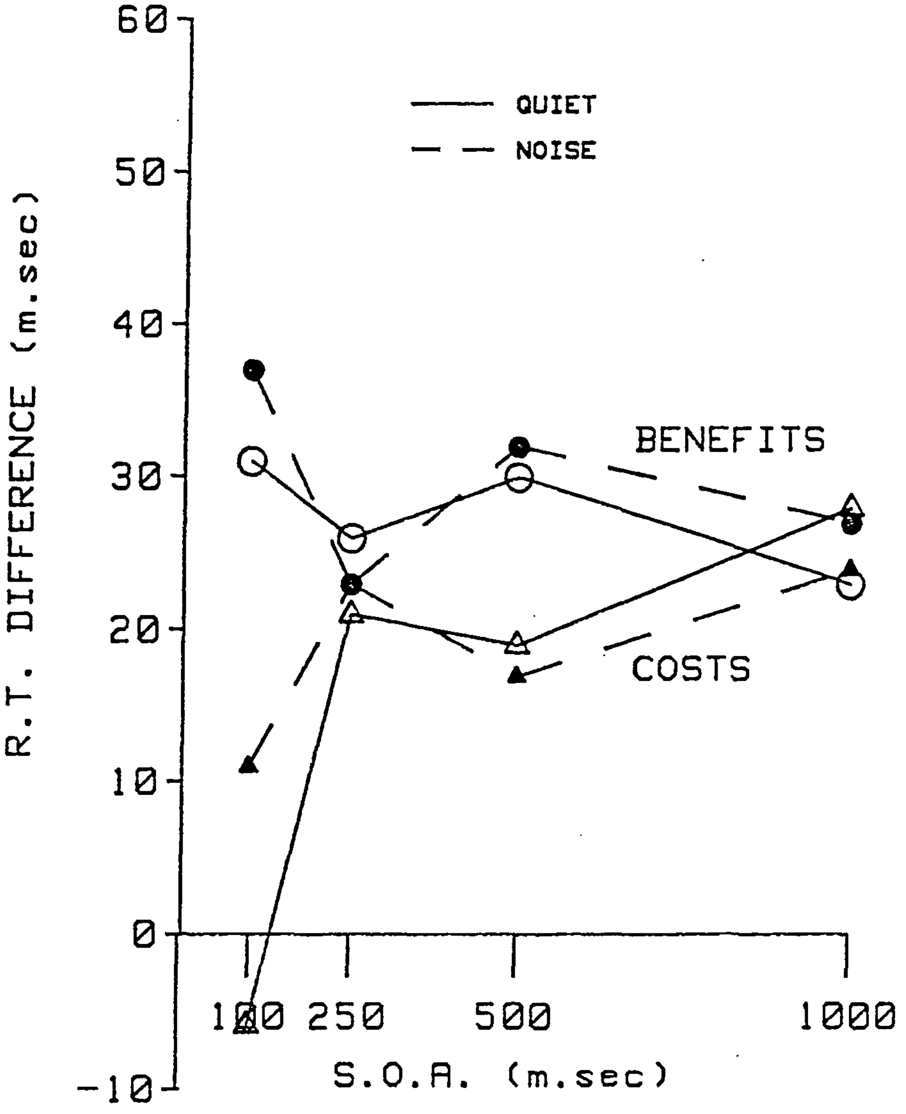


Figure 4.5 : Results from Experiment 1 - Costs and benefits

reaction time tasks subjects require a fixed minimum SOA to prepare optimally for a subsequent target. In this particular experiment the optimal SOA for prediction of target onset is 250-500 msec, and as the SOA increases subjects become less accurate at estimating SOA duration and show a corresponding reduction in their ability to predict target onset (see Rabbitt 1981).

These observations were confirmed by a three-way analysis of variance (noise level x SOA x trial type). There were highly significant effects of both SOA [F (3,39) = 18.89, $p < .001$] and trial type [F (2,26) = 97.18, $p < .001$], and a significant interaction between the two [F (6,78) = 5.76, $p < .001$]. Figure 4.5 shows the same data expressed in terms of costs and benefits. Clearly on the basis of expected input attention can be deliberately oriented toward a sensory event, producing a bias towards the pathways activated by that expected input and an inhibition of processing in pathways not already activated.

From Figure 4.5 it is interesting to note that costs clearly increase across SOA, a result which is consistent with what is known about the time course of the development of pathway activation, as first discussed by Posner and Snyder (1975a, b). The fact that benefits are much higher than costs at the early SOA is unusual (compare with Posner, Nissen and Ogden 1978). This is attributed to longer RT for the neutral condition when SOA is short - i.e. it is probably a result of a sub-optimal warning period. A three-way analysis of variance performed on these data (noise level x SOA x cost/benefit) showed the interaction between SOA and cost/benefit to be highly significant [F (3,39) = 13.85, p < .001]. There was also a main effect of SOA [F (3,39) = 4.13, p < .02]. Highest costs are shown at the longer SOAs (see also Figure 4.6), with benefits remaining high from the outset. Again this is consistent with much of the alerting literature (e.g. Spencer 1983). Thus the data clearly reflect the operation of internal processing mechanisms resulting from active shifts in attention (as found by Posner and Snyder 1975a, b), but what are the effects of noise on this task?

Effects of Noise

The analysis of variance performed on the raw reaction time data shown in Figure 4.4 failed to show any overall effects of noise on the task [F (1,13) = 1.52, p > .1], nor were there any significant interactions between noise and the other two factors. There appears to be a difference in reaction time at SOA 100 for invalid trials, noise and quiet, although the noise x SOA x trial type interaction was non-significant [F (6,78) = 1.70, p > .1]. A simple effects comparison between these two points showed the difference between them in fact to be significant [F (1,13) = 20.5, p < .01].

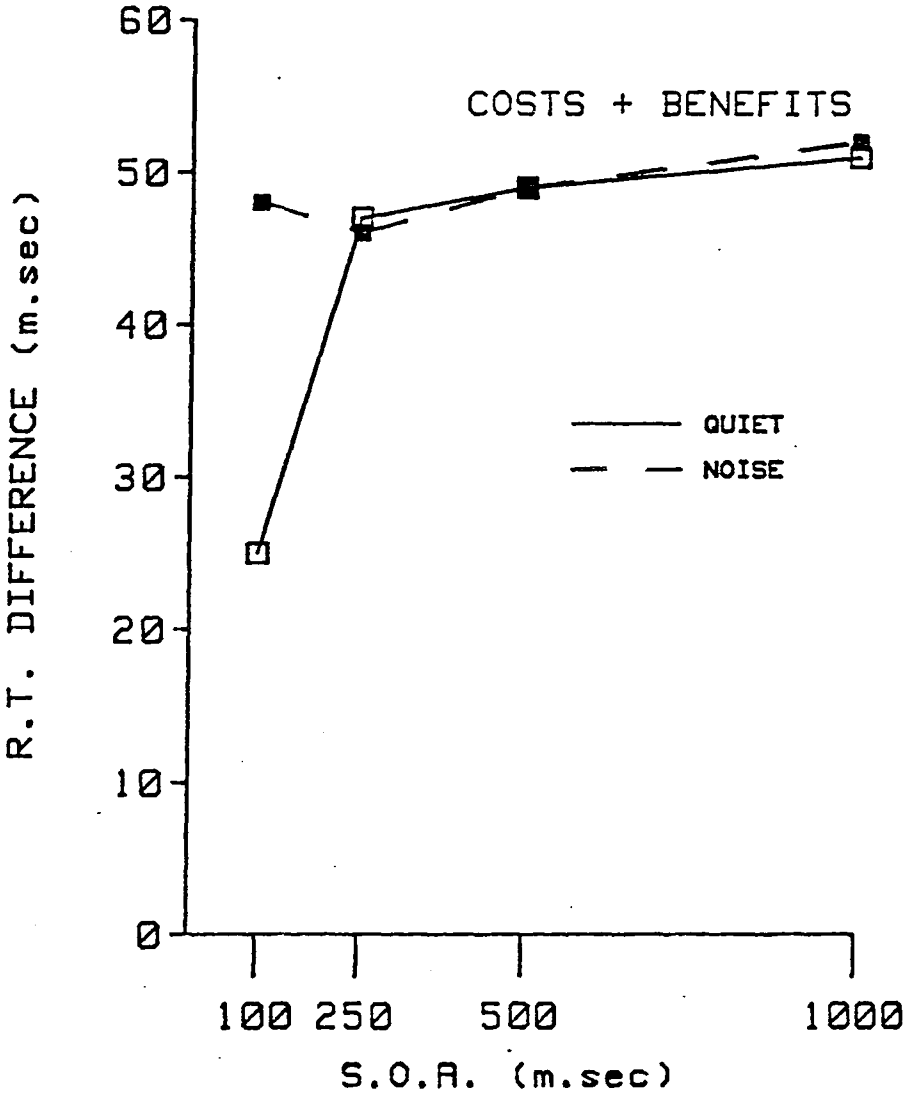


Figure 4.6 : Results from Experiment 1 - Costs-plus-benefits

Returning to the data plotted in Figure 4.5, the result of this difference can be seen in terms of costs and benefits. There was no main effect of noise on this presentation of the data [F (1,13) = 1.1, p > .3] but there was a significant interaction between noise and SOA [F (3,39) = 2.9, p < .05]. This effect is most likely to have its origins in the increase of both costs and benefits at SOA 100 in noise. These differences in reaction time are also responsible for the difference in the measure of costs-plus-benefits in noise and quiet visible in Figure 4.6. This measure is defined by Posner (1978) as an overall indicator of cue use, and is simply another way of expressing the difference between reactions to valid and invalid targets.

In terms of what would be predicted from the selectivity hypothesis (see Section 4.2.1), this suggests that subjects are able to utilize response information more fully in noise as opposed to quiet at the fastest SOA. As these attentional mechanisms are generally supposed to be active in nature (see Chapter 1), this result suggests that subjects may be able to process positional information more actively in noise in situations where normally such processing is automatic. If pathways are usually primed automatically at SOA 100 (resulting in high benefits but low costs) then these data seem to indicate that subjects performing in noise are in fact responding somewhat differently. There is an earlier commitment of conscious attentional mechanisms than is usual. It is unlikely to be the case that noise is exerting an effect on automatic pathway activation because costs are increased in addition to benefits. In fact this increase is mainly what is responsible for the corresponding rise in the measure of costs-plus-benefits seen in Figure 4.6.

So one possible interpretation of these data is that subjects demonstrate a more rapid commitment of attentional resources under conditions of increased arousal, which results in a greater active processing of positional information. Such an interpretation is in keeping with the view that noise induces a particularly heightened form of responding which will result in a more selective and intensive allocation of processing resources. However by the same token it could just as easily be argued that the effect discussed above arises mainly from the fact that performance on invalid trials at the early SOA in quiet is the aspect of behaviour which is particularly aberrant. Reaction times for this condition fall consistently beneath those recorded for neutral trials, with 11 out of the 14 subjects demonstrating this tendency. It may be the case that noise is resulting in a real change in information processing, or it could be that these results are simply a type one error. Experiment 2 was conducted to decide between these two alternatives.

Overall, it is true that there are no indications of an <u>overall</u> change in patterns of selectivity in the task. This leads to the conclusion that the warning signal, presented clearly and unmistakeably before target onset is reducing ambiguity to such an extent that noise is not forcing subjects to respond in any compensatory manner. It is reasonable to conclude that the phasic alerting effect of the cue is resulting in a specific state of preparation within the subject which results in performance being resistant to additional environmental arousal. Thus although there may be a specific effect of noise on performance at the shortest SOA, it is important that there are no effects at later SOAs. Here consciously controlled orienting is in full operation and demonstrates itself to be resistant to the effects of noise.

4.3 Experiment 2

4.3.1 Introduction

As stated above there were no general effects of noise on performance in Experiment 1, but it was possible that noise was having a limited but highly specific additional alerting effect at the fastest SOA. Thus Experiment 2 was conducted to test the generalizability of such a small effect by a specific manipulation of the length of the SOA variable. The prediction was that noise would heighten attentional selectivity, resulting in slower RTs for invalid trials in noise. Essentially there were two possible results from this study which would decide between the two interpretations of the effects obtained from Experiment 1. These were either a replication of the noise effect at short SOA intervals, which would suggest an effect of noise upon attentional selectivity, or no such alteration in response times, which would indicate the effect to be of little general applicability.

4.3.2 Method

Subjects

Fourteen subjects (8M, 6F) took part in two twenty-minute experimental sessions in noise and quiet on separate days, counterbalanced as described in Section 3.5.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

The general procedure once again followed the pattern outlined in Section 3.5. The specific procedure relevant to this study closely resembled that employed in Experiment 1. The proportions of valid/invalid trials remained at 80/20 but as the primary result of interest arising from Experiment 1 centred around what happened to responses to invalid trials, there was no neutral condition in this experiment. This was excluded because it was felt that neutral trials had not contributed in any way to the effect found in Experiment 1. The predictions concerning the outcome of these experiments manipulating noise and orienting centre mainly on what will happen to responses to valid and invalid trials (see Section 2.4). In that sense, responses to neutral trials are less interesting, and it was considered omitting then from Experiment 1. Despite the fact that their absence in this study reduces the comparability between Experiments 1 and 2 further, it is argued that as the main aim of this study was to test the generalizability of the finding from Experiment 1, this is not crucial. In fact Jonides and Mack (1984) argue for the omission of the neutral condition in studies such as these as a general policy.

The distribution of trials is shown in Figure 4.7. There were 288 trials in all, occurring in two sets. Each set contained 4 blocks of 36 trials, one at each of the four SOAs. As this study was designed to focus on the effects of noise on short warning intervals, the SOAs used in Experiment 1 were altered to 80, 120, 160

SUMMARY OF CONDITIONS IN EXPERIMENT 2

2 Identical sets, each containing 4 blocks

Each block contains one of 4 SOAs

36 trials within each block

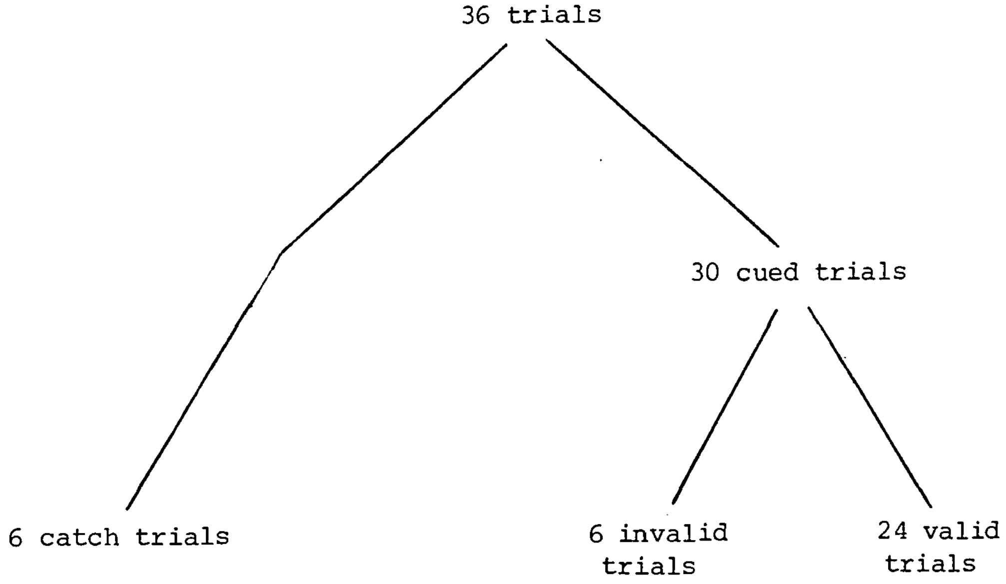


Figure 4.7

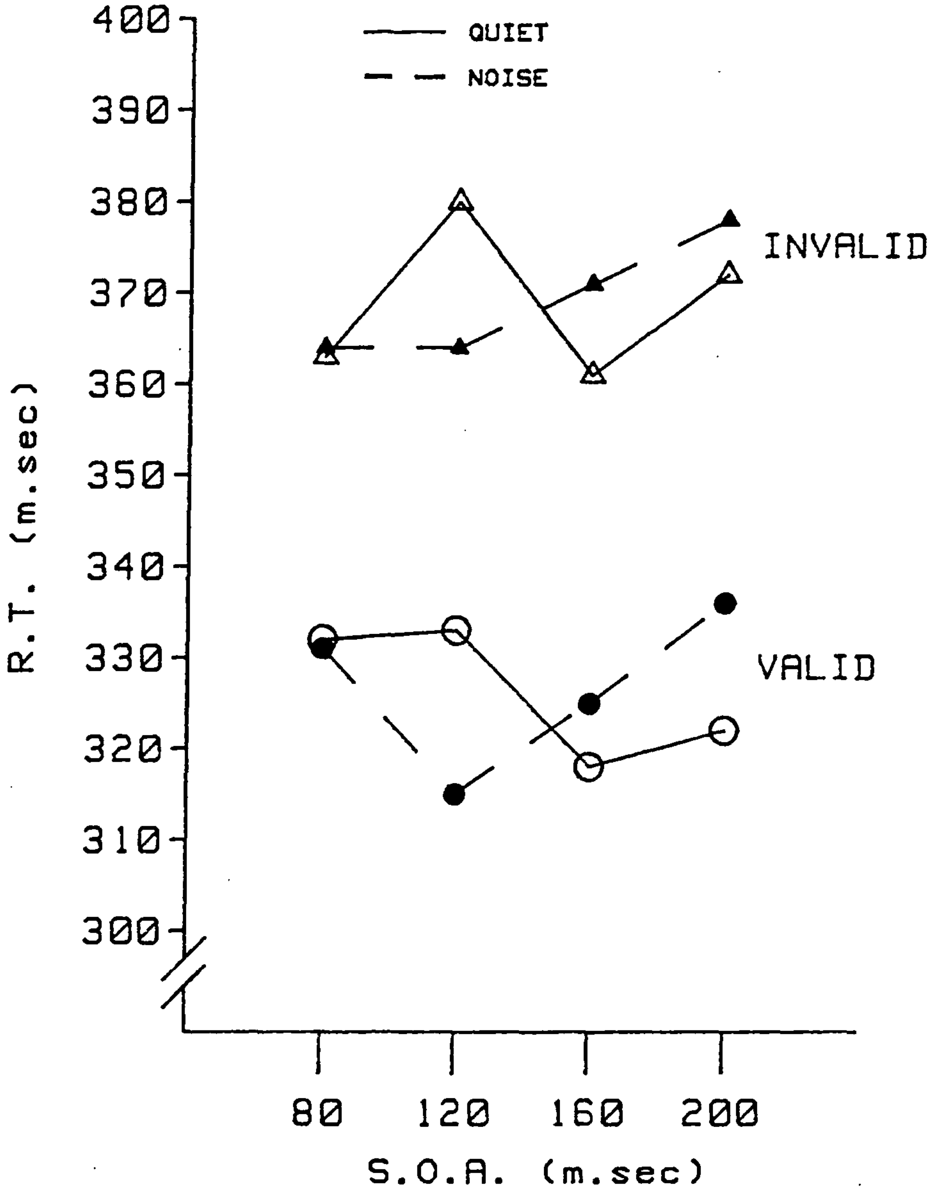


Figure 4.8 : Results from Experiment 2 - Reaction times

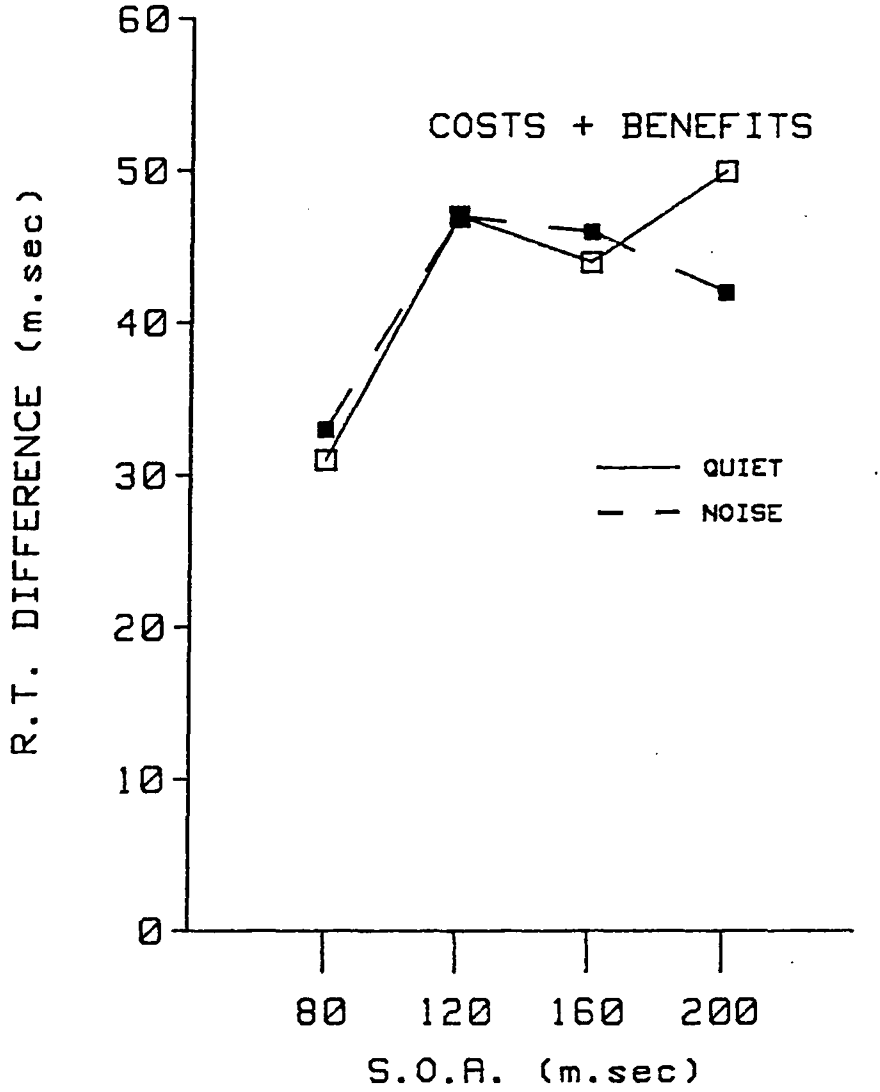


Figure 4.9 : Results from Experiment 2 - Costs-plus-benefits

and 200 msec. It is acknowledged that this choice of intervals does not give an SOA of 100 msec and so provide a point of direct comparability with the effect from Experiment 1. However, this was not deemed important as the aim of this experiment was to test the generalizability of the earlier finding. If the effect were robust then it would be manifest in this setting also. In all other respects the experiment was identical to Experiment 1.

4.3.3 Results and Discussion

General Effects

Error rates were 3.7% (quiet) and 3.85% (noise). As before, median reaction times were taken for each type of trial for each of the fourteen subjects, and the means of the medians are presented in Figure 4.8. They were entered in a three-way ANOVA (noise level x SOA x trial type). It is clear from the figure that subjects are benefitting from accurate information about forthcoming target locations, with reaction times for valid trials being faster than invalid across all SOAs [F (1,13) = 33.77, p < .001]. One particular point of interest is that there was no change in reaction time as SOA increased [F (3,39) = 0.46]. In other words the standard warning signal effect (see Section 1.3) which commonly produces a decrease in reaction time as a function of SOA, is absent. The precise reason for this is unclear.

Effects of Noise

It is also clear from Figure 4.8 that noise is not having any effect on performance of the type previously reported. Both main effects [F (1,13) = .02] and the noise x SOA x condition interaction [F (3,39) = .14] were non-significant. This is also seen in Figure 4.9 which presents the measure of costs-plus-benefits (i.e. invalid response times minus valid response times). Clearly noise is having no effect of the type described in Section 4.3.3 on this task, for if it were the use of cue measure would be higher for noise than for quiet. A two-way ANOVA (noise level x SOA) showed that this is not the case, there being no effect of noise: [F (3,39) < 1]. This suggests that the effect found in Experiment 1 is not a generalizable one, and is perhaps simply a type one error. In fact if the effect were an important one and a general feature of behaviour under noise then one might not expect it to have disappeared with the type of structural changes introduced in this experiment.

Therefore the main conclusion from these two baseline studies on the effects of noise on internally controlled orienting is that the stressor is not resulting in any differential state of responding to high or low probability events. Instead, overall performance is generally stable across conditions of both noise and quiet. It is concluded that this is mainly due to the fact that the alerting produced by the warning signal is maximal, causing subjects to respond in a precise and concentrated manner. Such a task, where attention is locked on to a target by clear information is not the most usual situation where noise has an effect on the selectivity of performance. There are of course other aspects of task structure which render this situation of attentional orienting very different to many early sustained attention studies. Although concerned with the detection of and response to visual targets, frequently these tasks were unbroken by rest periods and involved the presentation of signals which were not preceded by any warning (see Chapter 2, Section 2.2.1). Thus although the structure of these tasks is important in interpreting the results of Experiments 1 and 2 the length of uninterrupted time on task may well be another feature relevant to the pattern of noise induced performance effects. This question is addressed by Experiment 3.

Of course Experiment 2 cannot be seen as an exact replication of Experiment 1 for a variety of reasons. Firstly the structure of the task was different inasmuch as there were no neutral trials in Experiment 2. This resulted in a greater overall proportion of cued trials occurring in each block (30/36 as opposed to 20/36 in Experiment 1). However it is unlikely that any such alteration would affect the specific effects of pathway activation responsible for the difference in response times to valid and invalid trials. In addition there were no trials occurring with an SOA of exactly 100 msec, but it is unlikely that any reliable effects present at an SOA of 100 msec would disappear at other intervals differing by only 20 msec either way.

A possible reason for the result obtained from Experiment 1 is that it arises from the fact that the SOA of 100 msec is the shortest of the four used in the task, and is subjectively perceived as being so, leading to a specific state of performance associated with the fastest warning signal alone. Thus it is not the length of the warning signal that is of specific importance in itself but the range across which the warning signals vary. Subjects could be forced into a higher state of preparation than would ordinarily be the case simply as a result of the nature of the demands of the task. Thus in Experiment 2, with a completely different range of SOAs (with a maximum difference of 120 msec) the same experimental situation is not being reproduced.

However a comparison of median reaction times from Experiments 1 and 2 shows that when the absolute value of the SOA is low, reaction time is *not* reduced, discounting the range effect explanation:

Experiment 1:

SOA:	100	250	500	1000
RT:	336	317	315	329

Experiment 2:

SOA:	80	120	160	200
RT:	348	348	344	352

It is acknowledged that this comparison is across two experimental settings which vary in the aspects already noted above, and should be treated accordingly. The general slowing of reaction time in Experiment 2 is attributed to the fact that the SOAs used do not facilitate optimal responding. An examination of Figure 4.4 shows how responses at SOAs 100-250 are falling (see also Figure 4.12) from a sub-optimal value.

4.4 Experiment 3

4.4.1 Introduction

Experiments 1 and 2 were concerned with the detection of and response to visual targets in a way which was similar to much previous work on vigilance behaviour. This was true with respect to the general aims of the tasks but as discussed previously, they employed an experimental paradigm which was at the same time far removed from the early vigilance paradigm (e.g. Mackworth 1950). It was concluded that some specific features of the experiments were not conducive to an examination of effects resulting from environmentally induced changes in tonic alertness levels, especially the informative cue which preceded every trial. Experiment 3 was designed to create a setting which more closely resembled the type of sustained vigilance task referred to in Section 2.2.1.

It was discussed in Chapter 2 how noise often exerted an effect on such tasks towards the end of a prolonged period of work, and indeed, Broadbent (1979) argues that one of the conditions most conducive to the production of the effects of noise on performance is that the task should be long and uninterrupted. Experiment 3 was designed to produce a lengthy and demanding task situation which took this factor into account, whilst still maintaining the creation of specific expectations for forthcoming environmental events. Thus it still afforded an interesting setting within which to explore the effects of noise on selectivity. In addition to the simple fact that this experiment, by dint of being long and uninterrupted, afforded this particular examination of the effects of noise on orienting, Experiment 3 provided a sensitive study of changes in orienting behaviour over time. This is particularly interesting because of its implications for the relationship between the phasic and tonic components of attention (see Section 1.4). The effects of practice and/or fatigue on attentional orienting are not documented in the literature, and thus this study sheds new light on the question. In addition it addresses the issue of the possible interaction between the effects of noise and time on task on performance.

Another feature of Experiment 3 is that it presented subjects with a more demanding task than those used hitherto, not just because it was longer but because intertrial intervals were extended. It was seen in Chapter 2 that experimental situations which placed high processing demands on subjects were more likely to show a noise-induced alteration in performance and a change in this particular aspect of task structure results in subjects simply not knowing when the next cue will occur. Thus further uncertainty results. It could be argued that in fact this change would result in subjects doing less processing per unit time than would otherwise be the case. However this ignores the fact that the nature of the task means that constant watchfulness is essential for optimal performance. In other words subjects will have to concentrate in a more intensive manner for longer.

In addition to these changes it was decided not to block the presentation of trials at different SOAs. This would firstly remove much of the predictability of the task and secondly allow a study of the effects of noise on the same range of SOAs as used in Experiment 1. Experiment 2 had shown that the effect from Experiment 1 was unlikely to be of any major interest and so the short SOAs were removed. If the Experiment 1 effect were generalizable, then it was predicted that it would re-appear in this setting.

4.4.2 Method

Subjects

As in Experiments 1 and 2, fourteen subjects (8M, 6F) participated in two experimental sessions, in both noise and quiet. The sessions lasted one hour, were run on separate days and were counterbalanced as described in Section 3.5.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

Apart from the general details given in Section 3.5, the specific procedure employed in this experiment was as follows. Each experimental session consisted of 704 trials, 176 trials occurring at each one of four SOAs (100, 250, 500 and 1000 msec). Trials at different SOAs were presented in a random order.

The distribution of trial types is shown in Figure 4.10. There were no rest periods in this experiment, as discussed above, but the task was divided into four identical blocks of 176 trials in order to allow for a comparison of the effects of performance over time. Subjects were unaware of this division as the blocks continued one after another. They contained 44 trials at each SOA. Thus the proportion of catch trials was lower (9%) than for Experiment 1 (16%), because it was presumed that the removal of the blocked SOAs would reduce the occurrence of anticipatory responses. As in Experiment 1 any anticipations - i.e. key presses made during the SOA - were deleted from subsequent analysis along with all excessively short or long responses as detailed in Section 3.7. Prior to the commencement of the experiment subjects were reminded to maintain central fixation throughout and a key press initiated 18 practice trials (4 at each SOA and 2 catch trials).

The timing of trials for this experiment is shown in Figure 4.11. As can be seen, the only difference between these trials and those in Experiment 1 lies in the variability of the intertrial interval. In this case it ranged between 2000 and 5000 msec. As discussed above such a change would increase the uncertainty of the occurrence of each trial. This, coupled with the uninterrupted nature of the whole experiment - taking 60 minutes to complete - increased the overall demands made upon subjects' attention capacity. The symbolic cue appeared for 80 msec, and was followed by the SOA

SUMMARY OF CONDITIONS IN EXPERIMENT 3

704 trials, in 4 blocks of 176 trials.

44 trials presented randomly at each of one of 4 SOAs

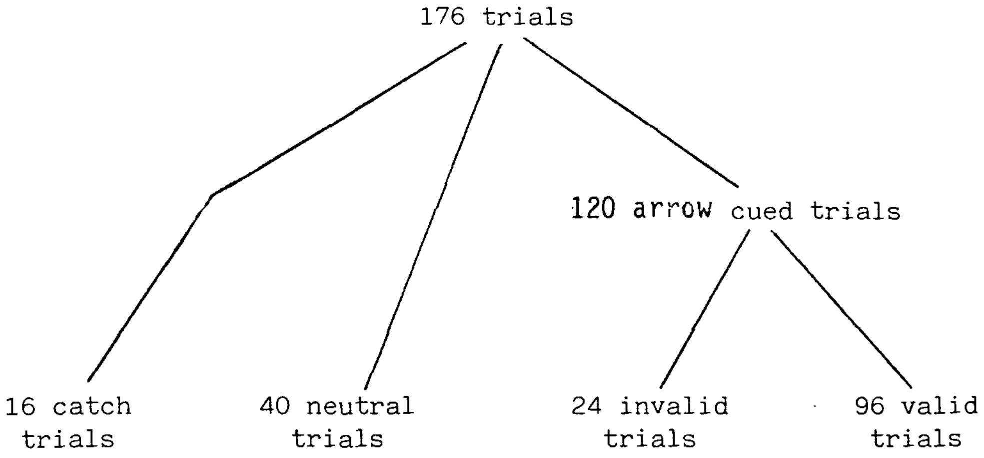


Figure 4.10

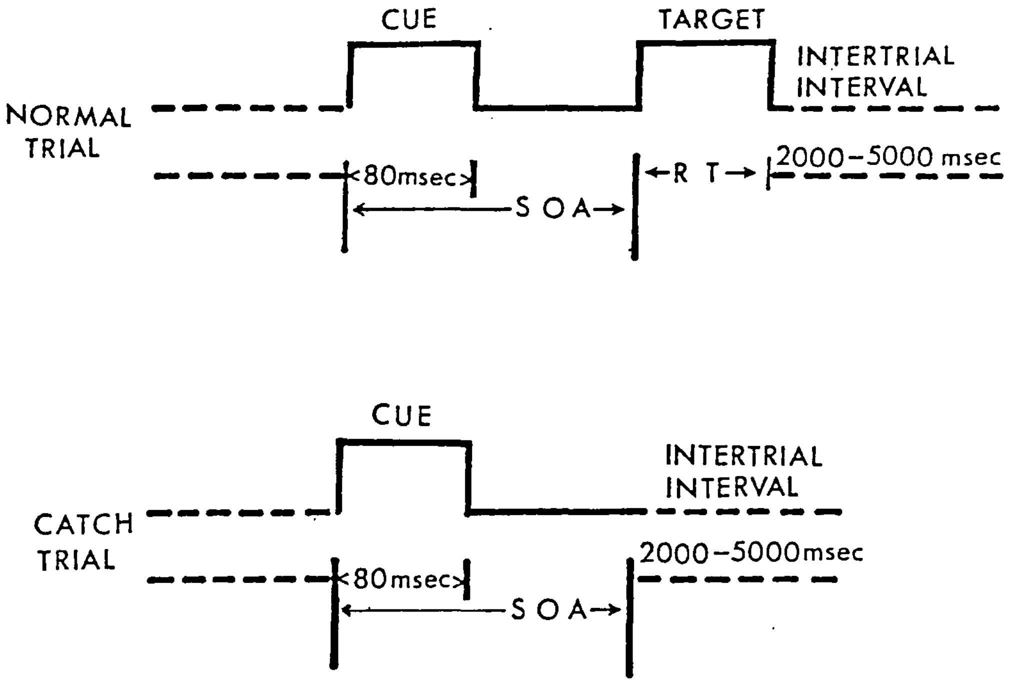


Figure 4.11 : Timing of trials in Experiment 3

and then the target, 40 times out of 44. A single key press caused the target to disappear and the next trial sequence to be initiated following the intertrial interval.

4.4.3 Results and Discussion

General Effects

Error rates were 3.5% (quiet) and 1.98% (noise). Once again the means of the medians for all 14 subjects were recorded and the overall data are presented in Figure 4.12. These data clearly replicate the pattern reported elsewhere (see Section 4.2.3) and found in Experiment 1. There is a sharp decrease followed by a gentler increase as SOA increases from 100 to 1000 msec. This effect was also found in Experiment 1 and probably arises as a result of the temporal warning properties of the cue. Again there is an optimum SOA which subjects require in order to benefit most fully from information presented in this way (e.g. Rabbitt 1981) and in this case it is between 250 and 500 msec.

Generally the data are slower than those recorded in Experiment 1 (mean reaction time being 360 msec for Experiment 3 compared to 324 msec for Experiment 1). A t-test comparing the two sets of data revealed this difference to be significant [t (1,26) = -2.29, p < .05). It is concluded that this difference arises as a result of the difference in the level of predictability surrounding any given trial.

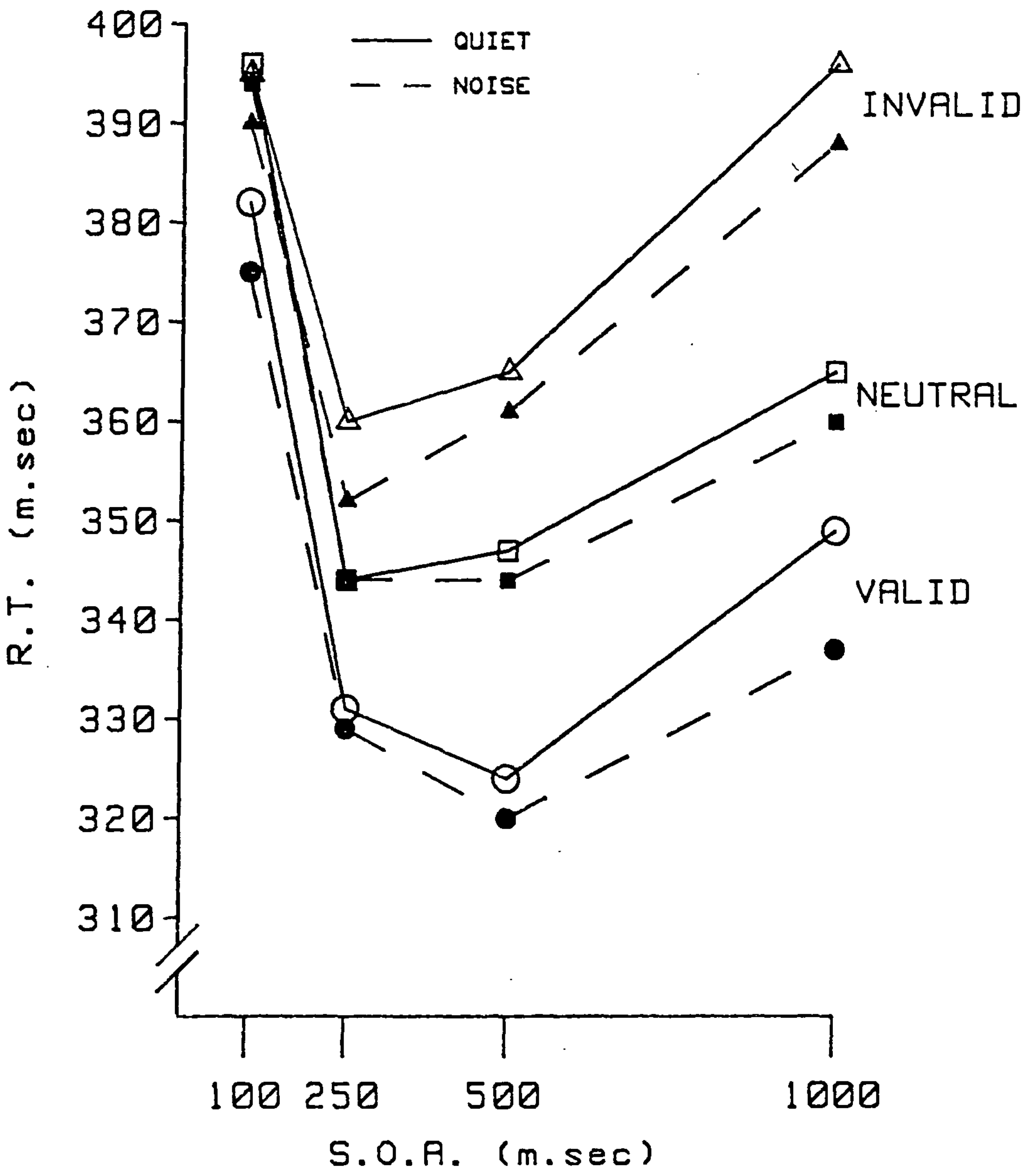


Figure 4.12 : Results from Experiment 3 - Reaction times

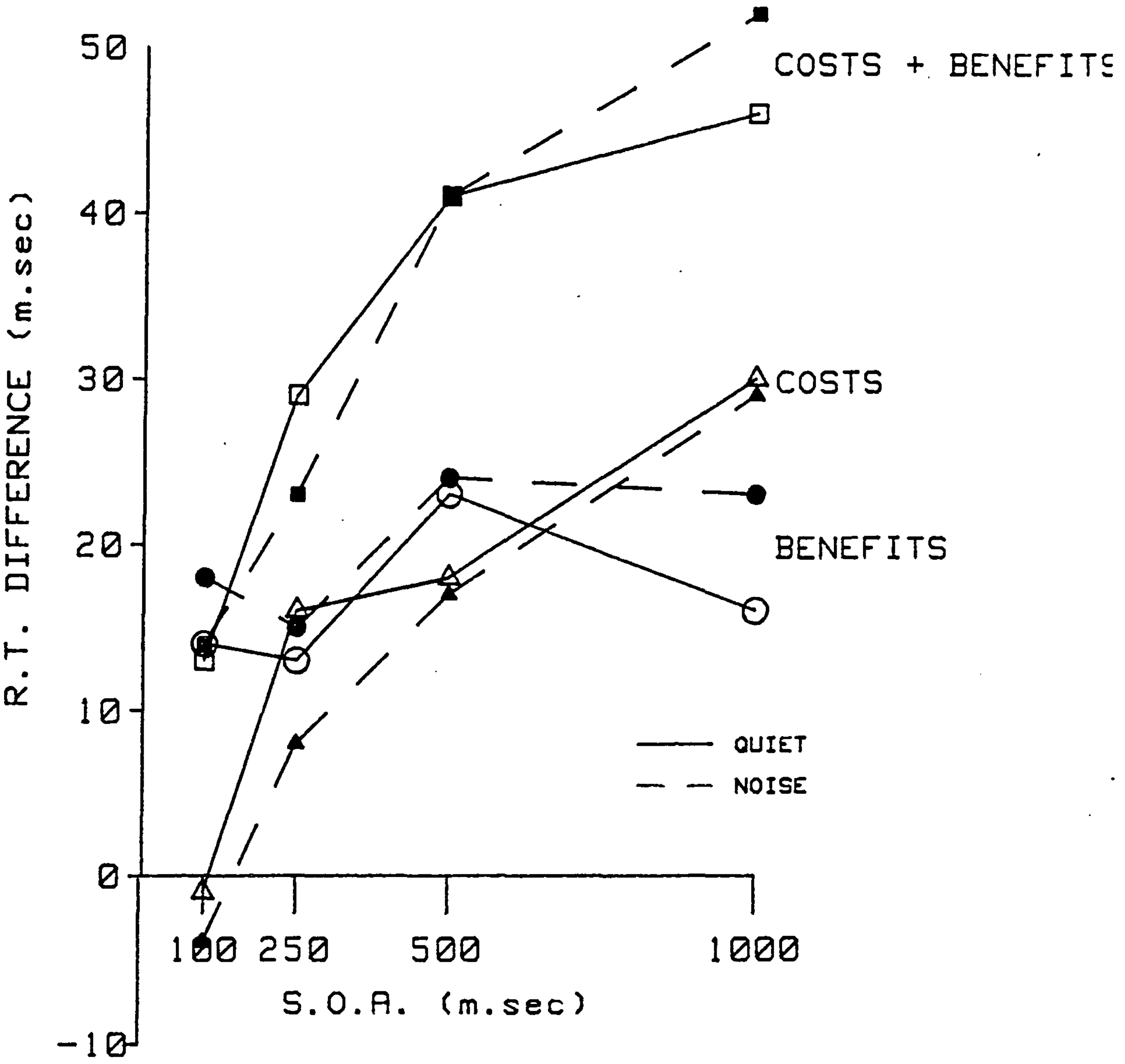


Figure 4.13 : Results from Experiment 3 - Costs, benefits and costs-plus-benefits

A three-way analysis of variance performed upon the reaction time data (noise level x SOA x trial type) showed the effect of SOA to be highly significant [F (3,39) = 69.78, p < .001] as was the effect of trial type [F (2,26) = 60.16, p < .001]. The interaction term between these two factors was also significant [F (6,78) = 11.99, p < .001], a reflection both of the fact that subjects were using the cue information and that this information was used more effectively as SOA increased. Figure 4.13 expresses the same data in terms of costs and benefits, and it is clear that the data provide further evidence which replicate the pattern of activation and inhibition of pathways found elsewhere (see Posner 1978, Section 1.2.1). Once again costs develop across SOA more than do benefits, as found in Experiment 1, which according to the argument developed there, is probably a result of RTs to neutral trials being unusually long when the warning interval is sub-optimal. The analysis of variance performed on these data (noise x SOA x cost/benefit) revealed the main effect of SOA to be highly significant [F (3,39) = 12.13, p < .001] though the main effect of cost or benefit was not [F (1,13) = 0.23]. The interaction term between these two factors was however significant [F (3,39) = 5.47, p < .005], probably a reflection of the obvious increase in costs at longer SOAs.

Effects of Noise and Time on Task

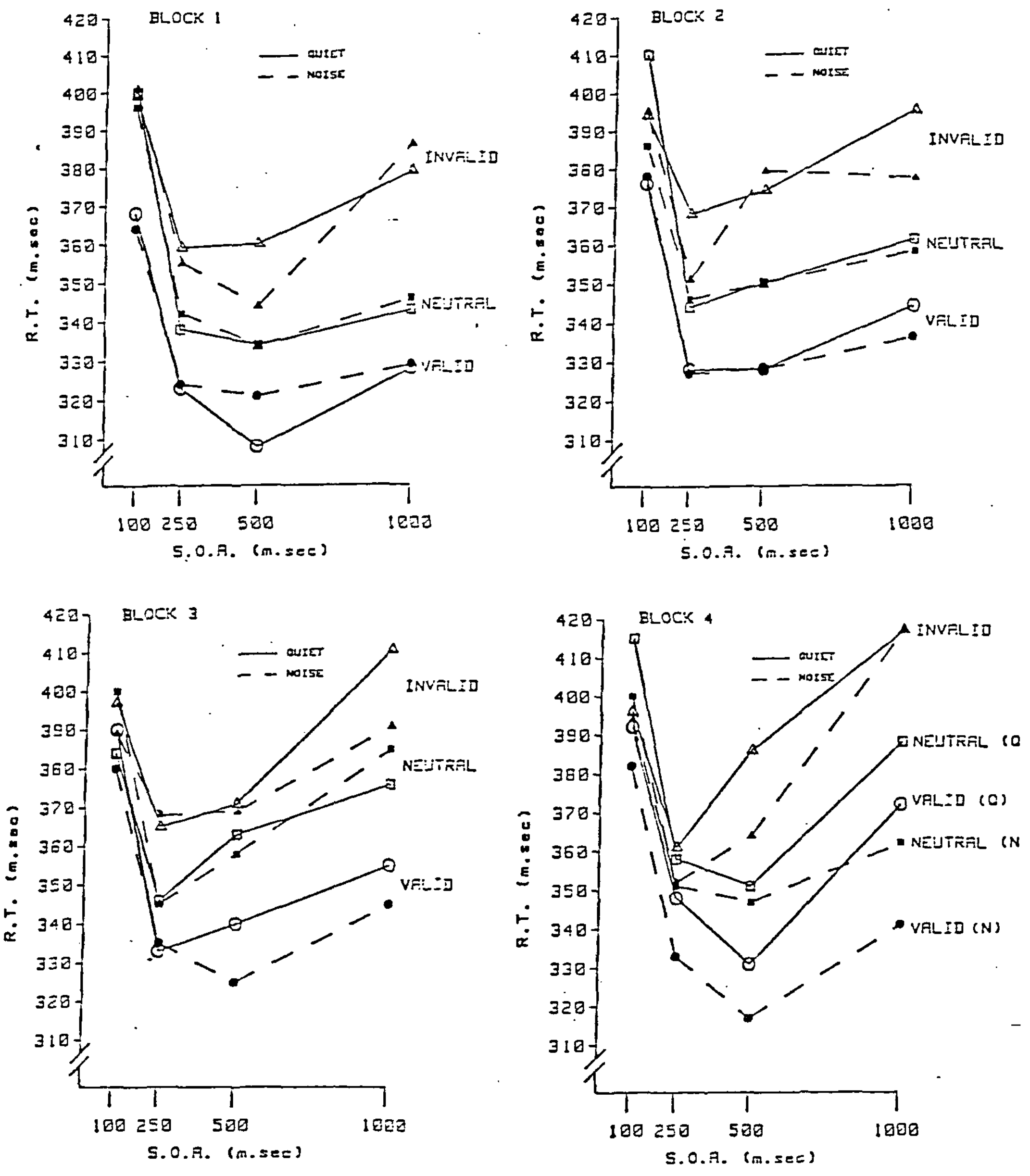
Both the analyses performed upon the data in Figures 4.12 and 4.13 failed to show any effects of difference in noise level on any aspect of task performance. Of interest is the failure to reproduce the effect of noise at SOA 100 found in Experiment 1. This would suggest that noise will not enable subjects to utilize response information any more fully, irrespective of SOA. It is possible of course, though unlikely, that this effect arose either as a result of the blocked nature of the trials used in Experiment 1, or from the fact that shorter intertrial intervals were used. However, from the data presented here it is clear that any enhanced ability to process positional information more effectively in noise when the warning interval is short is not a widespread one.

Visual comparison of Figures 4.4 and 4.12 suggests that in this setting noise is now associated with faster reaction times, but, as mentioned above, this effect was not significant [F (1,13) = .49]. Thus it is clear that noise is having no general effects upon allocation of attention in this task, despite its hour long duration and the resultant increased demands made upon subjects. These demands render the task similar to many of those already described in Chapter 2 where performance might reasonably be expected to be subject to the effects of noise. To some extent, one might also expect the increased temporal uncertainty surrounding the occurrence of each trial to add to the pressure of maintaining consistent performance over an hour-long vigil, and therefore perhaps contribute to some alteration in task performance over time rather than as a whole. Nevertheless, it is true that the overall analysis of the data clearly reveals a pattern of performance which is resistant to the effects of noise, as was the case for Experiments 1 and 2.

The way in which the task was constructed allowed for a detailed comparison of performance across different stages of the task. This allowed for the measurement of possible interactions between time on task, orienting of attention and noise. As mentioned in Section 4.4.1, of particular interest was the fact that the task provided a measure of the rate of change of use of environmental information over time, a measure which is absent from much of the literature on alerting and the attentional processes underlying orienting behaviour.

Two four-way analyses of variance were performed on the data. The first examined the relationship between noise level x block x SOA x trial type for the raw data and the second examined noise level x block x SOA x costs and benefits. Obviously the variable of particular interest in these analyses was the inclusion of the block number.

The first and most important point to note is that noise had no significant effect upon any measures of reaction time or the derived measures of costs and benefits in any of the blocks. The reaction time data for each particular block are presented in Figures 4.14 to 4.17 and it is clear that there is no consistent



Figures 4.14 - 4.17 : Block by block analysis of reaction times

change in performance over time as a result of noise. Thus there is a very impressive consistency of responding across all sections of the task irrespective of time length. Two things in particular can be concluded from these results: First, that the introduction of a long and uninterrupted period of responding in this experiment did not make the task of orienting any more susceptible to environmental stress; Second, that the increase in task demands did not make any difference to the overall pattern of performance in noise over time. From these facts it can be reasoned that although this experiment was lengthy, uninterrupted and demanding, and thus fulfilled many of the criteria shown in Chapter 2 to be important in the creation of a task setting where noise will alter performance, efficient orienting was still maintained. Presumably this was because of the commanding central cue which was locking attention to a given location in such a powerful manner that additional arousing effects of noise left those mechanisms unaffected.

Having said that it is interesting to note that there were specific effects on these attentional mechanisms arising as a result of time on task alone. Thus although noise is not causing any change in performance, other variables which are also traditionally associated with changes in tonic alertness levels (see Chapter 1) do seem to be exerting an overall influence on behaviour in this situation. From the analysis on the reaction time data, the first thing to note is that there is a main effect of time on task (i.e. block), [F (3,39) = 5.32, p < .01]. In other words there is a general slowing of response as performance on the task continues. This main effect of block can be seen most clearly in Figure 4.18, which collapses reaction time across all of the experimental conditions, to represent the change that takes place in responding over time.

The interaction term between SOA and block is also highly significant [F (9,117) = 4.32, p < .001]. In other words responses vary between the different SOAs as time on task continues. These data are presented in Figure 4.19 (collapsed across noise level and trial type).

Overall performance at SOA 100 is slower than for the other three warning intervals, a difference which persists across blocks. Hence regardless of whether the subject has only just begun responding or whether he has been performing for nearly an hour, he will respond comparatively poorly when the SOA is fast. In other words he is unable to utilize cue information as readily when the warning interval is so short.

Responses at SOAs 250 and 500 are those which are continually the fastest. This can be seen in a comparison of the data represented in Figures 4.20, 4.21 and 4.22 and is another way of presenting the overall data already plotted in Figure 4.12.

Responses for SOA 1000 are those which show the greatest relative change over time (33 msec compared with a mean of 11.7 msec for the other three SOAs). This change is most likely to be responsible for the

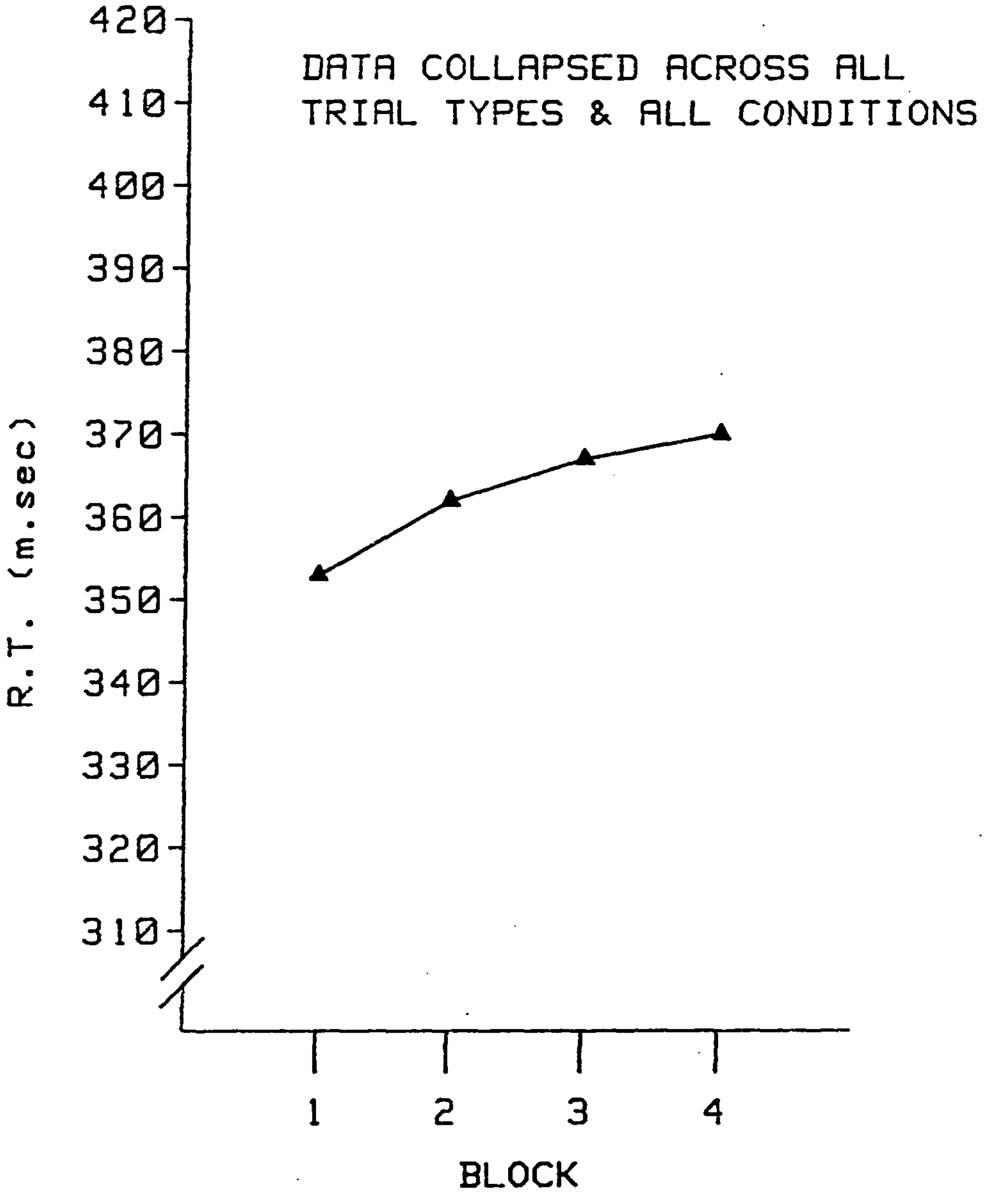


Figure 4.18 : Results from Experiment 3 - Effects of time-on-task

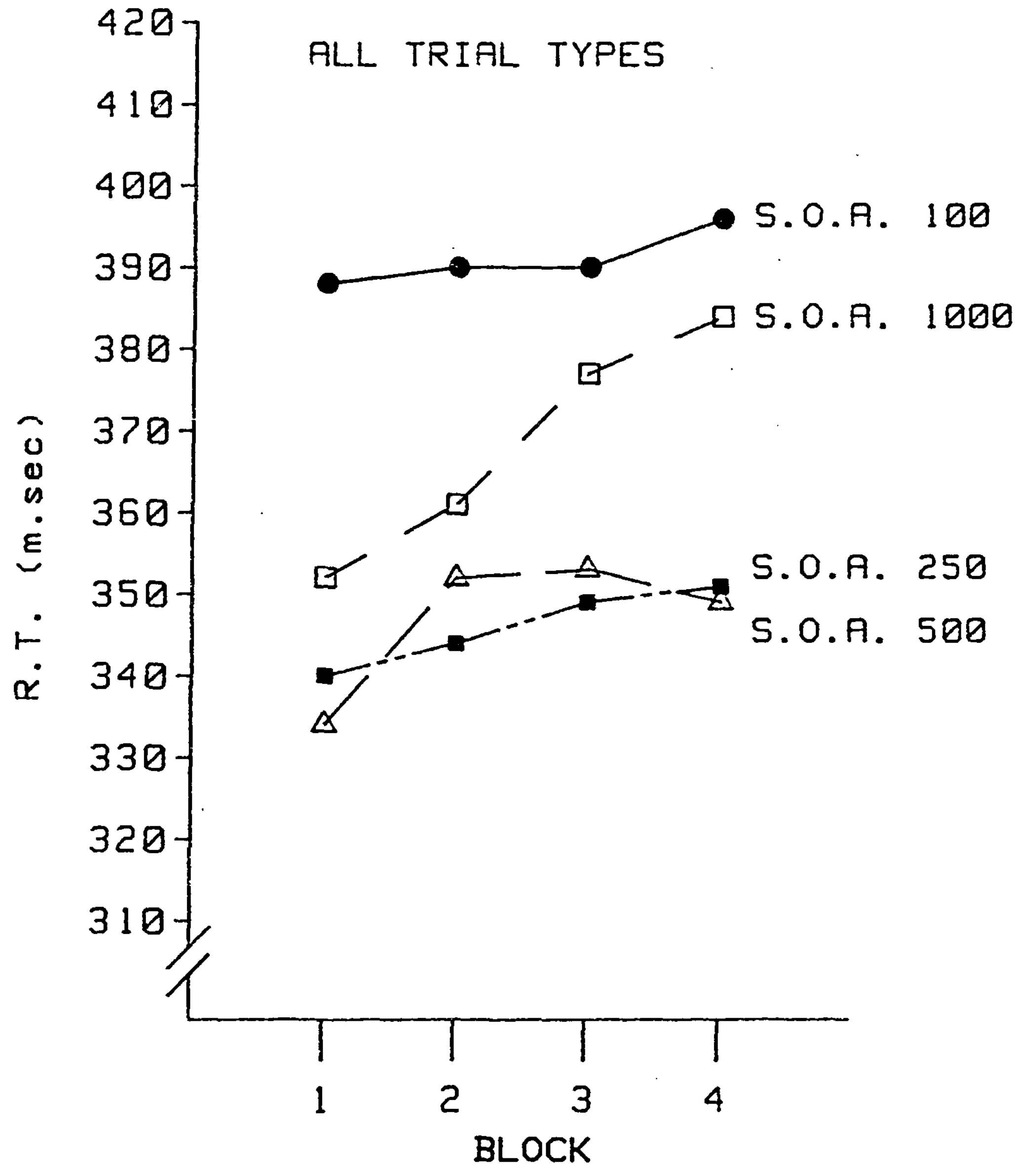
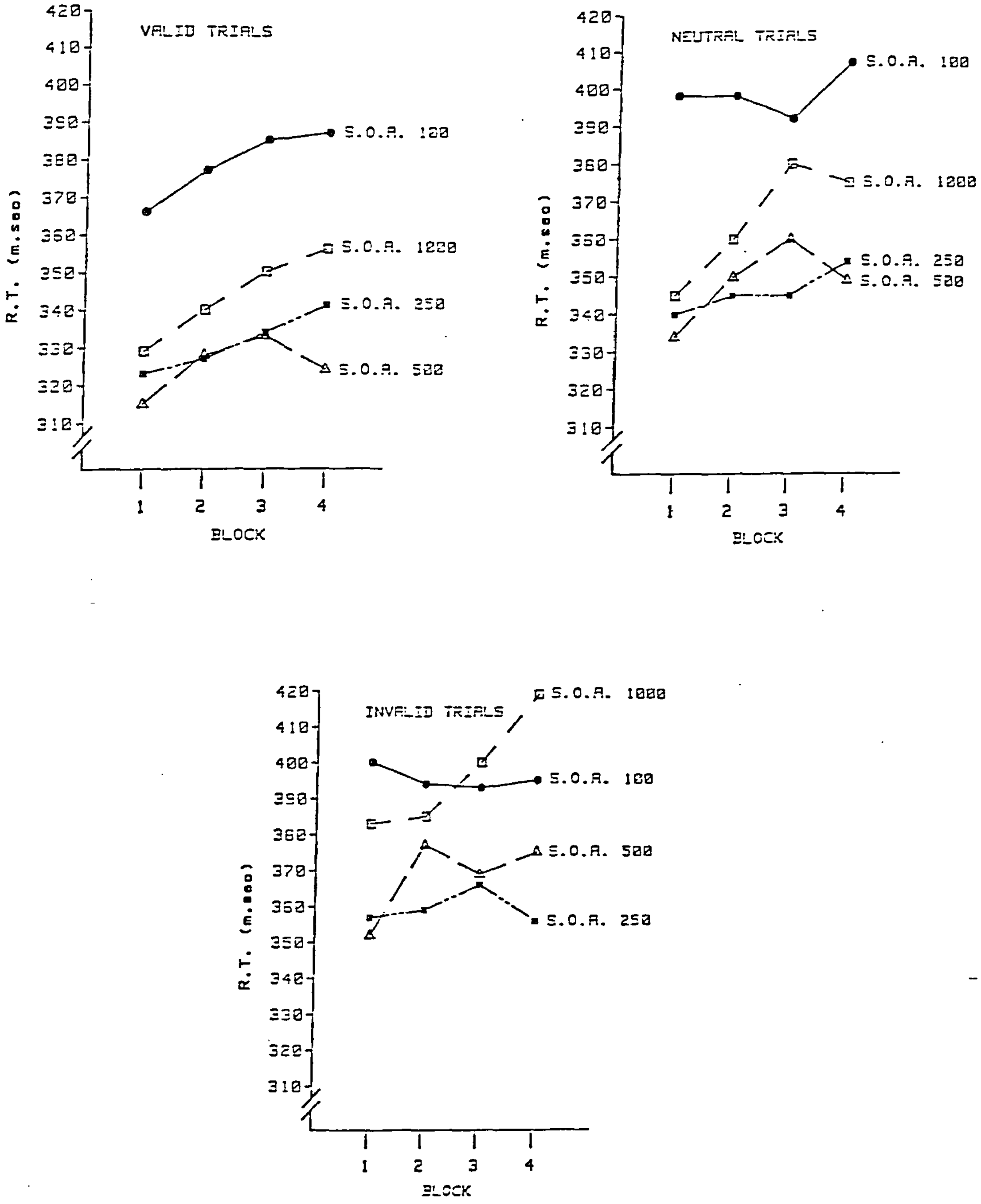


Figure 4.19 : Results from Experiment 3 - Effects of time-on-task on all trial types



Figures 4.20 - 4.22 : Effects of time-on-task on valid, neutral and invalid trials

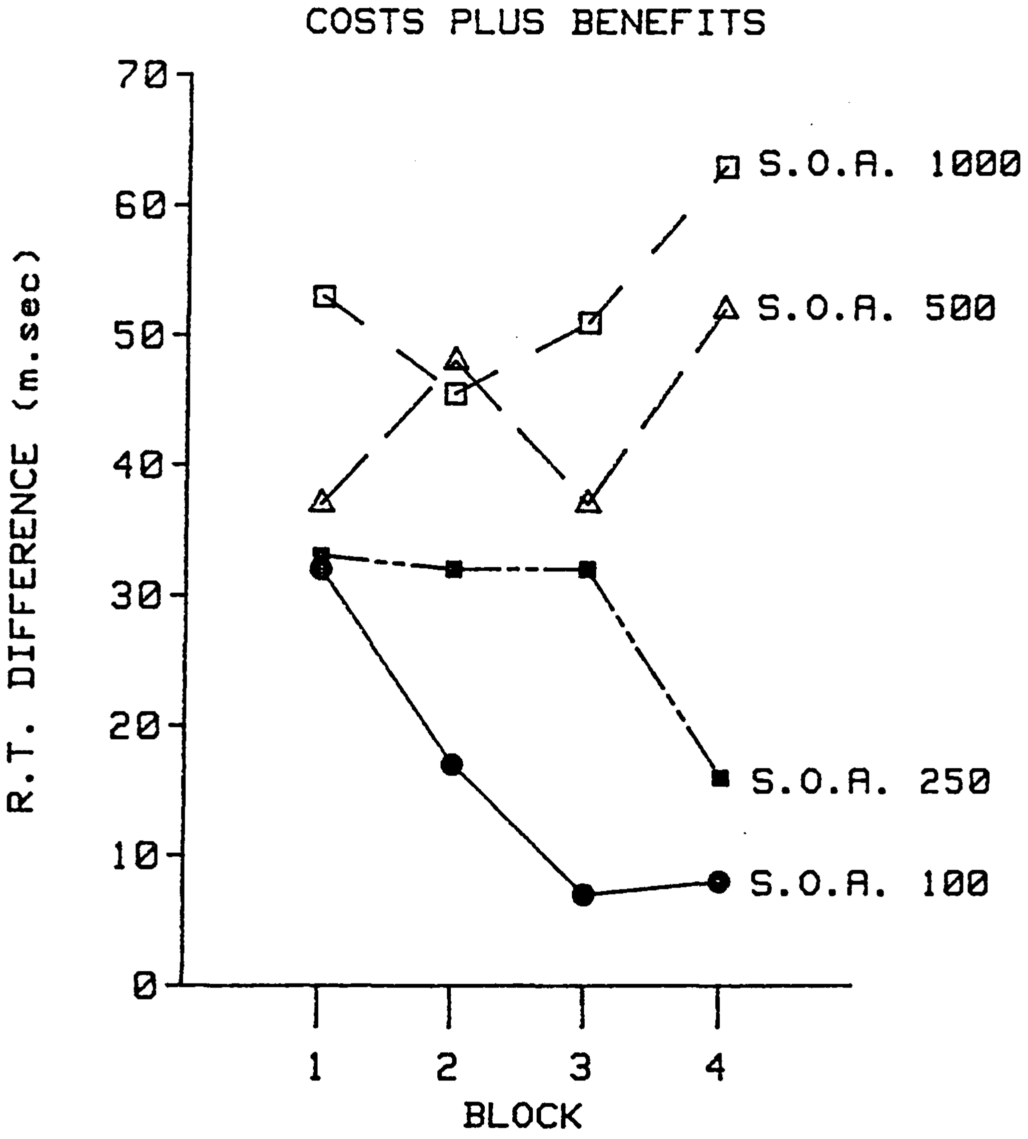


Figure 4.23 : Results from Experiment 3 - Effects on time-on-task on costs-plus-benefits

significant interaction between SOA and block. Despite this fact, reaction times for this SOA are still mid-way between response times for the other SOAs, probably a reflection of subjects' falling ability to estimate target onset time at this SOA (Rabbitt 1981).

The rate of change over time for these data is partly a result of the active nature of prediction - when a subject is fatigued he will further lose this ability to estimate target onset. In addition, the active nature of orienting results in an effect which is contributing to this pattern. This can be seen from the invalid reaction times plotted in Figure 4.22. Here it is clear that responses for SOA 1000 are the ones that change most noticeably over time. If target information is false it will cost a subject more to respond when pathway activation has been primed for a post-optimal length of time, especially when his attentional system as a whole is fatigued.

Figure 4.13 showed how costs and benefits are greater at the longer SOAs, and Figure 4.23 shows the effect of time on task on the combined measure of cost-plus-benefits. This is the best overall measure of rate of use of information over time (Posner 1978) and it can be clearly seen that there are major differences between the values for the four SOAs. A three-way ANOVA (noise level x SOA x block) performed on these data alone showed the main effect of SOA to be significant [F (3,39) = 23.24, $p < .001$] as was the interaction term between SOA and block [F (9,117) = 2.15, $p < .05$]. Clearly cues are being used most fully at the two longer SOAs, a difference which becomes more marked as the experiment continues. For the shorter SOAs (especially 100) subjects are getting maximal effects at the onset of the experiment, presumably because they are fresh and alert and better able to commit their attentional resources to a given location on the basis of the cue. As the experiment continues and fatigue begins to play a more important part in the processing of information, subjects demonstrate they cannot commit themselves as fully at the faster SOAs as compared to the slower ones. This result makes sense bearing in mind the active nature of orienting and the difficulty in using positional information which is presented quickly to actively control orienting (Posner and Snyder 1975a, b).

4.5 General Conclusions from Experiments 1-3

The experiments reported in this chapter have all demonstrated the effects of informative cueing on simple reaction time to subsequent targets. They show how attention can be allocated under internal control to a peripheral location and speed the detection of targets from that location with respect to others in visual space. This decrease in detection speed varies with the length of time the warning signal precedes the target. These effects appear to be highly stable and reproduce the findings of other researchers in the area (e.g. Shulman, Remington and McLean 1979; Posner 1980).

However, despite the fact that these tasks contain a hierarchy of priorities similar to many dual task studies which have shown noise to affect the selectivity of attentional allocation, as situations for measuring the effects of noise on such mechanisms they prove to be generally inappropriate. It has to be concluded that the main research hypothesis has not been confirmed by the data reported thus far. It is presumed that this is primarily because of the alerting properties of the central cue which pre-empt any additional alerting effects arising as a result of changes in the environment caused by the presence of noise. However orienting tasks are not totally insensitive to more tonic shifts in arousal level, and Experiment 3 in particular demonstrates how a particular pattern of changes in alertness is revealed when performance is analysed over time.

CHAPTER 5

BLOCKED CUEING

SUMMARY

Five experiments are reported which together examine the effects of noise on a task where attention is no longer directed by an alerting cue but by means of information presented prior to a sequence of ten trials. The use of such experimental procedures typically results in a failure to sustain orienting to the expected location. This loss of orienting has been attributed to inhibitory effects arising from responding to previous trials. The characteristic loss of orienting was also shown here, but this phenomenon could <u>not</u> be adequately explained in terms of inhibition. An alternative explanation was suggested.

Two experiments showed how noise could alter response times to expected and unexpected targets, and these results were interpreted in terms of the effect that noise has upon altering attentional priorities. In addition, noise was shown to have a specific effect upon inhibition. These effects were removed upon the re-introduction of a central alerting cue, bolstering the arguments proposed in Chapter 4 concerning the important role such signals play in alerting processes.

5.1 Introduction

As Jones (1984) points out, a major factor in the variability in results in the noise literature is the overlooking of sometimes subtle but salient features of tasks which can remove or produce a certain experimental effect. In Chapter 4 it was argued that the presence of the central cue was highly alerting and thus prohibited the action of noise by creating a specific state of responding which was resistant to any additional increase in alertness produced by the stressor. This chapter presents an experimental technique which removes this particular element from the task whilst maintaining the manipulation of attentional priorities afforded by the study of orienting.

Posner, Snyder and Davidson (1980) report an experiment specifically designed to compare detection latencies for stimuli which were cued on each trial and those for a non-cued situation in which subjects prepared for one location over a whole block of trials. Two types of non-cued block were used, "equal" and "unequal". In equal blocks subjects were presented with a neutral warning signal which preceded a group of trials where any one of four locations was equally likely as a subsequent target position. Unequal blocks contained targets which occurred at one location 79% of the time, and the other locations 7% of the time. Subjects were informed of the most likely stimulus location which was in operation prior to the commencement of these blocks. Results for the non-cued blocks showed there to be no evidence of benefit from knowledge of target location compared to the neutral condition though costs for responding to incorrect information remained. Posner et al were unsure as to exactly why this should be the case (see Posner, Snyder and Davidson 1980, p. 165), but these results were interpreted as a reflection of subjects' inability to maintain spatial selectivity for an extended period, or "the tendency of subjects to avoid the task of placing their attention at the expected location when not cued to do so on each trial" (p. 165). Such a finding has been reported elsewhere in the literature (e.g. Grindley and Townsend 1968; Shiffrin and Gardner 1972) and Posner and colleagues argue that such researchers failed to find benefits due to prior knowledge of visual location because "subjects did not continue to set themselves for the position in space at which the signal was most expected" (p. 163).

Posner, Cohen, Choate, Hockey and Maylor (1984) describe two similar experiments which involved the presentation of a locational cue prior to a block of trials. The cue was either a cross or an arrow pointing to the left or to the right. Following its presentation were 10 targets (Experiment 1) or 12-20 targets (Experiment 2) which occurred to the left or right of a central fixation point. A target-target presentation procedure was employed, i.e. there was no warning signal prior to target onset. The intertrial interval was approximately 2000 msec in Experiment 1 and varied between 300 and 1000 msec in Experiment 2. Subjects had to respond with a single key press to targets. These occurred in the direction indicated 80% of the time when the cue was an arrow, and with equal probability on either side of fixation when the cue was a cross. For both experiments results indicated that for early trials in a block reaction times for valid targets were faster than for neutral targets, which in turn were faster than responses to invalid targets. However by the end of a block of trials these effects had disappeared, indicating a reduction in the efficiency of maintaining spatial selectivity over successive trials.

In addition, Posner and colleagues report that in both experiments when successive targets occurred on the same side, reaction times were systematically longer than when they occurred on opposite sides, an occurrence they referred to as a "negative sequential dependency effect", and described elsewhere (e.g. Maylor and Hockey 1985) as inhibition. Posner et al (1984) attribute the failure to maintain spatial selectivity shown by their experiments and by Posner et al's (1980) study to this inhibitory effect. They argue that whatever benefit might be obtained by the allocation of attention to a cued location is counteracted by the inhibition that occurs when targets successively appear at the same location. Arguments for the appropriateness of this explanation can be found in Section 5.2.2.

The methodology adopted in both of the above studies provides an experimental situation which is similar in many ways to that used in Chapter 4 inasmuch as it maintains the potentially interesting balance of attentional priorities manipulated by warning signals which predict target occurrence with either 80% or 50% accuracy. But an important dimension in which the two situations differ is that in the latter case the priorities set up by the cue continue to operate over a succession of trials rather than on one individual trial. Thus the immediate alerting consequences of the cue, which it was concluded in Chapter 4 were preventing any demonstration of the effect of noise on attention allocation, are removed in this setting. Because of this, this particular experimental technique for manipulating the orienting of attention was decided upon as a more suitable test-bench for an analysis of the effects of noise on orienting behaviour.

Experiment 4 was initially conducted to replicate and extend the findings of Posner, Cohen, Choate, Hockey and Maylor (1984) and establish their reliability and applicability for this experimental situation. It was felt that this was important because the amount of published data in this area is small and a strong baseline was needed for generating hypotheses concerning the effects of noise on tasks of this type. Having produced data which clearly resembled that of Posner et al, Experiment 5 went on to examine the effect of noise on this task, and Experiments 6 and 7 investigated the relationship between noise effects, negative sequential dependency and the inability to maintain orienting over time. Finally Experiment 8 re-introduced the central alerting cue used in Experiments 1-3. This was to specifically test the hypothesis that this element of task structure was responsible for the differences between the two general patterns of results found thus far.

5.2 Experiment 4

5.2.1 Method

Subjects

Ten subjects (8M, 2F) participated in a single experimental session which took approximately 20 minutes to complete. There was no manipulation of noise levels, and headphones were not worn.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

As far as was possible the design for this study followed that adopted by Posner, Cohen, Choate, Hockey and Maylor (1984). Subjects were given 30 blocks, each of which contained 10 targets. Each block was preceded by a plus sign or an arrow to the left or to the right, 10 of the blocks using each form of cue. In blocks preceded by a plus sign targets occurred to either side of the central cross with equal probability. They occurred on the side indicated 8 times in every 10 on blocks preceded by an arrow. These different blocks were presented to subjects in a completely random sequence and the same sequence was given to all 10 subjects. Within each block of trials the pattern of targets was also presented completely randomly. This gave an overall total of 100 neutral trials, 160 valid trials and 40 invalid trials.

The cue at the onset of a block of trials remained on the screen for 5 seconds along with the information:

"This is the most likely target position for this block." The time between the response made to one target and the occurrence of the next was 2000 msec (as in Posner et al 1984, Experiment 1) except on those trials when an anticipatory response was made. In such cases an "ERROR" message was presented to subjects (as described in Section 3.6), after which the trial sequence continued. Such anticipatory responses were deleted from subsequent analysis, as were any responses which exceeded 1000 msec or were less than 180 msec in duration.

After a response had been made to the tenth trial in a block, subjects were offered a rest period, terminated at their own wish by a single key press. Subsequent to this subjects were reminded that they should seek to maintain central fixation and were invited to begin the next block of trials. This again they did by means of a single key press, and the symbolic cue pertaining to the next block of trials appeared.

5.2.2 Results and Discussion

Overall error rate for this study was 0.7%. The means of the median reaction times for all ten subjects are plotted for each trial type as a function of position in a block of ten trials in Figure 5.1. Data are presented for positions 1-8 only because of the effects of predictability which become increasingly strong as a block of trials proceeds. For example if a subject has already received two trials in the

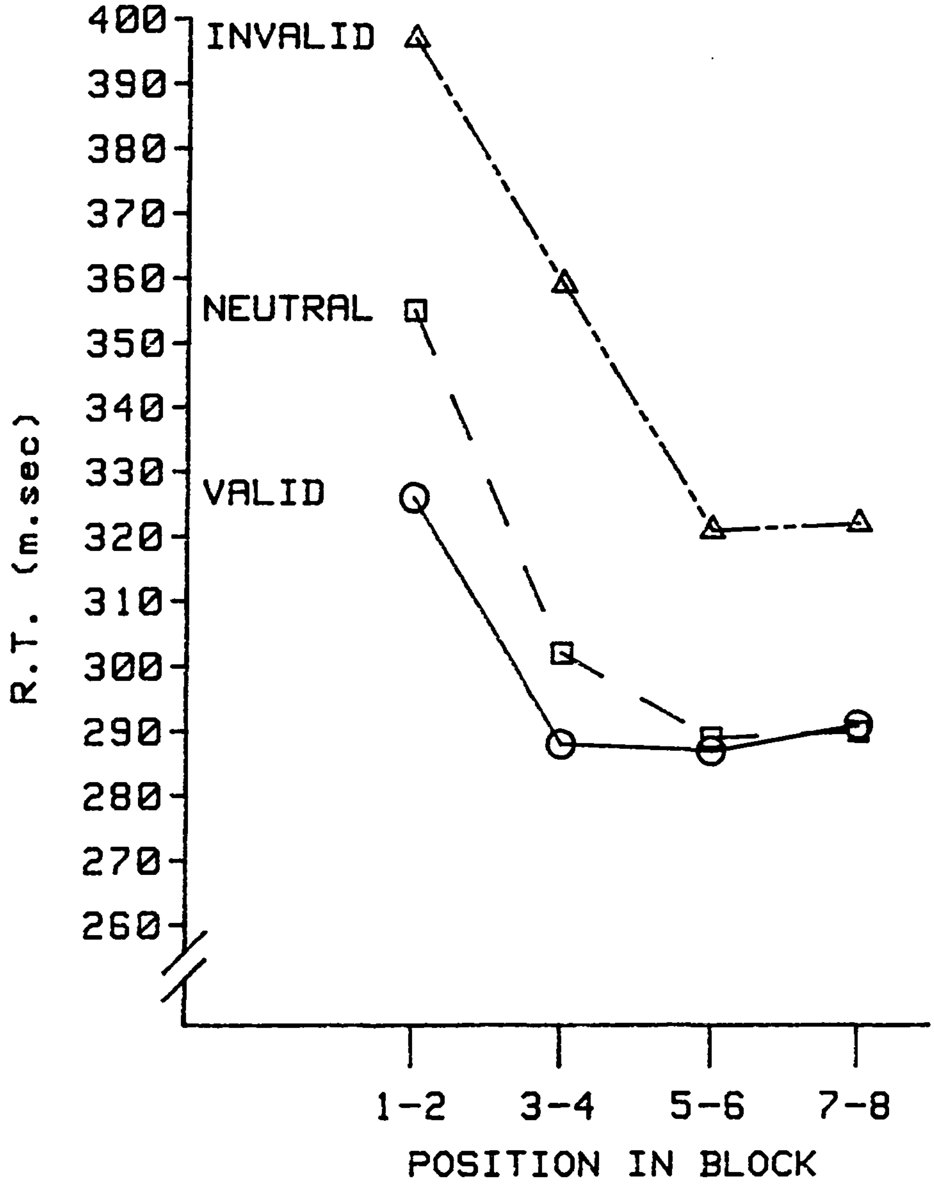


Figure 5.1 : Results from Experiment 4 - Reaction times

unexpected location on an arrow-cued block, then each successive trial would in fact carry 100% chance of appearing at the expected location, and so on. In this respect the design of the experiment was less than optimal. However the design was both chosen here and pursued in further experiments for two principle reasons:

1) In order to replicate Posner et al (1984).

2) In order to maintain the likelihood of target occurrence at exactly 80% within each block of trials.

The practice of omitting these later trials is continued for all the experiments reported in this chapter.

From Figure 5.1 it can be seen that there are clear effects of attention in the expected direction (that is valid RT < neutral RT < invalid RT) for early trials in a block. However as the block of trials continues, the data reflect the findings obtained in the previous studies which have used blocked trials - i.e. the benefit of a valid trial over a neutral one soon disappears - see Figure 5.2. This is exactly the result found by Posner et al (1980) and Posner et al (1984, Experiment 1) where it was reported that benefits were more labile than costs, as seems to be the case here.

A two-way analysis of variance carried out on the overall data (valid, invalid and neutral RTs x position in a block) revealed highly significant effects of both trial type [F (2,18) = 26.08, p < .001] and position [F (3,37) = 22.29, p < .001]. The interaction term between

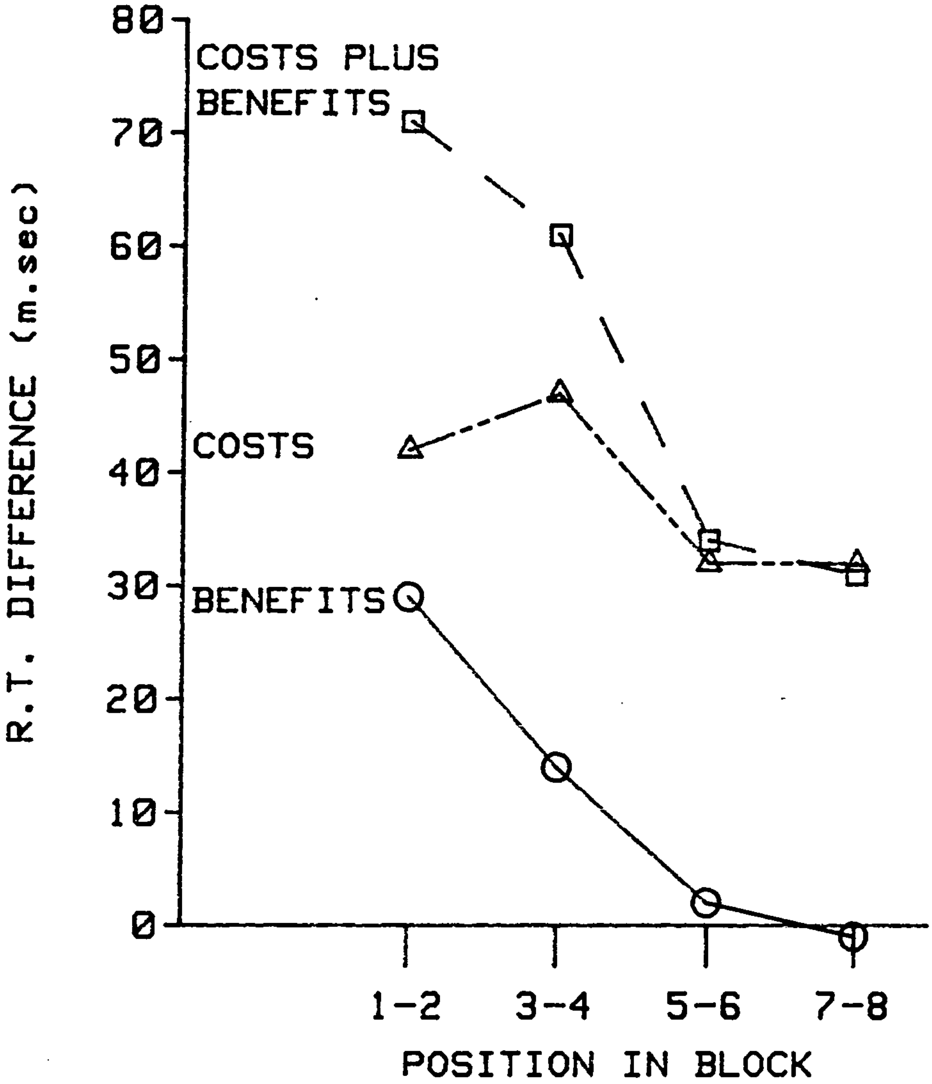


Figure 5.2 : Results from Experiment 4 - Costs, benefits and costs-plus-benefits

these two factors just failed to reach significance [F (6,54) = 1.97, p < .1]. A second two-way analysis of variance (cost/benefit x position in a block of trials) revealed the difference between the amount of costs and benefits to be significant [F (1,9) = 21.64, p = .001]. Thus of the two measures of performance, benefits are generally smaller than costs. Posner et al (1984) would argue that this is because of the fact that the inhibitory effect will obviously have the most effect upon valid as opposed to invalid trials, simply as a result of the numbers of trials involved in each case.

In the analysis performed on the cost/benefit data the main effect of position only narrowly missed significance, indicating that the fall as a function of position was not exclusive to benefits [F (3,27) = 2.46, p < .1]. This is an important suggestion, and is mentioned here because it is backed up both by later results obtained from Experiments 5-7 and the fact that the interaction between cost/benefits and position failed to reach significance [F (3,27) = 0.58]. It means that though costs are certainly higher than benefits in this case, they may still be affected by the same process which leads to the clear fall of benefits. This point will be returned to later in the chapter.

As stated above an important feature of the data reported by Posner, Cohen, Choate, Hockey and Maylor (1984) was the negative sequential dependency effect which was produced when successive targets occurred on the same side. They also report (from Experiment 2) that this inhibitory effect tends to decrease as the response to stimulus interval increases, a result which is in keeping with other work by Maylor (1983) and Maylor and Hockey (1985) investigating inhibition. Using a target-target procedure these experimenters clearly show how the inhibitory effect decreases as response-stimulus intervals increase from 300-900 msec (though the effect is still present at 900 msec). Maylor (1985) also presents data showing inhibition to be present at up to 1300 msec after presentation of a stimulus at the same location, and Posner and Cohen (1984) report a similar effect resulting from a peripheral cue, which lasts up to 1500 msec. From these findings it is to be expected that any inhibitory effect found by Posner et al (1984) would be smaller for Experiment 1 (R-S interval = 2000 msec) than for Experiment 2 (R-S interval between 300 and 1000 msec). In fact the authors do report these effects to be "very tiny" and other than reporting the mean reaction times for same location versus different location, do not discuss the statistical significance of the effect. In considering the same data Maylor (1983) in fact only refers to the negative sequential dependency effect being present for Experiment 2.

A two-way analysis of variance was performed, with reaction times for valid and neutral trials as two levels of the first factor and same and different target location as the two levels of the second. (A "valid same" trial was a valid trial occurring at the same location as a previous trial of any type, and a "valid different" trial one occurring at the opposite location to the previous trial). The data for these are plotted in Figure 5.3. Invalid trials were not included in this or any later analysis of this type simply because there were not enough trials to satisfy the "same location" criterion. The following were of significance: There was a main effect of location [F (1,9) = 17.5, p < .005] and a significant interaction between location and trial type [F (1,9) = 7.24, p < .05]. As can be seen from Figure 5.3, these results are a reflection of the operation of an inhibitory effect similar to that reported by Posner et al (1984). This effect is virtually non-existent for valid trials, a fact which can be attributed to a combination of at least two reasons: The first is that the inhibitory effect is likely to be at the furthest reach of its influence at 2000 msec and thus effects are likely to be small in any case. In addition to this all valid trials are "contaminated" by the fact that any effect arising as a result of a "same-different" distinction between trial types will also be affected by specific locational expectancies associated with each particular trial, i.e. a "valid different" trial can only be one which is preceded by an invalid trial. For the neutral trials however any such contamination is absent. This problem could be eliminated by running an experiment with four possible target locations, two either side of fixation, one immediately above the other. In such a situation it would be possible to have a valid trial

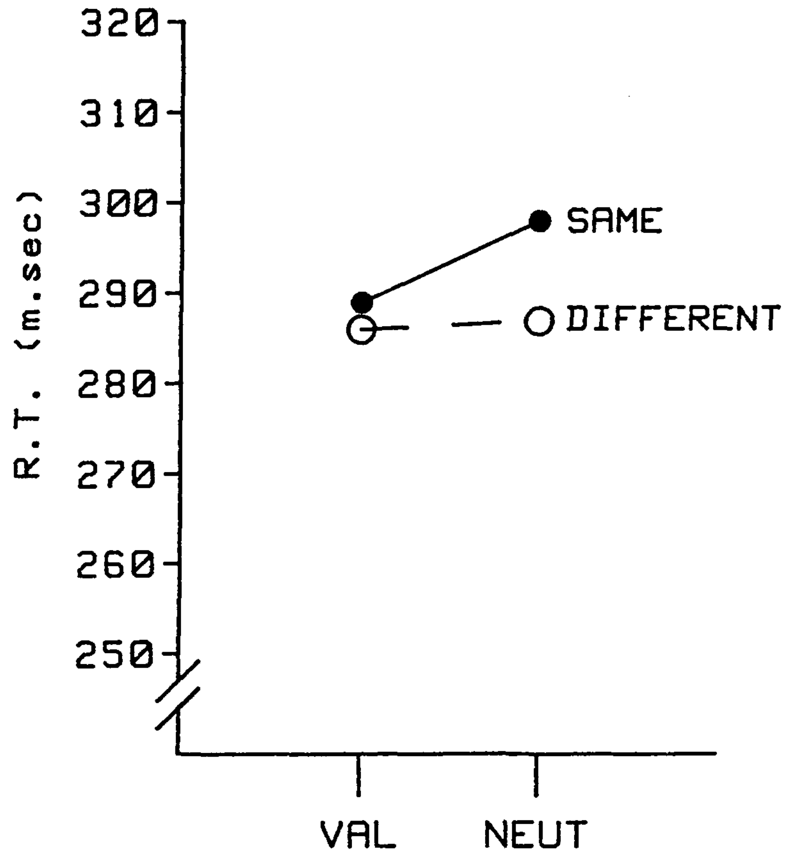


Figure 5.3 : Inhibitory effects in Experiment 4

following another valid trial but in a different location. This would provide a purer measure of inhibition than the above, provided that the two adjacent locations were sufficiently close to one another to allow the development of the inhibitory effect. It is interesting to note that Posner et al (1984) also report that the inhibitory effect for neutral trials is greater than that for valid trials.

As stated above, Posner et al (1984) argue that the reason subjects fail to maintain selectivity is due to the operation of this negative sequential dependency effect. Maylor (1983) however, disputes this explanation as she says the inhibitory effect is not in fact significant in Experiment 1, and also that the intertrial interval used by Posner et al (1980) would have been, she argues, at least 2000 msec per trial and sometimes more, which would make the operation of inhibitory processes unlikely. Also she cites an experiment by Sanders and Reitsma (1982) which used response-stimulus intervals of between 6 and 24 seconds, and where subjects showed a similar inability to maintain orienting to the periphery. They conclude that this orienting is "so demanding that it can only be maintained for a short period of time" (p. 144), and suggest that loss of orienting is due to the fact that it is a demanding cognitive operation rather than anything else. Maylor (1983) concludes in a similar fashion that the inability of subjects to maintain a constant expectancy over a block of trials must be due to some other factor, i.e., not necessarily inhibition.

The result reported here, i.e., that inhibitory effects are present only for neutral trials is of particular relevance to this question. If it is the case that the reported loss of selectivity is primarily a result of negative sequential dependency effects operating on reaction times to valid targets, then, if anything, one would expect these trials, and not neutral ones, to be those which display the greater degree of inhibition. This is not the case at all, and therefore it is concluded that Posner et al's (1984) explanation of the reason for loss of orienting is incorrect. Instead the following explanation is favoured: The loss of a selective state of preparation, as discussed by Sanders and Reitsma (1982) and Maylor (1983) will be to some extent the result of the fact that such selectivity is a highly demanding and concentrated form of preparation, the effects of specific alerting being maximal for only a short period of time (see Chapter 1). Like many other cognitive processes, orienting is a state of responding which is difficult to maintain for any length of time.

It is possible to draw two opposite predictions from each of the above two theoretical positions. If Posner et al (1984) are right in arguing that loss of orienting is due to inhibition then there should be more evidence of the inhibitory effect at later trials rather than earlier ones. However, if on the other hand inhibition arises as a result of orienting (Maylor

1985) then there should be more inhibition at the start of a block of trials, simply because orienting has not had time to diminish. Visual inspection of Figure 5.1 indicates that orienting has been reduced most considerably by positions 5-6 in a sequence. Thus it was decided to compare same/different reaction times for both valid and neutral trials at positions 1-2 (early) and 5-6 (late), with the specific prediction that there would be more inhibition for early trails.

These data are plotted in Figure 5.4 and were entered in a 2 x 2 x 2 ANOVA (valid/neutral x same/different x position). There was a significant main effect of trial type (i.e. valid/neutral) [F (1,9) = 7.91, p < .05], and the main effect of position in a block narrowly missed significance [F (1,9) = 4.40, p = .06]. This latter effect is a reflection of the overall drop in reaction time as a block proceeds seen in Figure 5.1. There was a significant interaction between position and trial type [F (1,9) = 6.32, p < .05], again a reflection of the pattern seen in Figure 5.1 where valid reaction times do not fall as rapidly as those of other trial types. The specific prediction that inhibition would be greater for early trials rather than late ones seems to be held up by inspection of the data for valid trials. The responses to "valid same" and "valid different" clearly cross over, and despite the fact that the three-way interaction is not significant: [F (1,9) = 3.27, p > .1], a simple main effects comparison was carried out upon the data for valid trials at the early position and showed the

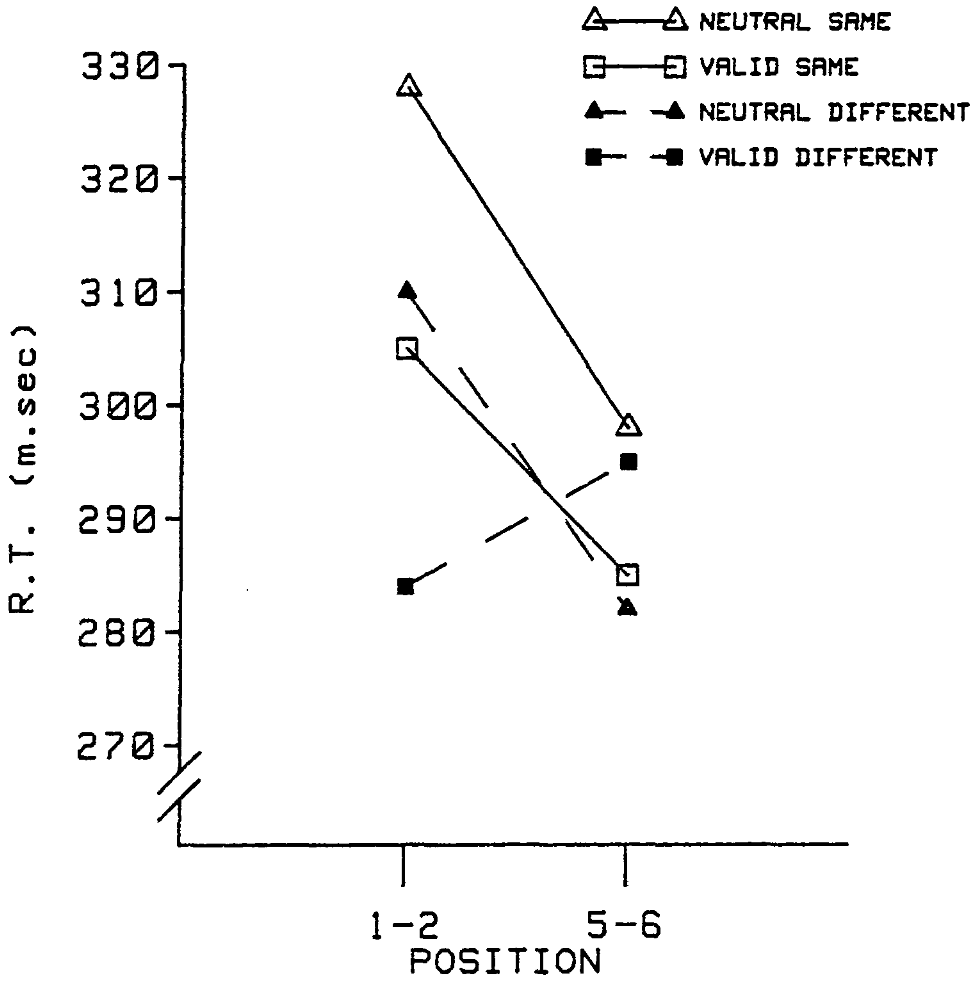


Figure 5.4 : Inhibition at early and late positions in Experiment 4

inhibitory effect to be significant at this point [F (1,9) = 5.96, p < .05]. Clearly there is no such effect at the later position.

This result has several interesting implications. Firstly it provides more powerful evidence that Posner et al's (1984) account of loss of orienting cannot be sustained, because there is certainly no increase in the size of the inhibitory effect with later position. In addition, the drop in inhibition for valid trials is quite striking, and clearly supports the alternative position outlined above. In terms of subjects' responses within a block of trials, the following may be argued: At the beginning of a sequence of arrow cued trials orienting is strong and results in a large amount of inhibition. This is equally true for blocks of neutral trials, and for these trials obviously orienting does not diminish across a block simply because it is not directed to any one location. Instead, subjects will orient to each target as it appears. In line with Maylor (1985), this would explain why the inhibitory effect is equally strong at later positions. For the valid trials however, orienting has diminished by positions 5-6, resulting in the corresponding loss of inhibition. This explanation would account for the pattern of data already reported in Figure 5.3 where there was a difference between targets occurring at "same" and "different" locations for neutral trials only. For these trials the effect is consistent across all positions whereas for valid trials the early effect is probably offset by what happens later on.

Having reasoned from Experiment 4 that subjects soon lose the ability to maintain spatial selectivity and that an inhibitory effect is in operation under some circumstances, it is possible to address some interesting questions as to the possible effects of noise on this task. With the commanding effects of the central cue used in Experiments 1-3 removed, noise could differentially alter the speed of responding to expected and unexpected targets. It could also, by increasing alertness, actually increase the length of time over which selectivity can be maintained in this experimental setting.

As discussed in Chapter 1, Maylor (1985) argues that orienting is a necessary condition to produce inhibition. Thus if noise heightens attentional selectivity and results in greater orienting then one might also expect greater inhibition. As it is argued that loss of orienting over time is not due to inhibition then it is quite plausible that both will increase in noise, a result which would again directly contradict any prediction made upon Posner et al's (1984) analysis. Experiment 5 was conducted to provide answers to these questions.

5.3 Experiment 5

5.3.1 Introduction

It was concluded from Chapter 4 (Section 4.5) that there were no major effects upon attentional selectivity of the type that would be predicted by the original research hypotheses outlined in Chapter 2 (Section 2.4). It was adduced that this was a result of the alerting properties of the central cue which marshalled attention in such a highly specific manner as to preclude the possibility of any action of noise on performance. It was argued in Section 2.2.3 that situations of ambiguity were those where noise effects were most likely to be found, and it is possible that the experimental setting used in the previous study is one such situation. The specific prediction is that when the central informative cue is removed, noise will have an effect upon the selectivity of attention of the type discussed in Section 2.4. This will be manifest either in a speeding of responses to valid targets (leading to more processing benefit), a slowing of responses to invalid targets (leading to more processing cost), or both. In addition to this, there are the specific predictions concerning the inhibitory effect based upon the arguments presented in Section 5.2.2 above.

5.3.2 Method

Subjects

Twelve subjects (10M, 2F) participated in two separate experimental sessions, one in noise and one in quiet. Each took approximately 20 minutes to complete and these sessions were counterbalanced as described in Section 3.5.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

These were identical to those adopted in Experiment 4, with the same computer program being used in each case.

5.3.3 Results and Discussion

General Effects

Error rates for this study were 1.75% (quiet) and 2.33% (noise). The data are plotted in the same way for Experiment 4, with the means of the medians for each subject for each successive pair of trials being plotted as a function of position in a sequence of trials. Data are plotted for performance in both noise and quiet (see Figure 5.7) and are collapsed across this factor in Figure 5.5. The data are presented in this form so that the pattern of responding can be readily compared to that found in Experiment 4 (see for e.g. Figure 5.1).

It is clear that the data in Figure 5.5 follow the same pattern as those produced in Experiment 4. The effects of attention clearly fall in the expected direction for early trials in a sequence (that is valid RT < neutral RT < invalid RT). However as the block

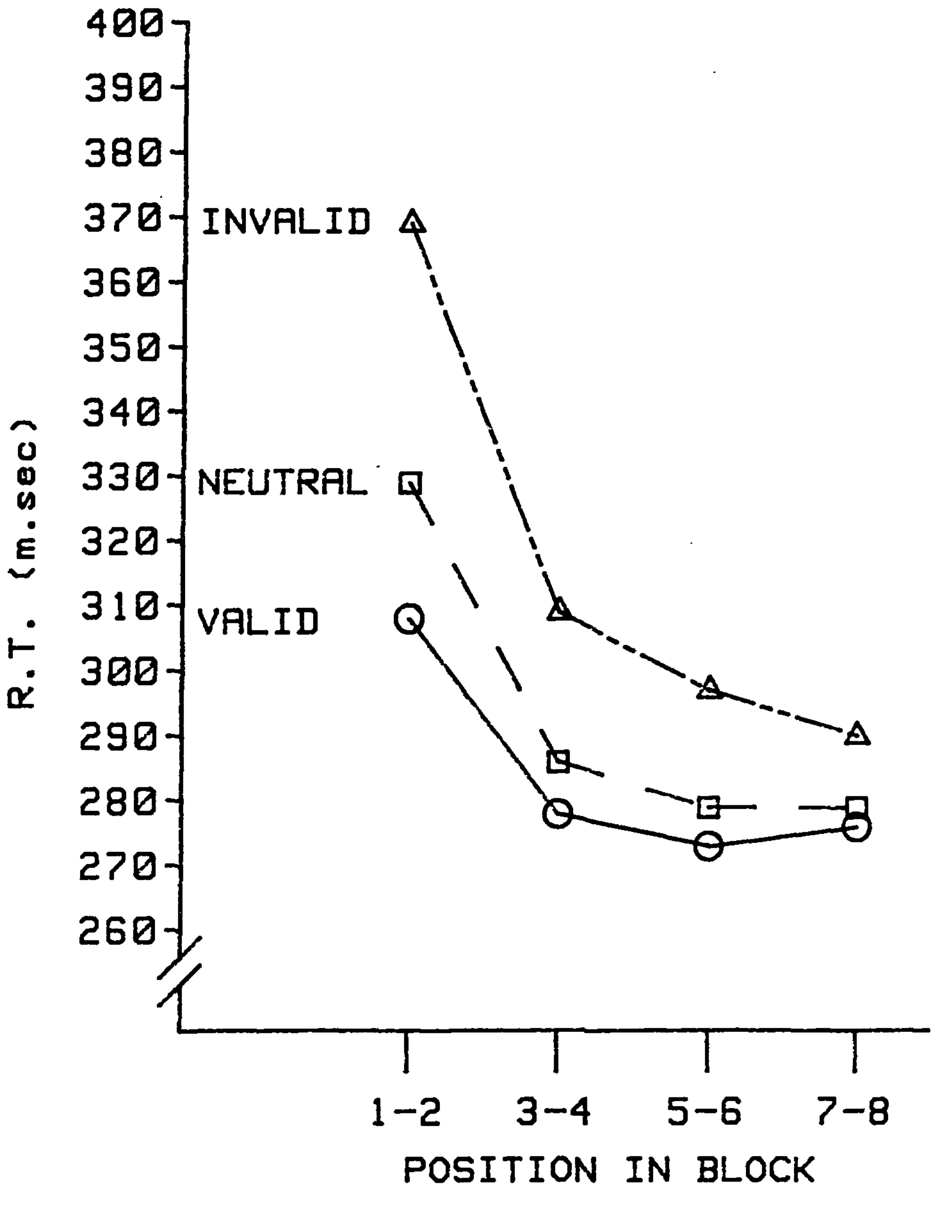


Figure 5.5 : Results from Experiment 5 - Reaction times collapsed across both noise levels

continues these differences diminish, especially for neutral and valid trials, just as in Experiment 4. A three-way analysis of variance (noise x trial type x position) showed these effects to be highly significant, with a main effect of trial type: [F (2,22) = 24.98, $p < .001$], position: [F (3,33) = 27.6, $p < .001$] and a significant interaction between the two: [F (6,66) = 10.12, $p < .001$].

As shown by Figure 5.6 both costs <u>and</u> benefits clearly drop as position in the block of trials increases, a reflection of the inability to maintain orienting over time already demonstrated. This is a different result from that obtained by Posner et al (1980), who claimed that costs were "less labile" than benefits, and is also different from Posner et al (1984, Experiment 1), where costs also remained. However, in their second experiment they actually fell more rapidly than benefits. The precise reason for this is unclear and will be discussed later in this chapter, but it does indicate that the same mechanism is affecting both these measures of performance, rather than benefits being selectively reduced.

The data were entered in a three-way analysis of variance (noise x cost/benefit x position). This verified the reliability of the effect of position [F (3,33) = 22.49, $p < .001$], and also the overall difference between the measures of cost and benefit [F (1,11) = 7.96, $p < .05$].

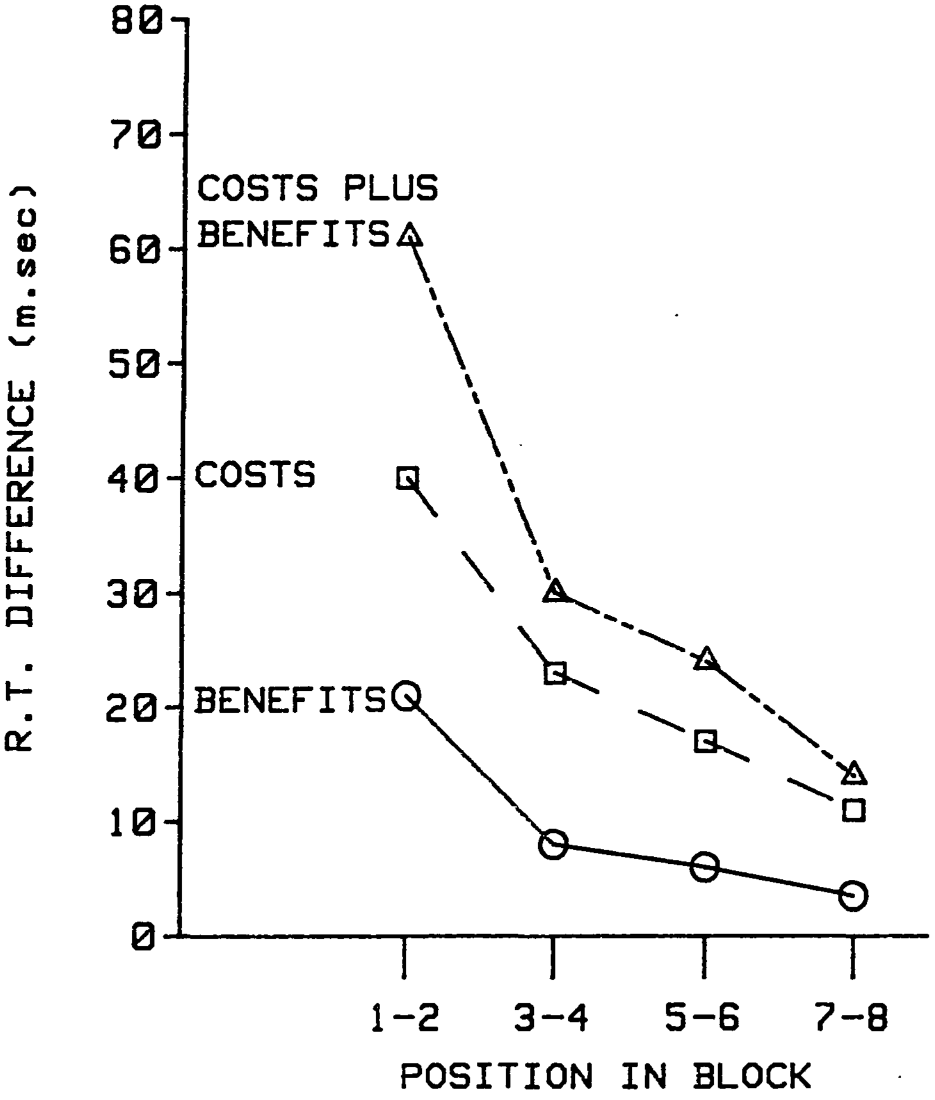


Figure 5.6 : Results from Experiment 5 - Costs, benefits and costs-plus-benefits collapsed across both noise levels

The inhibitory effect reported in Experiment 4 was also present in this study, but because noise seemed to be exerting an interesting effect on this process, discussion of it is presented in the following section.

Effects of Noise

An analysis of variance performed on the data shown in Figure 5.7 showed there to be no significant effects of noise on the task [F (1,11) = .04], nor any significant interactions between noise and any other variable. The size of the F ratio for the interaction between noise and cue type is of relevance to later discussion [F (2,22) = 1.4]. Simple main effects comparisons for invalid-quiet vs valid-quiet at position 5-6 showed these points were not in themselves different [F (1,22) = 1.01]. The same points in noise however were significantly different [F (1,22) = 15.3, $p < .001$]. With the data plotted in terms of costs and benefits (see Figures 5.8 and 5.9) it is easier to see what is occurring during task execution under noise. The main effect of noise on cost and benefit just failed to reach significance: [F (1,11) = 4.7, $p > .05$] - suggesting that noise is increasing cue use in this task. Referring to the raw data this means that the difference between the neutral and valid reaction times and the neutral and invalid reaction times is greater in noise. In other words it can be argued that subjects are benefitting more and showing more cost from locational information in noise. Looking at the costs-plus-benefits measure alone (Figure 5.9) it is

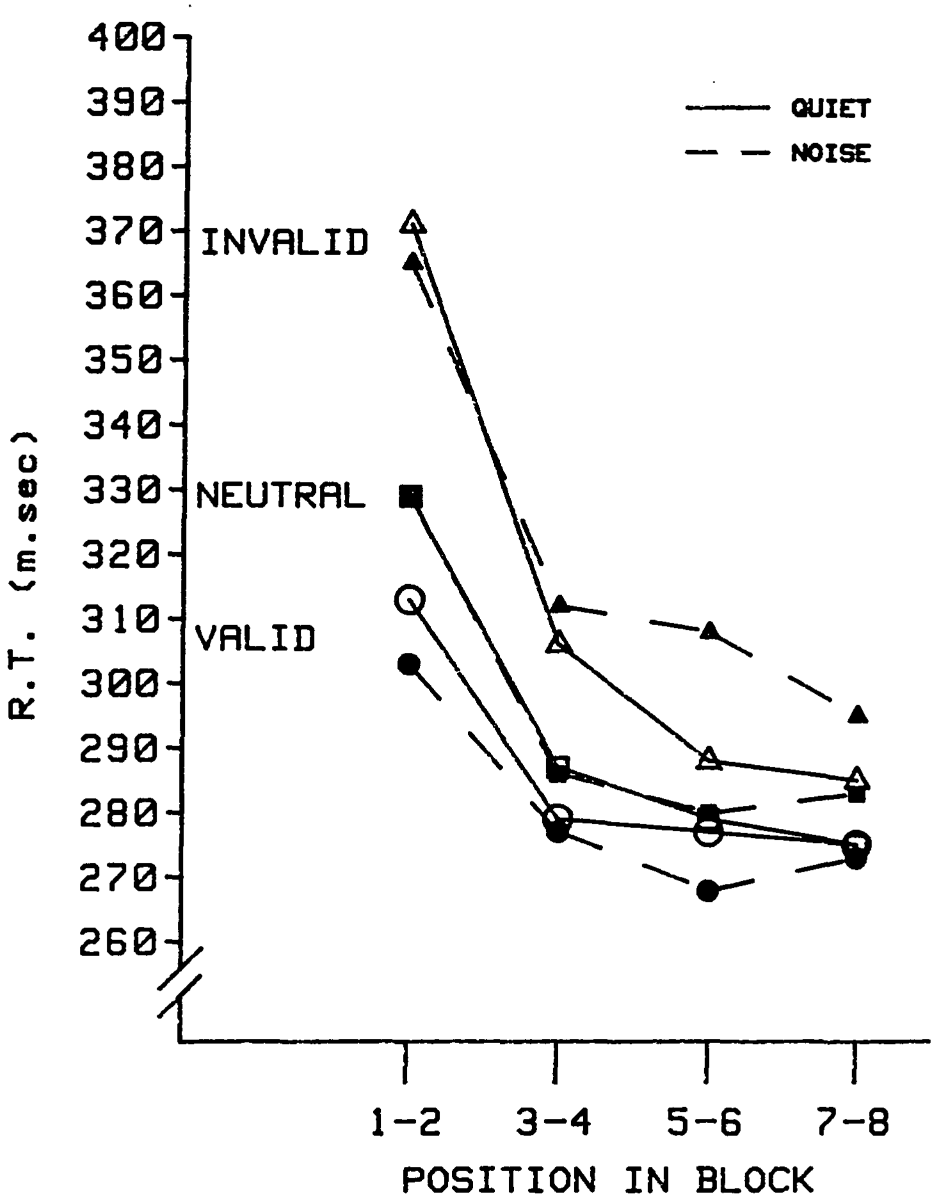


Figure 5.7 : Results from Experiment 5 - Effects of noise on reaction times

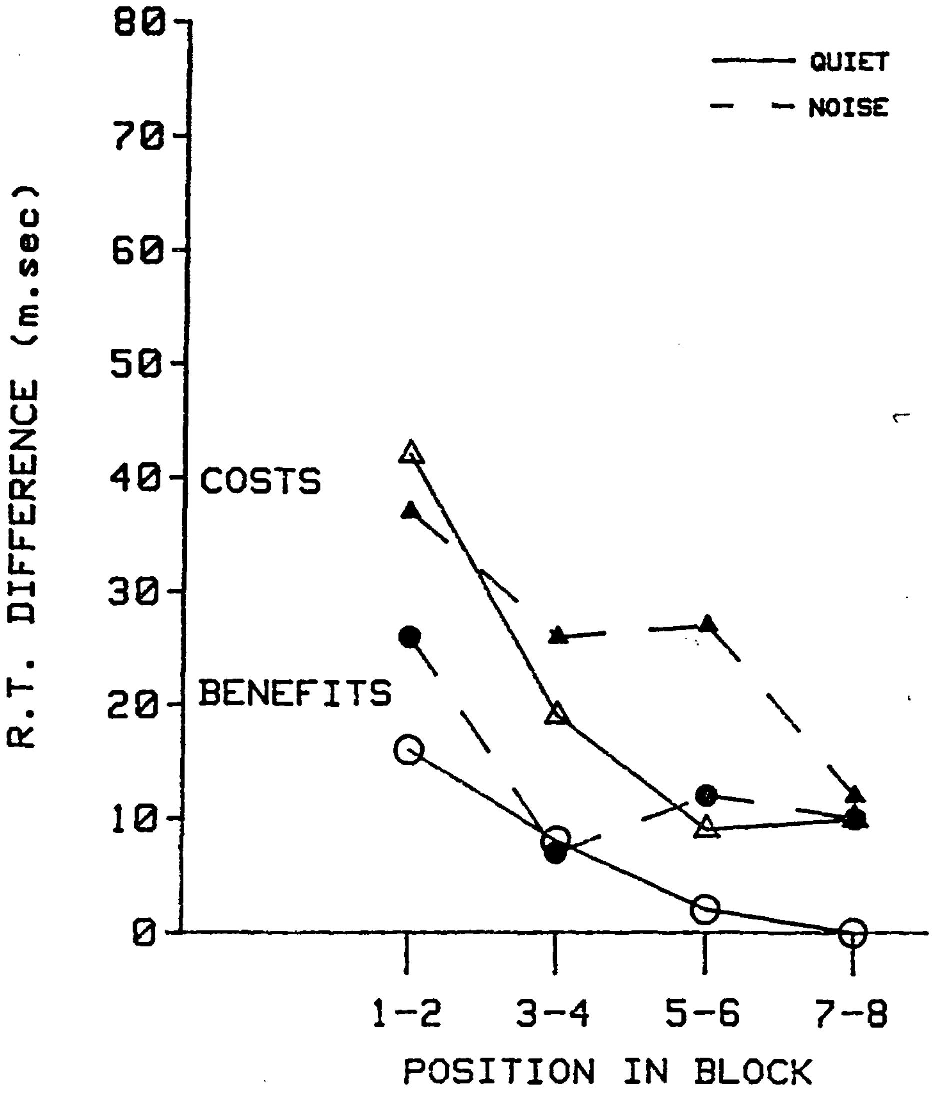


Figure 5.8 : Results from Experiment 5 - Effects of noise on costs and benefits

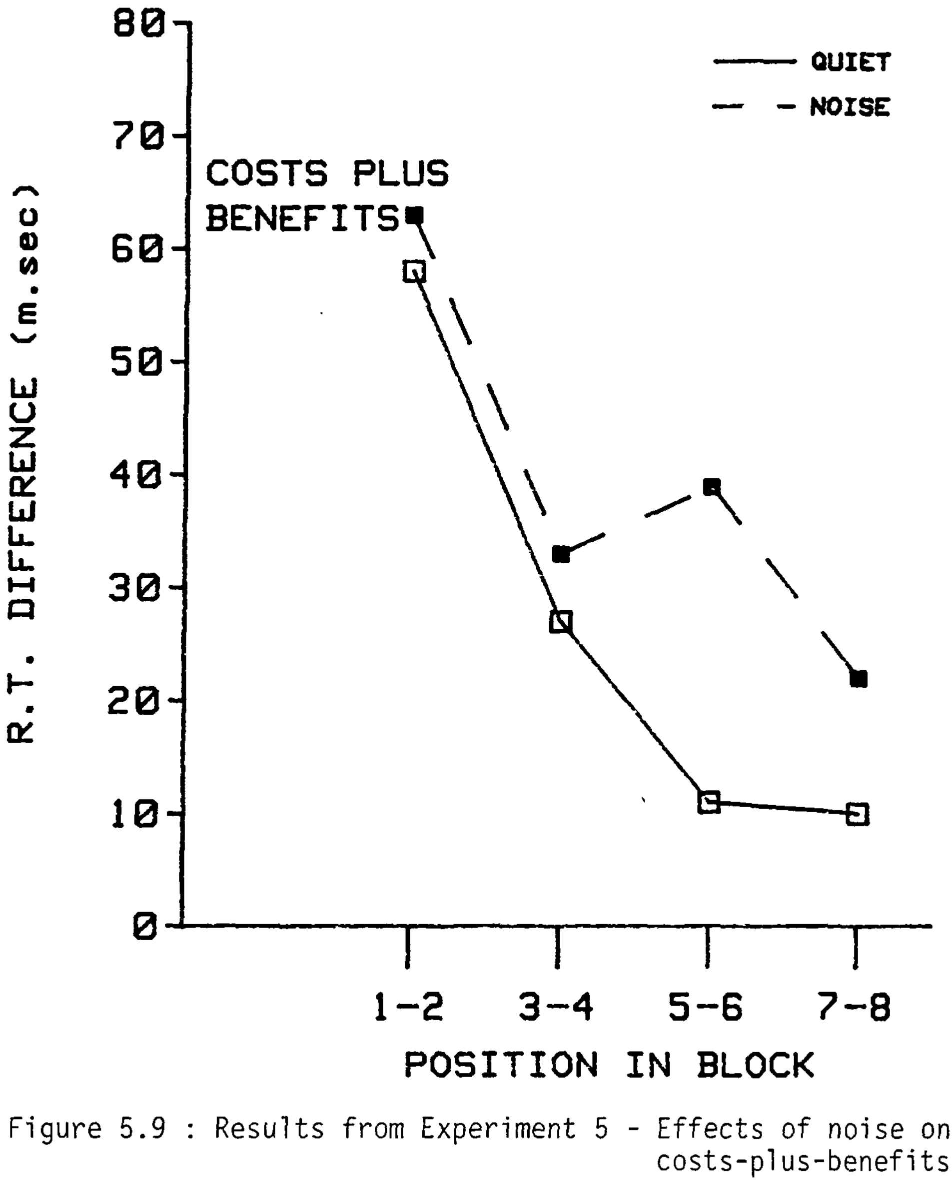


Figure 5.9 : Results from Experiment 5 - Effects of noise on costs-plus-benefits

clear that in noise subjects are showing a greater use of cue later into the sequence of trials than they are in quiet. There was a significant simple main effect of noise at position 5-6 in a sequence [$F(1,33) = 6.92$, $p < .025$]. Thus it can be argued that the loss of active orienting demonstrated so clearly in Experiment 4 is reduced in part by the presence of loud noise.

Such a result can be readily interpreted in terms of much of the established literature on the effects of noise on performance (see Chapter 2). There is an increase in the extent to which subjects are committing their attentional resources to the expected location, and this results in faster reaction times on a valid trial and correspondingly slower responses for an invalid trial. Because the effect is subtle and becomes more pronounced later in a sequence whereas in general costs and benefits decrease with position, these data argue against the operation of any "mechanical" effect of noise on performance. This point is returned to later.

These differences in reaction time are similar to those found by Hockey (1970b) and Smith (1985) who showed noise to have an effect upon the speed of responses to high and low probability signals. Like theirs, these data argue against any kind of explanation of the effects of noise in terms of masking of the kind suggested by Poulton (1977a) - see Section 2.2.6. These particular data also add to the small body of evidence (see Section 2.4) that show how reaction times to signals of high and low priority can be a sensitive tool in the analysis of effects of noise on attentional selectivity.

Figure 5.10 shows data obtained from the analysis of "same" and different" targets performed on valid and neutral trials. These data were entered into a three-way analysis of variance (noise x valid/neutral x same/different). It is quite clear that there is a large inhibitory effect which, although in operation for both trial types, [F (1,11) = 28.35, p < .001], is again greater for neutral trials. This effect is reflected in the significant interaction between trial type and location [F (1,11) = 16.86, p < .005], and is similar to the pattern reported for Experiment 4. Visual inspection of these data suggest that there is a sharper rise in the difference between "same" valid trials and "same" neutral trials in noise than in quiet. From this it can be reasoned that there is a tendency for the difference between "same" and "different" trial types for neutral trials to be accentuated by noise. In other words noise may be increasing the amount of inhibition. This statement is extrapolating considerably from the available statistical evidence, but bearing in mind the small sample size and the fact that one would expect inhibitory effects to be weak with an intertrial interval of 2000 msec in any case, it is possible that this trend is indicative of a genuine effect of noise on performance. It would imply that the processes which produce the inhibitory effect - shown recently by Maylor (1985) and Maylor and Hockey (1985) to be

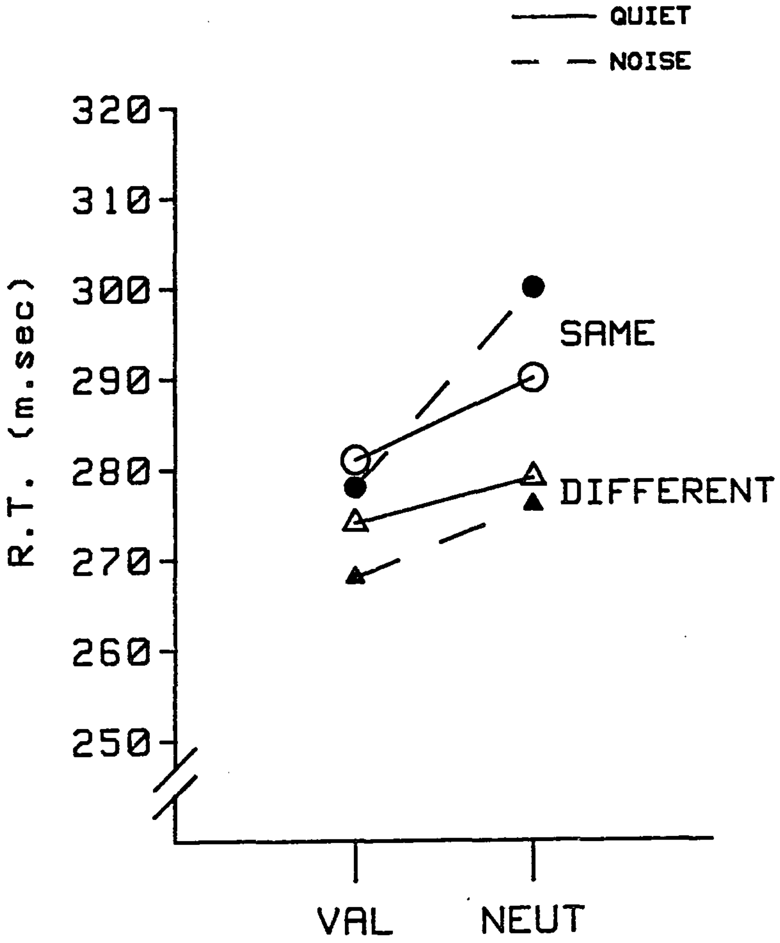


Figure 5.10 : Inhibitory effects in Experiment 5

attentional rather than sensory and dependent upon externally controlled orienting - are affected by loud noise. An interesting speculation would be that because it is the occurrence of a visual event in the periphery that leads to both facilitation and inhibition, processing of this event may be enhanced or deepened in noise, resulting in the effect discussed above. This point is of particular relevance when considered alongside similar data from Experiment 7 (see Section 5.5.3), and is certainly in line with the hypothesis that noise can alter attentional processing so that certain meaningful events are attended to more selectively than others.

These data also raise the point of interest discussed in Section 5.2.2. It has already been shown that noise is both decreasing response times to valid targets and perhaps producing more inhibition for neutral responses than quiet. If negative sequential dependency effects are responsible for valid reaction times becoming increasingly slower over time, and if this effect is reduced in noise, then one would expect there to be less inhibitory effect for valid trials in noise compared to quiet. However, as the above analysis showed, this is not the case at all, with the only differences being for neutral trials, and then in the opposite direction - noise resulting in more inhibition than quiet.

This result adds further weight to Maylor's (1983) contention that failure to maintain orienting in blocked procedures such as these is probably due more to the demanding nature of orienting than to inhibitory effects per se. This conclusion is backed up by the fact that, as mentioned above, measures of both costs and benefits fall as a function of position in a sequence of trials. This should not be the case if, as Posner et al (1984) suggest, inhibitory effects exert most of their influence on valid trials.

According to the view that noise increases orienting and may well be affecting the degree of inhibition, it is possible to predict a specific effect of the stressor on the inhibitory effect, depending upon sequence position. The data in Figure 5.4 suggested that the inhibitory effect was greater for valid trials occurring earlier rather than later in a sequence. Therefore noise might increase inhibition later in a sequence of trials.

To test this prediction, an analysis investigating the inhibitory effect across positions 1-2 and 5-6 was carried out. The data were entered in a four way ANOVA (noise x same/different location x trial type x position). The effect of noise level was non-significant [F (1,11) = 0.54], as were all interactions involving this factor. Thus the specific prediction that noise will enhance inhibition later in a sequence was not upheld. This could be for a number of reasons, but is most probably because the effect of noise is a small one and cannot be easily identified by means of an analysis of such a small number of trials.

However, with the noise factor omitted, the data from this analysis fall into a clear pattern (see

Figure 5.11). These data are similar to those plotted in Figure 5.4. Although the main effect of position (1-2 vs. 5-6) misses significance [F (1,11) = 4.04, p > .05], the effects of location (same/different) and of trial type (valid/neutral) are clearly significant. Location: [F (1,11) = 12.02, p < .01]; trial type: [F (1,11) = 8.01, p < .05]. Of particular interest though is the interaction between position in a sequence and target location which narrowly misses significance: [F (1,11) = 4.3, p = .06]. This is a clear indicator of the trend already reported in Experiment 4. Inhibition is less for trials occurring later in a sequence, and this is especially so for valid trials.

Conclusions on the Effects of Noise from Experiment 5

Thus the main conclusion from the data obtained from Experiment 5 is that noise can be shown to have an effect upon selectivity of attention in settings concerned with the mechanisms of attentional orienting. This conclusion must remain tentative however because of the marginal significance of the effect concerned. In a task using identical target probabilities (Experiments 1-3) noise did not effect performance in a similar manner. This is an interesting result as the main difference between the two tasks lies in the presentation of cue information - a relatively subtle change. It is possible therefore that the prediction made at the beginning of this experiment has been upheld by the data: When the alerting cue is removed,

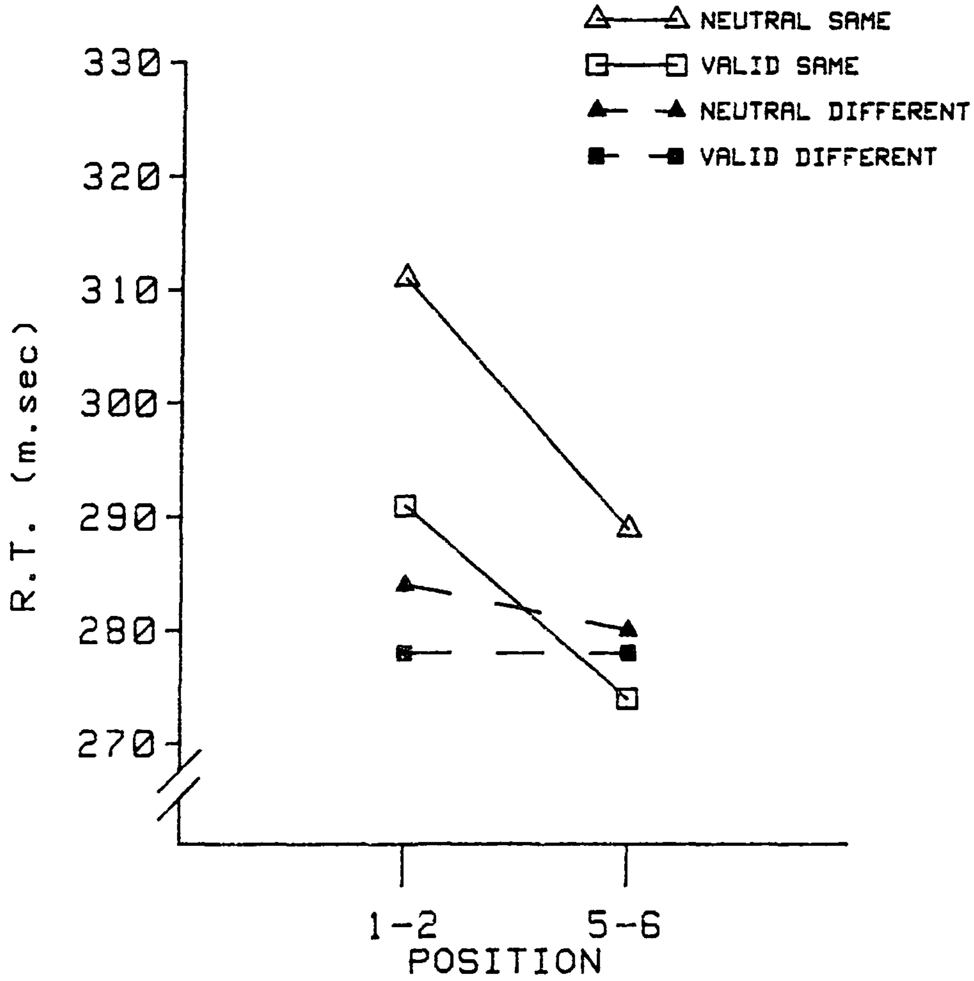


Figure 5.11 : Inhibition at early and late positions in Experiment 5.

noise can affect attentional orienting in a manner which would be predicted by the selectivity hypothesis.

The consequences of this for research into the effects of noise on performance in the laboratory and the real world are far reaching because a tiny change in the detail of a task can totally alter performance efficiency. If this is a major reason for some of the complexity of results in the noise literature, then it is important to discover which elements of task structure are the most relevant ones. A very slight change to a task, one which may well appear to be a "replication" or at least manipulate the same type of variables, can radically alter conclusions drawn from its results. The experiments reported thus form a potentially significant step towards the clarification of this issue.

5.4 Experiment 6

5.4.1 Introduction

Having established the pattern of effects reported in Experiment 5, Experiment 6 was conducted to address the following issues:

1) Would the inability to maintain orienting over time still occur in a similar experimental setting but one which was made more demanding on the subjects by the introduction of a varying intertrial interval? Posner et al (1984, Experiment 2) showed the effect to be present using intervals ranging between 300 and 1000 msec, but in this study it was decided to increase the range still further to vary between 2500 and 3500 msec. Sanders and Reitsma (1982) argue that covert orienting to the periphery may be "so demanding that it can only be maintained for a short period of time" (p. 144). If this is the case then this experimental setting should still result in a failure to maintain selectivity but not in any inhibition. At the very least such a result would provide evidence for the argument that although negative sequential dependency effects could sometimes contribute to a loss of orienting over time (Posner et al 1984; Posner and Cohen 1984), such effects are not <u>necessary</u> conditions for loss of orienting.

2) If loud noise is affecting subjects' ability to maintain orienting in Experiment 5 then would such an effect be heightened in a setting which is placing intrinsically greater demands upon subjects' processing resources by increasing the unpredictability of target occurrence? As discussed in Chapter 2 this kind of

situation is likely to increase subjects' susceptibility to the effects of noise. A change of response-stimulus interval in this setting removes the temporal predictability of individual targets as well as lengthening the interval between them. Of course there are a number of different kinds of demand that could have been introduced at this point (e.g. a secondary task, speed instructions, etc.), but it was felt that the lengthening of the ITI introduced a minimal amount of change into the study, allowing maximal comparability with Experiments 4 and 5.

5.4.2 Method

Subjects

Twelve subjects (9M, 3F) were run in two separate experimental sessions, counterbalanced as described in Section 3.5. Each session took approximately 25 minutes to complete.

Apparatus and Stimuli

See Sections 3.4 and 3.6.

Design and Procedure

These followed the practices adopted for Experiments 4 and 5, the only variation being the length of the response-stimulus interval which was increased from 2000 msec to vary between 2500 and 3500 msec. The same experimental program as was used for Experiments 4 and 5 was used here, with the same randomized presentation of trials.

5.4.3 Results and Discussion

General Effects

Error rates for this study were 1.25% (quiet) and 1.69% (noise). Figure 5.12 shows the data obtained for each cue type plotted against position in a block of trials. The data presented here are collapsed across the different levels of noise for the sake of clarity and the last two positions are once again omitted. These data were entered in a three-way ANOVA with noise level, trial type and sequence positions as factors.

As can be seen from Figure 5.12, although there are clear effects of cue type in the expected direction (i.e valid RT < neutral RT < invalid RT), the differences between responses to neutral trials and valid trials are very slight. There was a significant interaction between cue type and position in a sequence of trials [F (6,66) = 3.67, p < .005]. These data are very similar to those reported by Posner et al (1984, Experiment 1) where data from the invalid trials lay significantly above the neutral and valid data which were in themselves not different. As is the case here, they found that the difference between valid and neutral reaction times was very slight from the outset of a block of trials. This point is discussed below.

At this point it is appropriate to mention a facet of these data which is common to all of the blocked cueing studies reported in this chapter. That is concerning the large fall in reaction time from positions 1-2 to 3-4 in a sequence of trials. Information on location has to be maintained from the

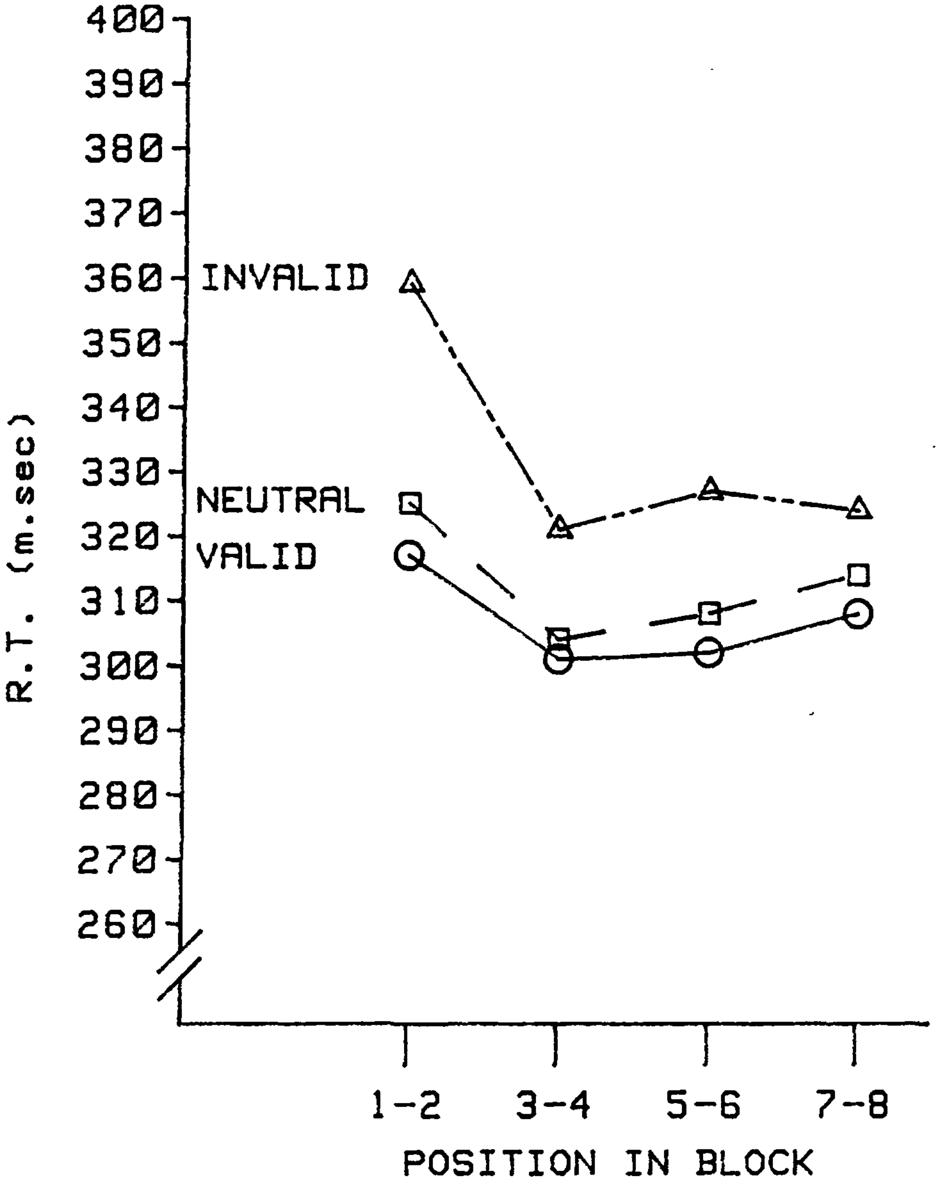


Figure 5.12 : Results from Experiment 6 - Reaction times collapsed across both noise levels

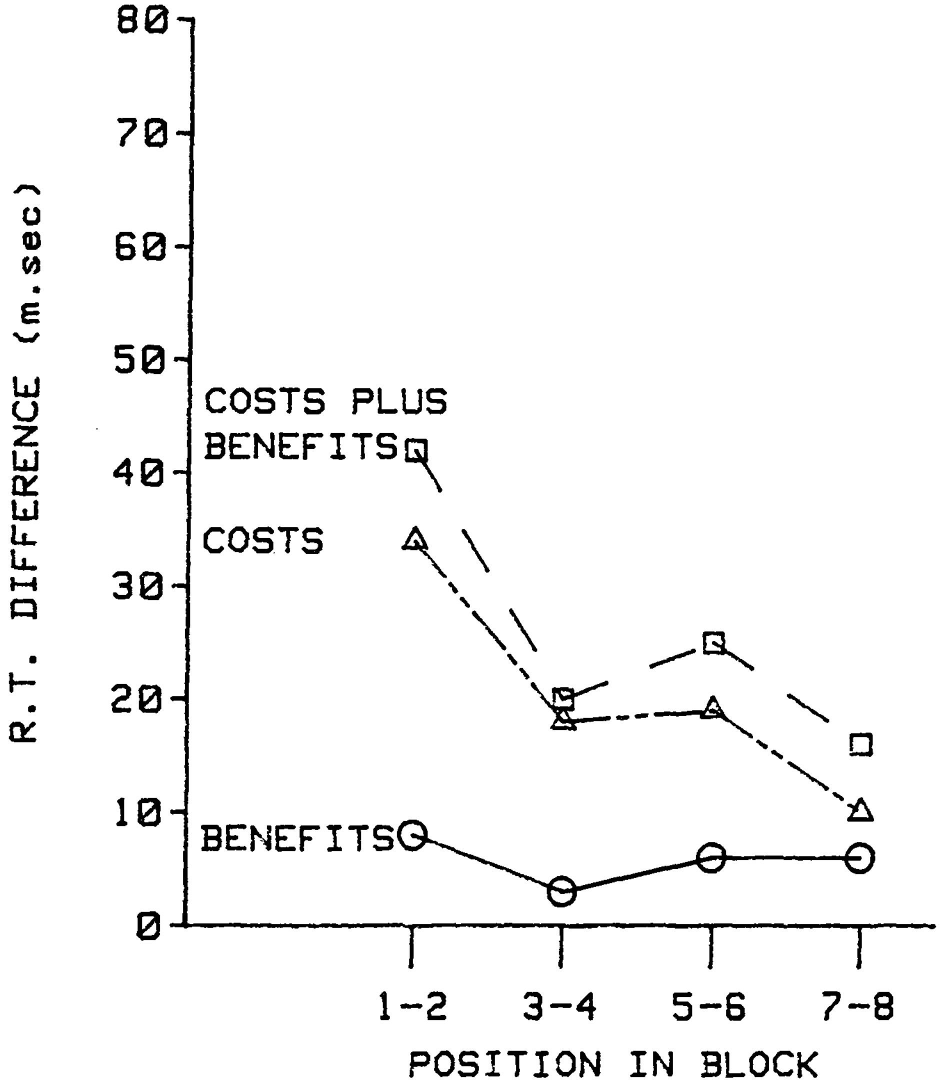


Figure 5.13 : Results from Experiment 6 - Costs, benefits and costs-plus-benefits collapsed across both noise levels

offset of the warning cue until the onset of the first target, a period of time which will depend upon the ITI being used. In this situation subjects have nothing further to warn them of a forthcoming target, and this in itself will impose an extra processing load for early positions in a sequence of trials. It has already been noted that there is a literature on the subject of optimal foreperiods for reaction time (see Chapter 1), and in this setting subjects are being placed in a demanding situation resulting in the general impoverishment of RT seen here.

The same data are expressed in terms of costs and benefits in Figure 5.13. These were also entered in a three-way ANOVA with noise level, cost/benefit and sequence position as factors. Benefits are very small indeed compared to costs and this resulted in a significant main effect of this factor [F (1,11) = 5.77, p < .05]. Visual inspection reveals how benefits are very much lower than costs at early positions in a block, despite the fact that the interaction between position and cost/benefit was not significant [F (3,33) = 1.56, p > .1] and the main effect of position was [F (3,33) = 5.19, p < .01]. These data indicate that in this experiment subjects are unable to benefit from accurate knowledge of target location even by positions 1-2 in a sequence of trials. It is argued that this is because of the long intertrial intervals operating here which precede every trial, including the first in a sequence. Thus even before a sequence is really underway, orienting is lost. However, this argument takes no account of the fact that costs remain high at early sequence positions. This difference between costs and benefits has already been demonstrated by Posner et al (1980), though no explanation was proposed as to why the effect should occur. Obviously if orienting to a given location has failed then the focus of attention must be elsewhere, in this case most probably it is at the point of fixation. If this is so then reactions to the occurrence of each target must be preceded by orienting which occurs repeatedly. When this is understood, the high costs are less of a problem because there is a clear difference between the readiness to orient and the activity itself. It is proposed therefore that subjects know where most targets are likely to occur and simply that this knowledge gives them an advantage on "valid" trials. Other authors (e.g. Posner, Cohen and Rafal 1981; Maylor and Hockey 1987) have already shown how such higher order effects can influence orienting in tasks of this type. Why costs should still fall as a function of position is however less clear.

Effects of Noise

Figures 5.14, 5.15 and 5.16 show the effect that noise has on performance in this task. It is immediately obvious that such a change in environment is not affecting subjects' ability to maintain orienting over time in the manner previously demonstrated in Experiment 4. This fact is reflected in the non-significant effect of noise level on the

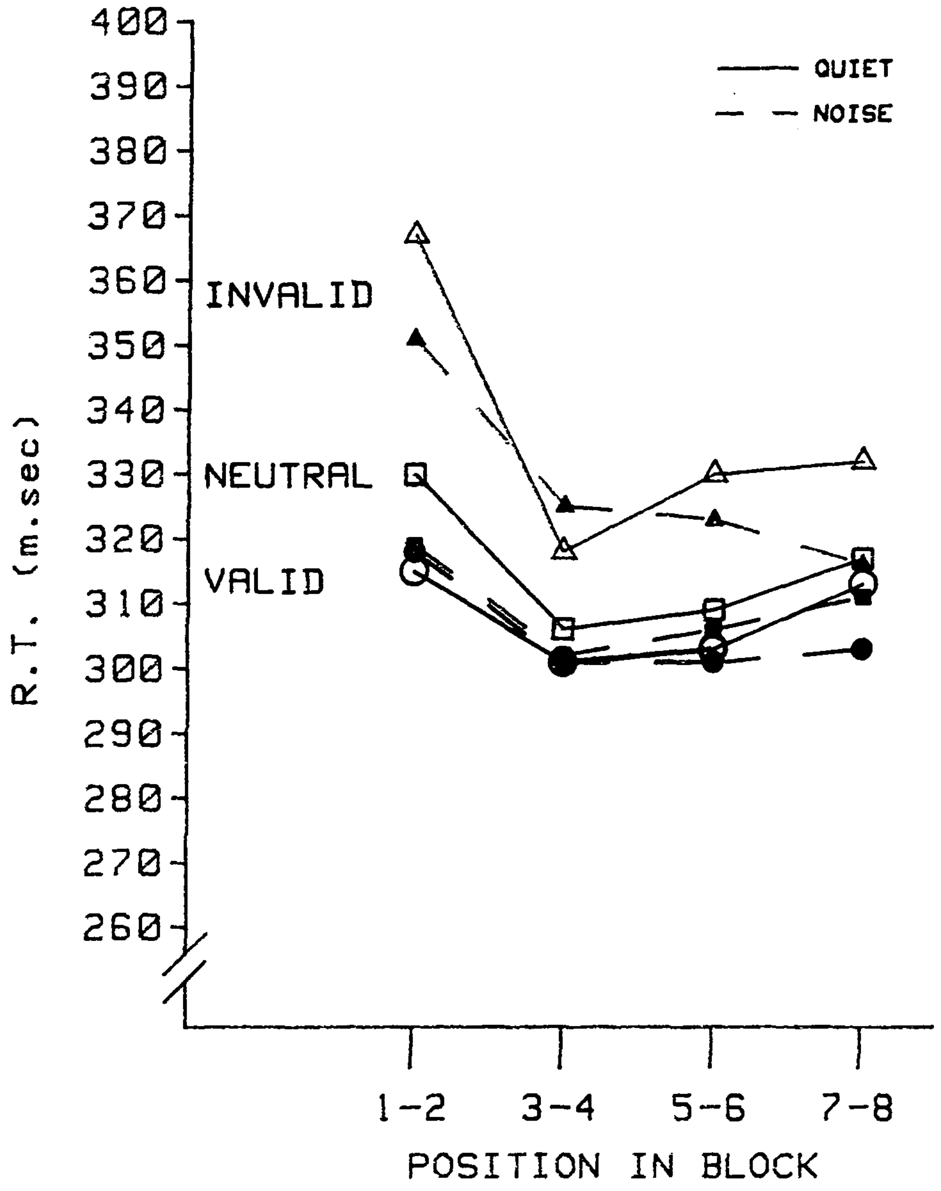


Figure 5.14 : Results from Experiment 6 - Effects of noise on reaction times

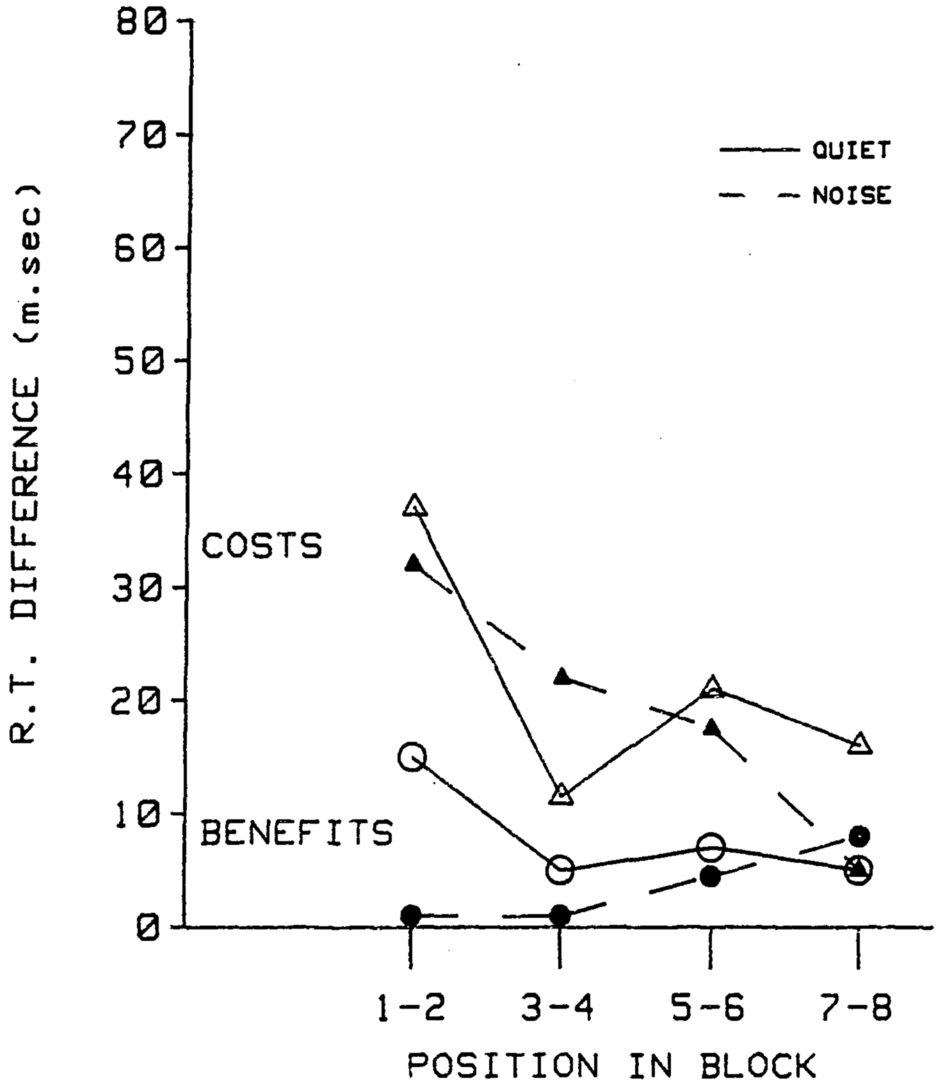


Figure 5.15 : Results from Experiment 6 - Effects of noise on costs and benefits

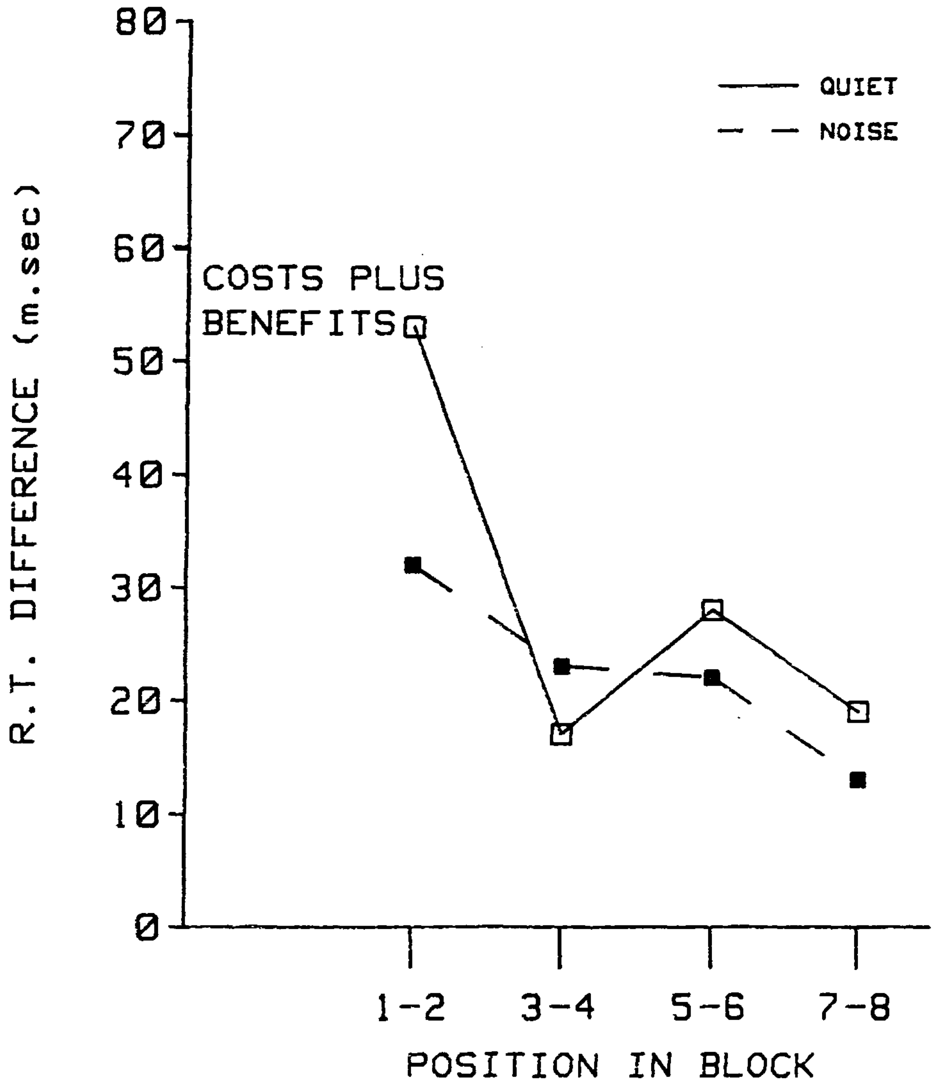


Figure 5.16 : Results from Experiment 6 - Effects of noise on costs-plus-benefits

reaction time data [$F(1,11) = 2.35$, $p > .1$]. However the effect of noise in Experiment 4 was not apparent in the study of the raw data.

Figures 5.15 and 5.16, which plot performance on this task in terms of costs and benefits, show that the effect is not present here either. The general increase in commitment of attention to an expected target location which was demonstrated in Experiment 4 is not reflected in a similar increase in costs and benefits here [$F(1,11) = 0.72$, $p > .1$]. Neither was the interaction term between costs and benefits, position in a sequence of trials, and noise level significant: [$F(3,33) = 0.72$, $p > .1$]. Thus far from increasing the likelihood of noise affecting the orienting of attention in this task, it seems that the increase in intertrial interval is pushing performance out of the range within which an increase in alertness caused by the environment can alter performance to any significant extent. The most likely reason for this is that with such a long gap between each target, orienting is barely present at all and therefore noise cannot affect it.

With such long response-stimulus intervals one would not expect to find any negative sequential dependency of the type described by Posner et al (1984), because such intervals as these are well outside the range over which inhibitory effects are acknowledged to operate (Maylor 1983, 1985). Investigation of the data showed this indeed to be the case, with the data for this effect being displayed in

Figure 5.17. As predicted there are no differences in reaction times to "same" and "opposite" targets. This was confirmed by the three-way ANOVA performed upon the data, with noise, trial type and location as the factors entered: [F (1,11) = 1.45, p > .2]. The only significant effect in these data came from the expected difference in speed between responses to valid and neutral targets [F (1,11) = 15.6, p < .005].

This result is again of particular relevance to the contention (Posner et al 1984) that inhibition is what causes the loss of orienting in this type of blocked experimental design. Clearly this cannot be the case, as Maylor (1983) argues, because this experiment demonstrates a loss of selectivity but no inhibition. Also these results cast doubt on inhibitory effects as an explanation for the way in which benefits seem to be more affected than do costs - an effect common to Posner et al 1980, Posner et al 1984, and the experiments reported thus far.

Conclusions on the Effects of Noise on Experiment 6

The conclusions from this experiment as far as the effects of noise on performance are that once again a small alteration in the structure of a task - in this case the lengthening of the intertrial interval by an average of about 1 second - can have a significant effect on performance. In this case an effect of inhibition and of an alteration in degree of attention allocation to a position in space are both removed while the inability to maintain selectivity remains. As

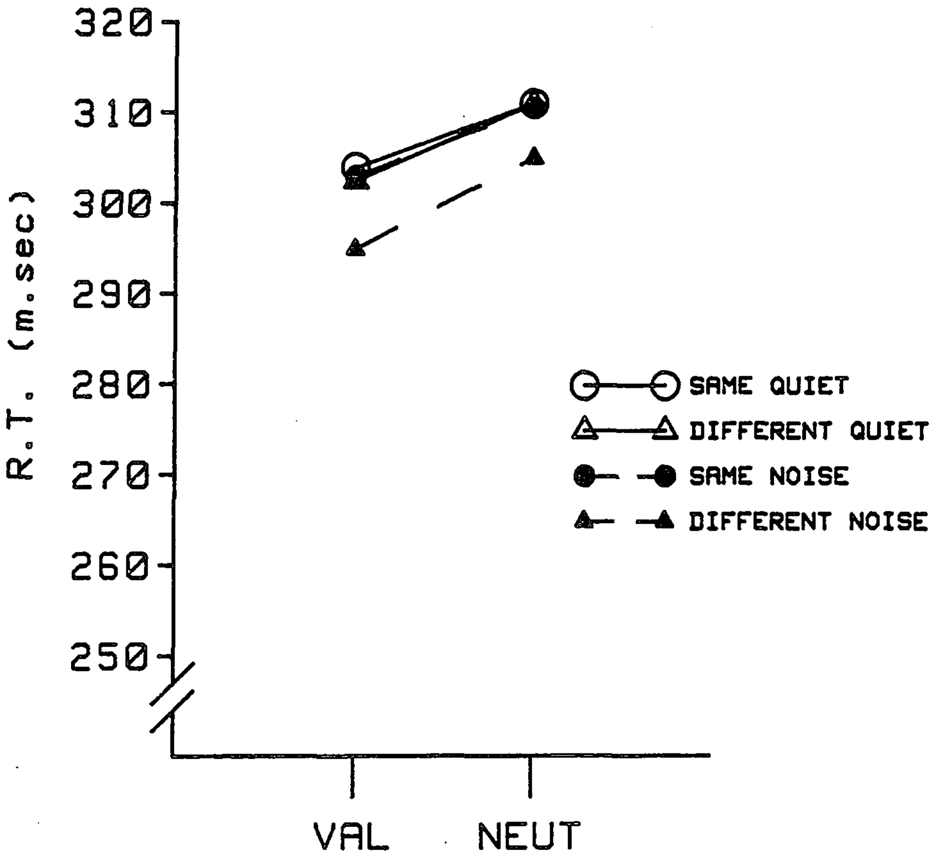


Figure 5.17 : Inhibitory effects in Experiment 6

the effects of noise do seem to be so highly situation specific, one is led to the conclusion that the selectivity hypothesis cannot be applied in a blanket fashion to the study of attentional orienting. If noise will affect performance at all then it is hard to see how any useful or predictive theory can be developed on the basis of the results reported thus far.

5.5 Experiment 7

5.5.1 Introduction

The aims of this experiment were as follows:

1) As discussed in Section 5.2.2, negative sequential dependency effects are unlikely to operate outside of the range of about 1500-2000 msec. Such effects were present in Experiments 4 and 5 where the interval between targets was 2000 msec, and thus one question of obvious interest is whether or not the same effects will be produced in greater measure when target-target intervals are reduced to fall well within the accepted range of inhibitory effects.

2) This is also relevant to the suggestion in Experiment 5 that noise resulted in greater inhibition (for neutral trials). One specific question addressed by Experiment 7 was whether a reduction in intertrial interval would increase the robustness of this effect. This is because the effects of inhibition should be greater with a reduced ITI.

3) In addition, it was decided that bearing in mind the size of the effect of noise in Experiment 5, another experiment needed to be conducted which included a similar manipulation of the variables which were deemed important in that study. It was decided to vary the length of the intervals used to preclude the possibility, though remote, that the specific effects of noise shown in Experiment 5 in fact arose as a consequence of the precise temporal predictability of target onset. Hence, if the effects of Experiment 5 have disappeared in Experiment 6 as a result of

variation in the target-target interval rather than of its length per se, then the effects should be absent in this setting too. However, if the conclusion that noise was affecting performance as a result of a change in attentional selectivity was a correct one, then a similar pattern of data should be found here. Thus this experiment set out to both replicate and extend the findings of Experiment 5.

5.5.2 Method

Subjects

Sixteen subjects (9M, 7F) were run in each experimental condition which lasted approximately 20 minutes. These sessions were again counterbalanced as described in Section 3.5.

Apparatus and Stimuli

Once again these are described fully in Sections 3.4 and 3.6.

Design and Procedure

These were identical to those followed for Experiments 5-6 but for the fact that the response-stimulus interval was altered to vary between 1200 and 1500 msec.

5.5.3 Results and Discussion

General Effects

Error rates were 1.25% (quiet) and 1.7% (noise). As for Experiments 5 and 6, overall data expressing the mean of median reaction times for each cue type, collapsed across noise and quiet and as a function of position in a block, are plotted in Figure 5.18. The same data expressed in terms of costs and benefits are represented in Figure 5.19.

As in the other studies using this experimental technique the effects arising from cue type are most prominent at the beginning of a block of trials. Figure 5.18 shows how the differences between valid, neutral and invalid response times are greatest at early positions in a sequence, but these differences rapidly diminish as a block of trials continues. This is similar to the pattern of data reported from Experiments 4-6 and in the experiments reported by Posner et al (1980) and Posner et al (1984). In other words, the characteristic loss of orienting over time is again present.

This is seen more clearly in Figure 5.19, where visual inspection shows that costs and benefits both fall as a function of position. These data were entered in a three-way ANOVA (noise x position x cost/benefit). There was a significant main effect of position [F (3,45) = 18.1, p < .001], and although the difference between the measures of cost and benefit narrowly missed significance [F (1,15) = 4.01, p = .06], there was a significant interaction between position and cost/benefit [F (3,45) = 2.99, p < .05]. This indicates that although both costs and benefits fall as position increases, benefits are lower at the start of a

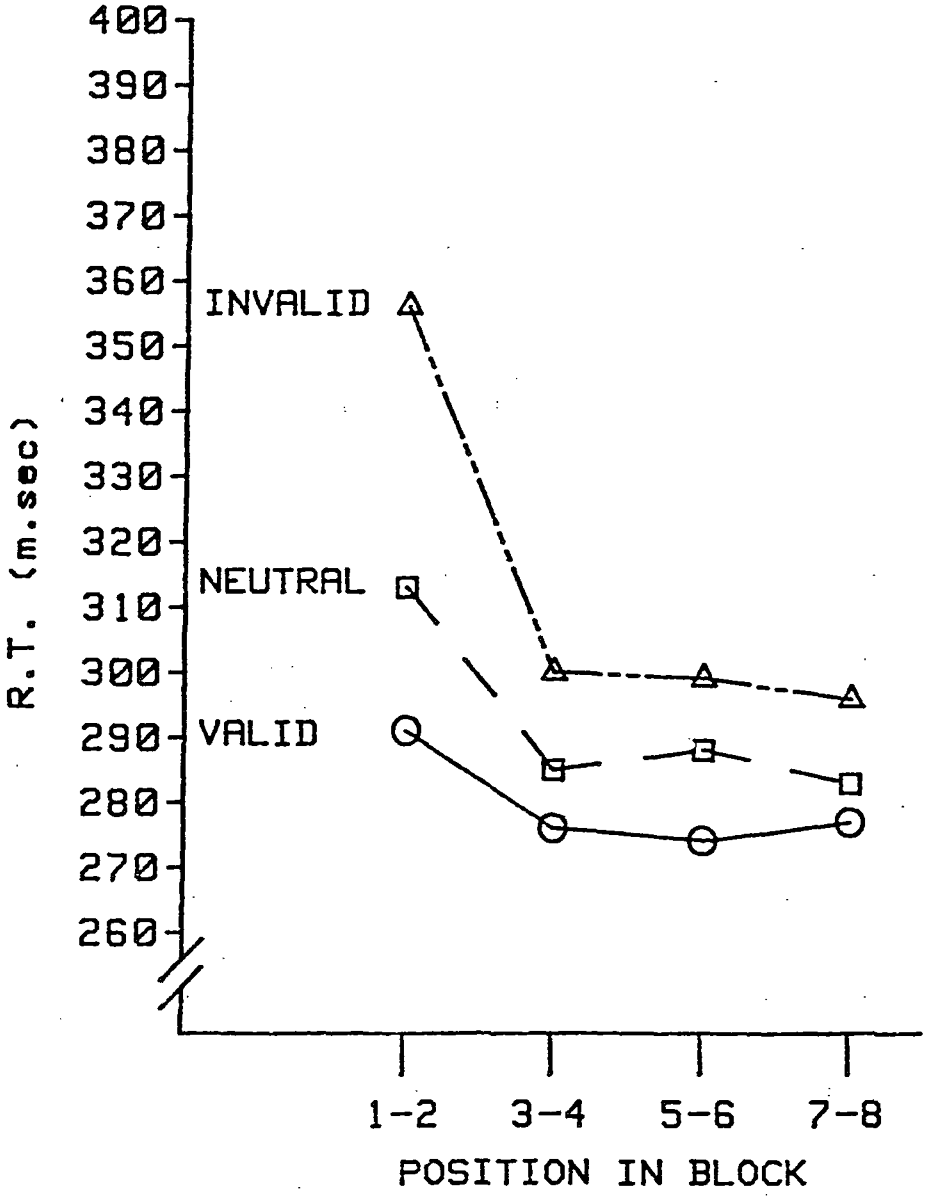


Figure 5.18 : Results from Experiment 7 - Reaction times collapsed across both noise levels

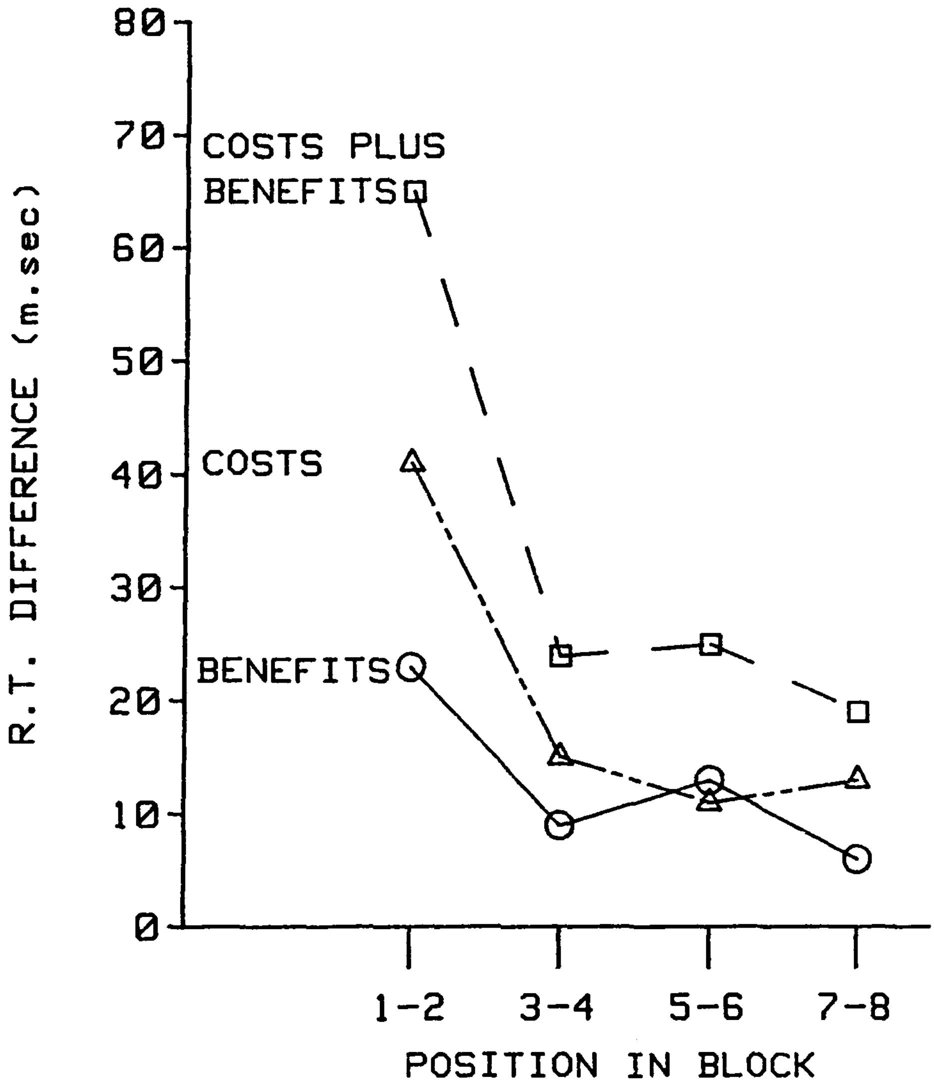


Figure 5.19 : Results from Experiment 7 - Costs, benefits and costs-plus-benefits collapsed across both noise levels

sequence. In this regard the data clearly replicate the pattern already discovered in Experiments 4-6.

Effects of Noise

Figures 5.20, 5.21 and 5.22 present the overall data for this experiment, including the effects of noise. The effect of major interest is that shown most clearly in Figure 5.22, namely the effect of noise on the measure of costs-plus-benefits. This was the clearest demonstration of the effect of noise on Experiment 5, and the pattern of effects is similar here. As position in the block of trials increases the presence of noise results in greater costs and benefits, a reflection of an hypothesized greater commitment of attentional resources. The analysis of variance performed on the data plotted in Figure 5.21 alone (noise x cost/benefit x position) revealed no main effect of noise [F (1,15) < 1] but a significant interaction between noise and position in a block of trials [F (3,45) = 4.21, p = .01]. In addition, the three-way interaction between noise, position and cost/benefit was significant [F (3,45) = 5.08, p < .01]. The two-way interaction between noise and position suggests that at the later positions there is a general increase in the measure of costs and benefits (and therefore costs-plus-benefits), in a manner similar to that reported for Experiment 5. However, the three-way interaction signifies that this effect varies between the two measures of performance, as can be seen from the figure. Thus it is not simply the case that

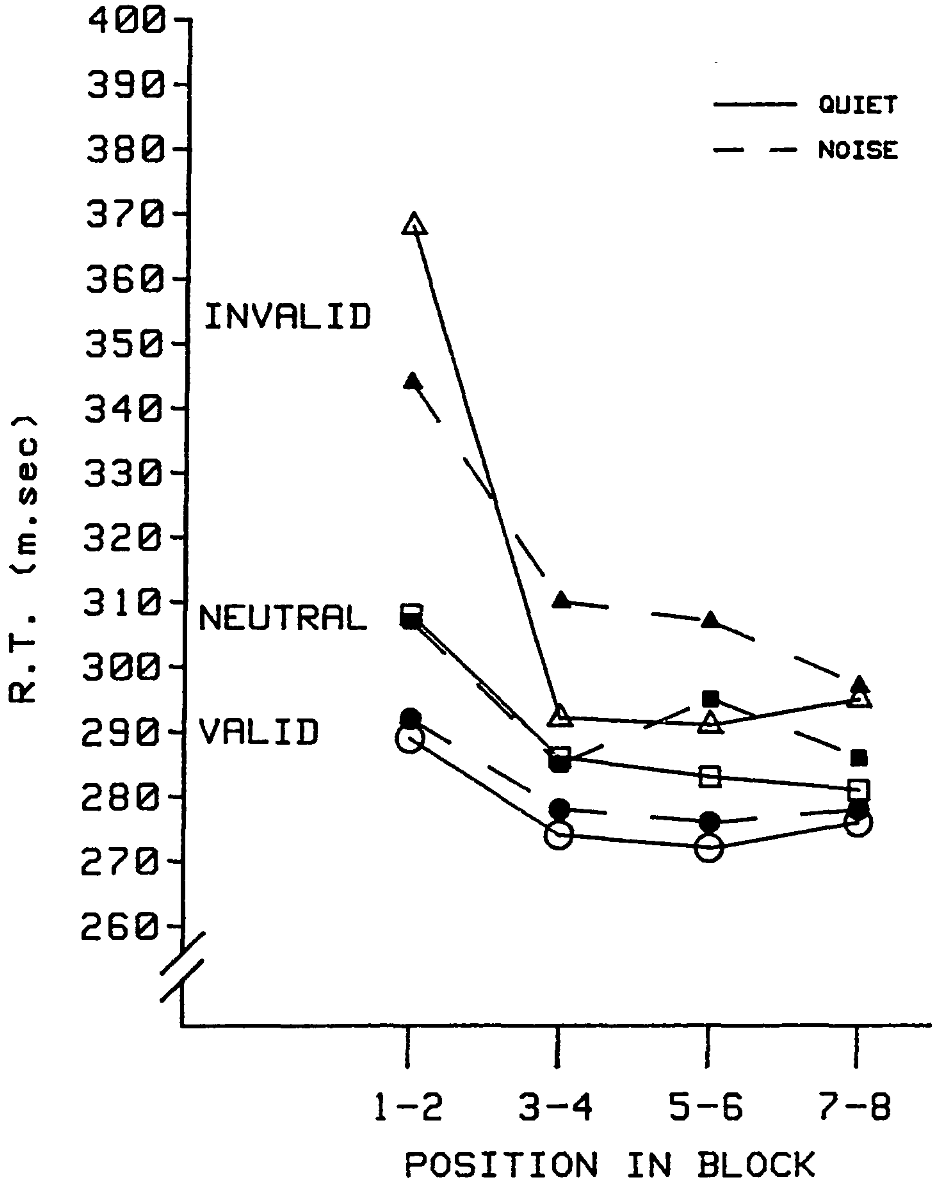


Figure 5.20 : Results from Experiment 7 - Effects of noise on reaction times

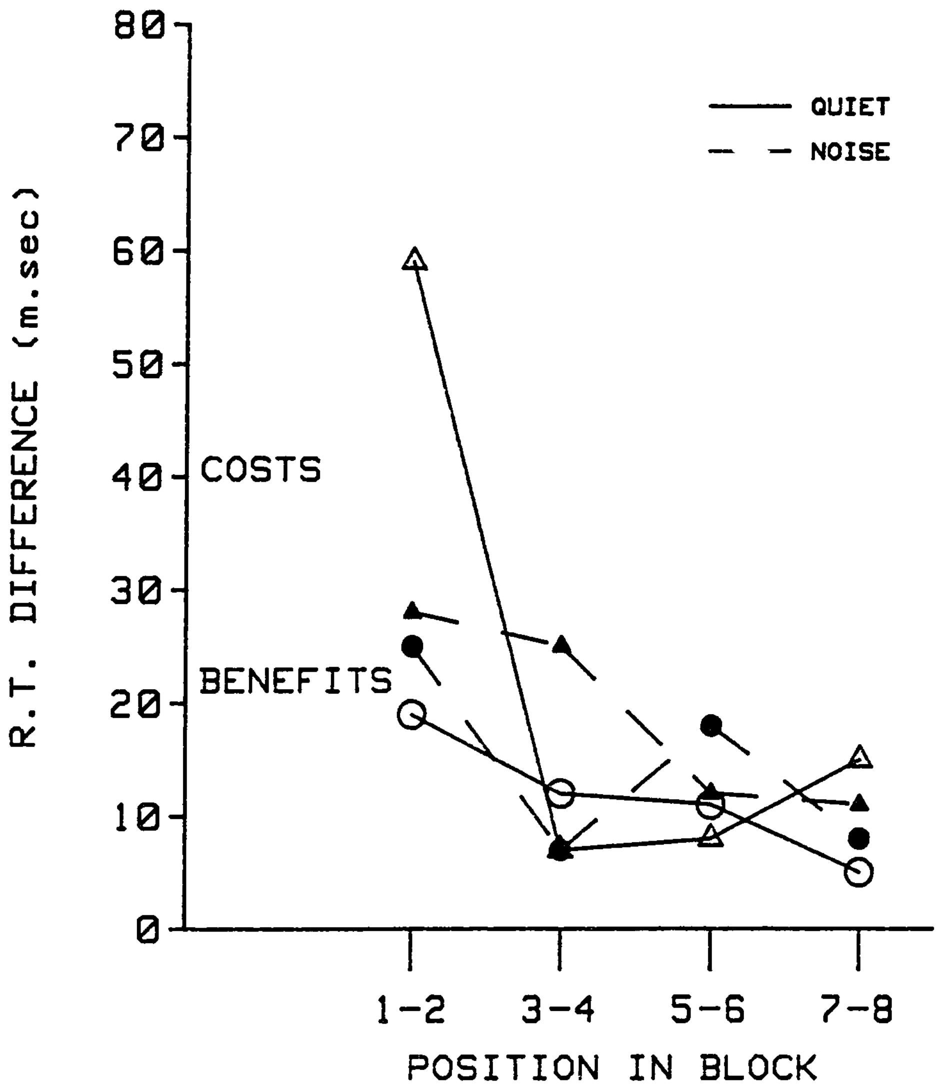


Figure 5.21 : Results from Experiment 7 - Effects of noise on costs and benefits

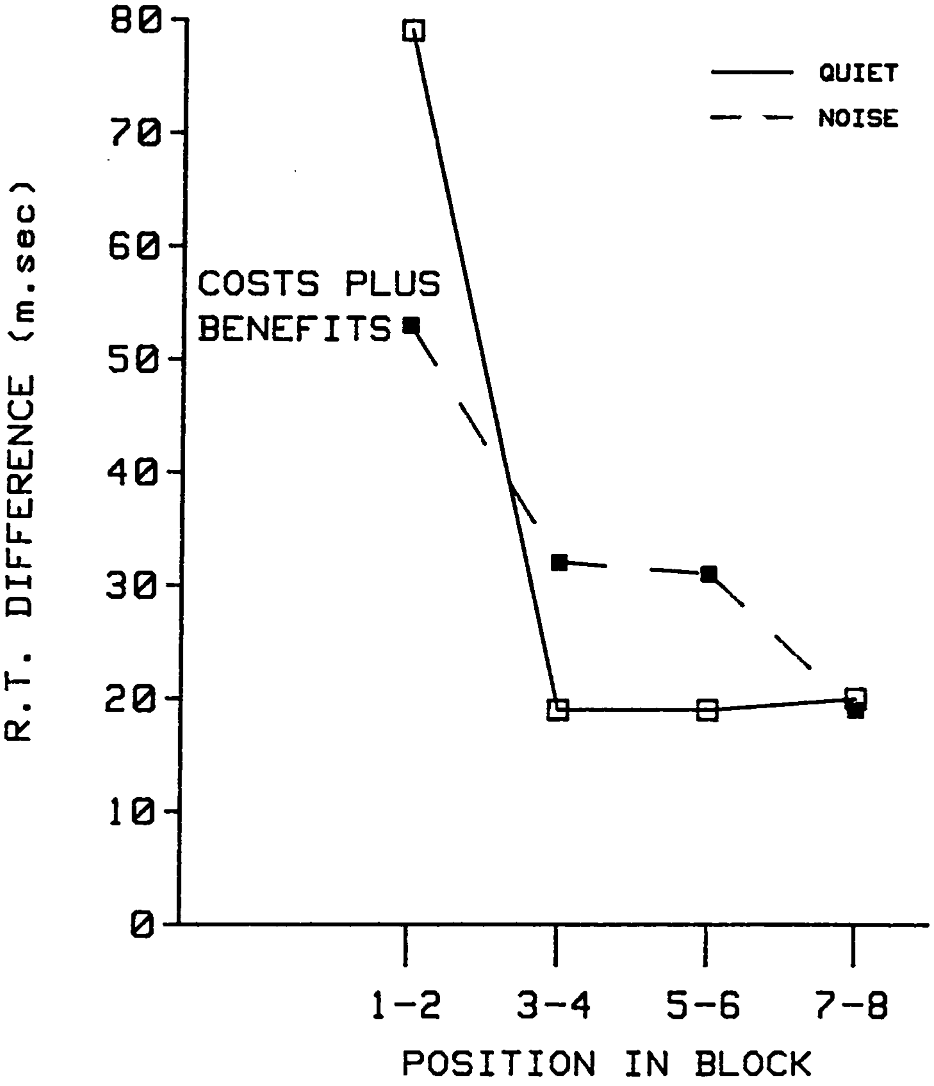


Figure 5.22 : Results from Experiment 7 - Effects of noise on costs-plus-benefits

noise is resulting in greater costs and benefits at later positions in a sequence, because of what is happening to the measure of costs at positions 1-2.

An inspection of Figure 5.20 reveals the origin of most of these effects and enables a clearer understanding of them. The following relevant significant effects were obtained from the 3-way ANOVA (noise x trial type x position) performed on these data: Noise x position: [F (3,45) = 2.95, p < .05] and noise x position x trial type: [F (6,90) = 4.52, p < .001]. It is the large increase in reaction time seen under noise for the invalid trials which is the result of major interest from this study, and is contributing most to the interactions discussed above. Simple main effects comparisons were carried out on the data for invalid trials (noise vs quiet), positions 1-2, 3-4 and 5-6. All proved to be significant: 1-2 [F (1,90) = 18.1, p < .001], 3-4 [F (1,90) = 9.6, p < .01], 5-6 [F (1,90) = 8.03, p <. 01]. Thus although noise is resulting in significantly greater invalid response times for later positions is a sequence of trials, the effect is reversed for positions 1-2. There are several possible interpretations of this effect.

The first of these appeals to the notion of a noise induced "strategy change" on the part of the subject. It can be interpreted as a reflection of the fact that when subjects are presented with an unexpected target they take longer to respond in noise than in quiet at later positions in a block of trials. It could be that subjects are paying more attention to the expected location in noise only as the sequence continues because that is the action of highest priority in this situation. For early trials an invalid target will come as more of a surprise anyway and it is as though this "surprise" element is still present for later trials in noise, evidence for concentrating on one aspect of the task at the expense of another. The only explanation for such a pattern of data which would fit with the selectivity hypothesis is to suggest that in this setting noise is inducing a particular type of strategy. At the start of a sequence it is as if subjects are deliberately witholding their attentional resources in noise, perhaps as a result of the uncertainty surrounding the occurrence of a trial. Such a witholding would account for the greater degree of the effect on invalid trials because of their low degree of occurrence. The only problem with such an interpretation is that it is entirely post-hoc and does not easily explain the pattern of data already reported for Experiment 6. Such an argument leads to the conclusion that the effects of noise on tasks of this type are likely to be so highly situation specific that a predictive theory of only the most general kind can be formulated. Such an explanation fits with the type of composite model for performance in noise suggested by Fisher (1984b) where several aspects of a task situation are contributing to the overall effect of noise on a task.

There was in addition the significant interaction between noise and position in a block. What appears to be occurring in Figure 5.20 is that reaction time is generally longer at late sequence positions (see especially positions 5-6). This could be a reflection of the type of effect discussed in Section 2.2.2, where in situations of temporal uncertainty, noise was shown to result in longer RT. But in this task uncertainty does not increase as a block of trials progresses, so the precise reason for this effect is unclear.

Comparing these data with those obtained from Experiment 5 it is apparent that the two studies are similar in that for invalid trials noise results in an increase in response latency. For Experiment 5 this effect, coupled with a decrease in responses to valid trials, brings about the increase in the measure of costs-plus-benefits in noise, but in this study the effect is limited to the invalid trials in particular. This could be for a combination of at least three reasons. The first is that reaction times are as fast as they can be in this situation, and the production of a state of heightened selectivity cannot reduce them any further. The second is simply the possibility that the pattern of results arises due to measurement error. The third is that noise is interacting with expectancy effects in a very specific manner, and the processes of pathway inhibition - results of the commitment of limited capacity attentional mechanisms (Posner and Snyder 1975a, b) are in actual fact affected by noise in a manner which is differential to activated pathways. These processes could be subject to all manner of higher order effects resulting from fluctuating expectancy, processing load etc. It is suggested that further research is necessary to explore the exact nature of this effect, and this question is returned to in Chapter 7.

With an intertrial interval shortened to fall more within the established range attributed to the inhibitory effect (Maylor and Hockey 1985), it would be expected that there would be strong negative sequential dependency effects operating in this setting. In actual fact the data obtained from this study closely resemble those found in Experiments 4 and 5, as shown by Figure 5.23. These data were entered in a three-way ANOVA (noise x trial type x location), and once again there were clear inhibitory effects [F (1,15) = 9.23, p < .01]. These effects were greater for neutral than for valid trials, as shown by the significant interaction between trial type and location: [F (1,15) = 15.93, p < .005]. Of particular interest though is the significant three-way interaction which was obtained between noise, trial type and location [F (1,15) = 4.56, p < .05]. In a manner similar to that demonstrated in Experiment 5, there is greater inhibition for neutral trials in noise. Thus in conditions which enhance the inhibitory effect (i.e. shortened target-target interval), and for those trials where the effect is operating most clearly, noise is resulting in deeper negative consequences for attending to environmental events. These effects are clearly very small, but the fact that once again they are in the direction of <u>increased</u> inhibition in noise, and that they occur for neutral

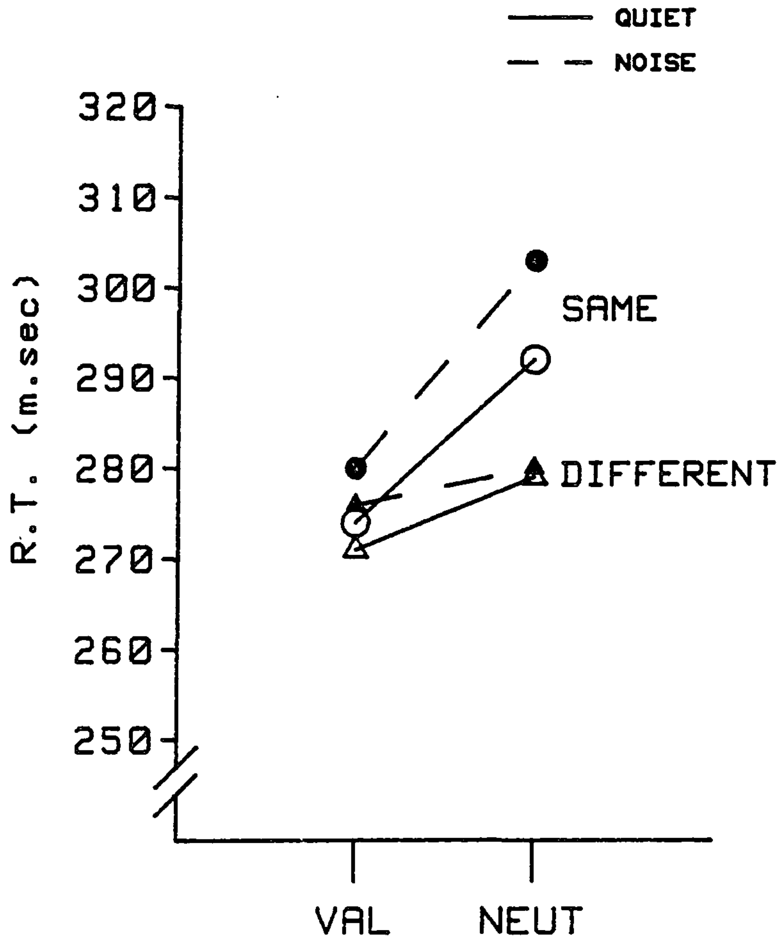


Figure 5.23 : Inhibitory effects in Experiment 7

trials rather than for valid ones argues against any simple interpretation of the phenomenon of loss of orienting over successive trials as being attributable to inhibitory processes. This difference between "same" and "different" reaction times for neutral trials was confirmed by a separate two-way ANOVA (noise x same/different) performed upon data from neutral trials alone. The result of interest here was that the interaction between noise and location was significant [F (1,15) = 6.31, p < .05].

A final analysis was performed upon the amount of inhibition occurring at early and late positions in a sequence of trials. These data are plotted in Figure 5.24. It is clear that the overall level of inhibition occurring for valid trials is very small indeed and that this effect is equally insignificant at either position in a block. For neutral trials however, the inhibitory effect is both large and consistent across sequence positions. These effects were confirmed by a three-way ANOVA (1-2/5-6 x same/different x valid/neutral) which showed the difference between valid and neutral response times to be significant [F (1,15) = 12.28, p < .01], and also the interaction between trial type and location [F (1,15) = 4.18, p = .05]. It is concluded that these data do not show the increase in the inhibitory effect at later positions in a block which, as discussed earlier in this chapter, would be predicted by Posner et al (1984). Neither though is there the <u>fall</u> in inhibition which would be predicted from the position taken thus far in this

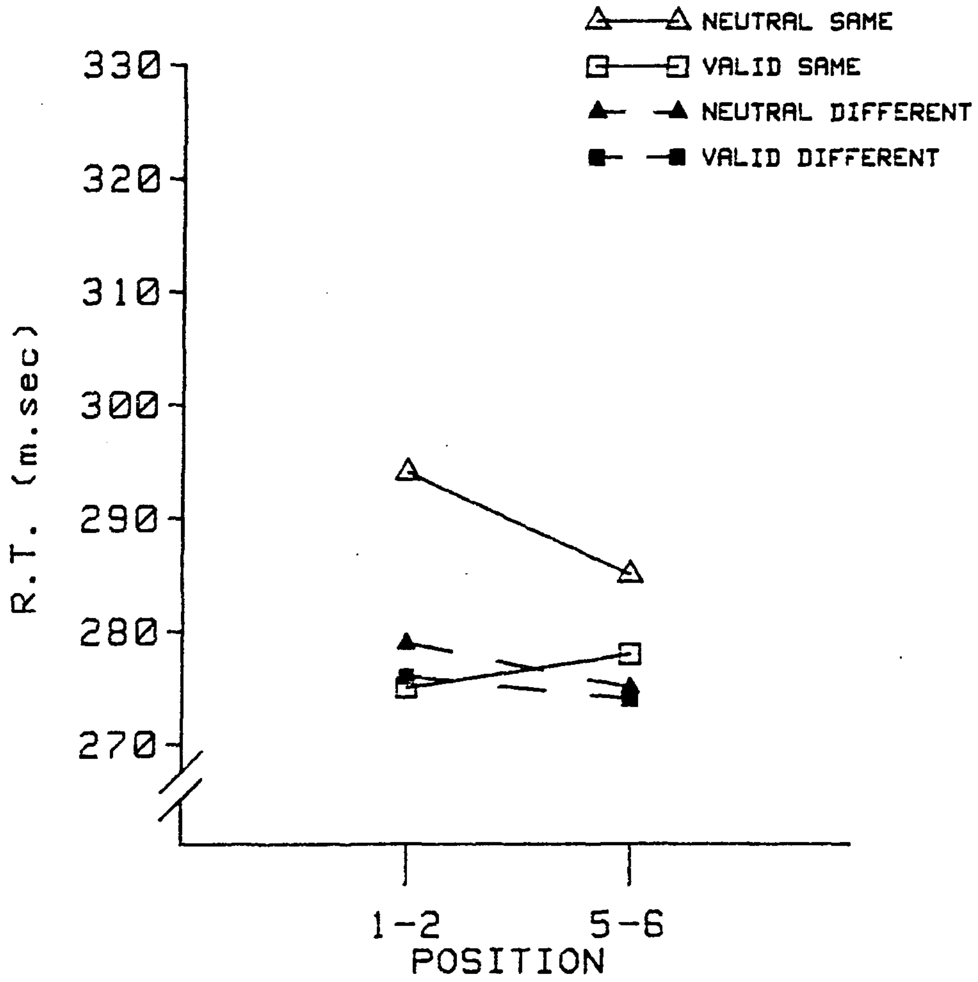


Figure 5.24 : Inhibition at early and late positions in Experiment 7

chapter on the reasons for failure to maintain orienting. It is concluded that this is probably because the initial amount of inhibition present for the valid data is too small to reflect any further change as a result of sequence position.

Conclusions on the Effects of Noise on Experiment 7

Noise is affecting performance, particularly to responses to invalid targets, in a way which can only be interpreted by appealing to a complex theory of noise effects. There is no mechanistic change as a result of the stressor, though several results do include suggestions of changes in attentional selectivity.

5.6 Experiment 8

5.6.1 Introduction

One of the central contentions from the data presented thus far is that the presence of the central warning signal, occurring immediately prior to target onset is a highly alerting phasic stimulus to subjects. Thus any further effect on alerting brought about by an increase in environmental stimulation, i.e noise, is unlikely to have a further demonstrable effect on performance in orienting tasks where such a signal is present. This point is of particular interest as it in fact argues along with Eysenck (1983) against a straight "limited attention" explanation of the effects of noise on performance of the kind proposed by Easterbrook (1959). It is clear that a broader model is required to account for these findings. This point is returned to in Chapter 7.

The above conclusion seems justified on the basis of evidence about the nature of performance changes under noise (see Chapter 2). However, if the alteration of one particular aspect of a task is responsible for the creation of a situation where noise will affect performance, then it is also possible that one of the other major differences between the experimental designs presented in Chapters 4 and 5 is responsible for the effects reported in this chapter. In particular the two sets of tasks differ in the number of trials presented in a sequence - a predictable 10 in Experiments 4-7, but varying widely in Experiments 1-3. It is argued that subjects alter their performance in noise in the former situation because of the nature of the locational priorities operating there. However it is also possible that the effect could be due to some other hitherto unspecified aspect of task structure, with the pattern of performance being perhaps totally different when trials are blocked than when they occur in longer sequences.

There are two separate ways of approaching this problem. The first possibility is to make the experimental setting used in Chapter 5 closer to that used in Chapter 4. This could be accomplished by keeping the blocked design but re-introducing the central warning signal prior to target onset. Alternatively the general design of Experiment 4 could be maintained, i.e. blocks of trials could be long rather than short, but the central signal could be removed so that attentional priorities were manipulated in a more general manner. The prediction in the former case would result in no effect of noise upon performance. In the latter experimental situation one would predict that noise would alter selectivity so that the speed of responses to high probability targets would be accentuated at the expense of low priority ones.

The first of these two possible designs was decided upon. Firstly this was because the inclusion of alerting cues in the small block design should ensure that orienting did not diminish over time as it had done in the other experiments reported in this chapter. Thus such a design should present an interesting contrast to the results which have been reported hitherto. In addition Hockey (1969) reports an experiment which is similar to the second design outlined above, and which produced results in the expected direction. He used a 2-choice task lasting over 40 minutes, in which subjects were presented with a series of signals which occurred at one of two previously indicated peripheral locations with a probability of 80%. Subjects were free to make overt head and eye movements, and this in addition to the fact that signals only came at an average of one every 30 seconds did make the situation somewhat different from the orienting studies reported here. Nevertheless results showed that 100 dB noise decreased response times to high probability targets relative to low probability targets.

Experiment 8 was conducted to examine the effects of noise on the other task situation, i.e. where the small number of trials used in Experiments 4-7 are maintained but attentional expectancies are once again commanded immediately prior to target onset instead of prior to a whole series of trials. Thus subjects would still receive 10 trials in a block, but each trial would be preceded by a directional cue.

The specific prediction for this experiment is that there will be no loss of orienting as a block of trials continues, because attention will be marshalled on every trial. Noise should have no effect on performance because the central cue will lock attention to a given location so effectively that additional tonic influences upon attentional mechanisms will exert no further effect upon selectivity.

5.6.2 Method

Subjects

Twelve subjects (8M, 4F) were run in each of two experimental conditions which lasted approximately 20 minutes. These sessions were counterbalanced as described in Section 3.5.

Apparatus and Stimuli

See Sections 3.4 and 3.6.

Design and Procedure

The general timing and procedure were similar to that used previously in Experiments 4-7. Targets were presented in blocks of 10, but the target-target procedure was abandoned. As before there were two kinds of block, those containing targets which occurred with equal probability on either side of fixation (neutral trials) and those which contained targets which appeared at the same location 80% of the time. These blocks were again preceded by information of the type presented in Experiments 4-7, telling subjects the most likely target location to follow.

In addition to this information, immediately prior to target onset, subjects received a central warning signal presented for 80 msec which again told them of the likely target location. This warning signal was identical to that presented at the onset of the block and thus served mainly as a specific alerting cue, containing no new information in itself. Cues preceded targets by an SOA which fluctuated randomly between 250 and 500 msec. These SOAs were chosen because Experiments 1 and 3 had shown them to be optimal in commanding attentional orienting, and the variability prevented a preponderance of anticipatory responses. Each target was followed by an intertrial interval varying between 1200 and 1500 msec.

The seemingly redundant information as to likely target location presented prior to a block of trials was maintained so that the first cue-target pair in the block was not treated differently from the other 9 trials in terms of the information it contained. The result of this was that the experimental procedure allowed for a specific test of the contention that the central cue would pre-empt the action of noise on the selectivity of performance.

5.6.3 Results and Discussion

General Effects

Error rates for this study were 3.63% (quiet) and 2.96% (noise). Figure 5.25 shows the overall reaction time data from this experiment, collapsed across noise conditions. The same data expressed in terms of costs and benefits are shown in Figure 5.26.

In contrast to the other studies reported in this chapter it is clear that the effects arising from cue type are not any more prominent at the beginning of a block of trials than they are at the end. In fact

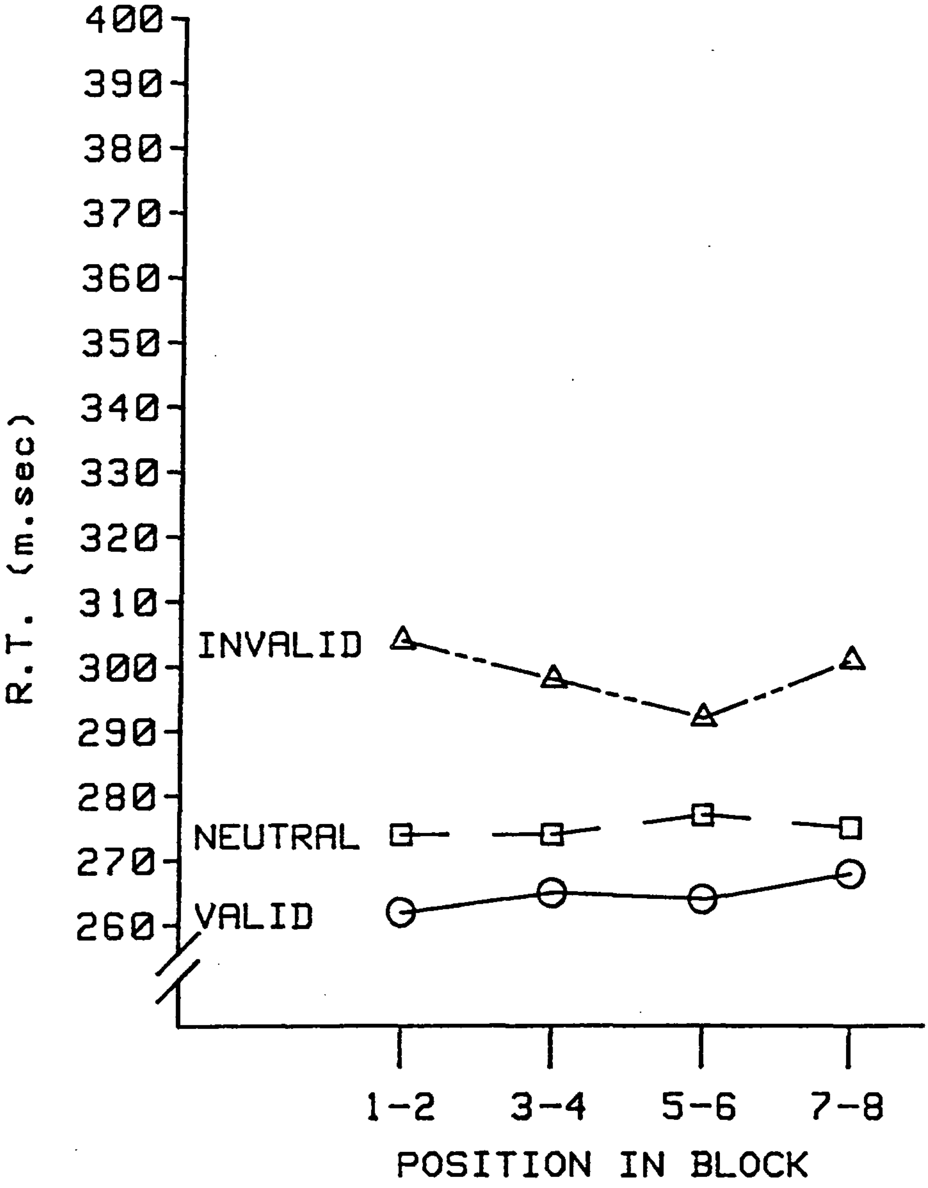


Figure 5.25 : Results from Experiment 8 - Reaction times collapsed across both noise levels

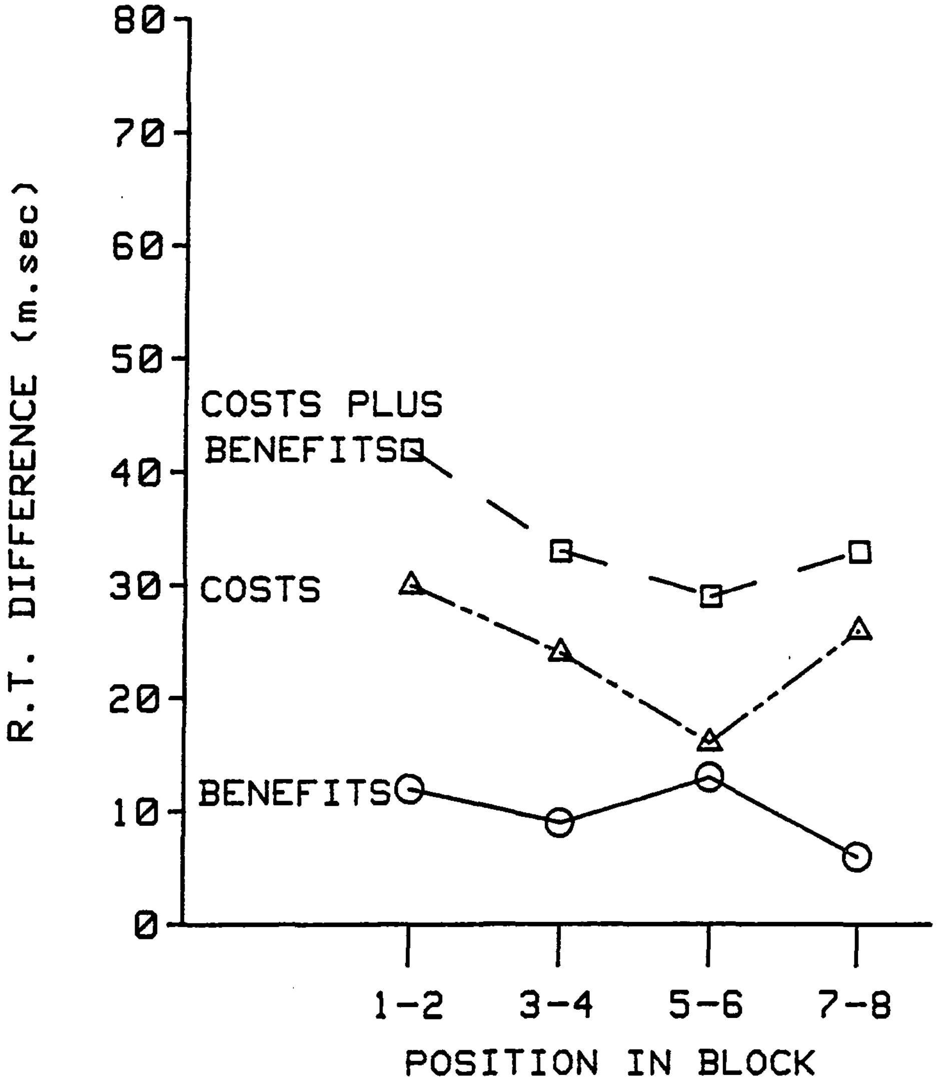


Figure 5.26 : Results from Experiment 8 - Costs, benefits and costs-plus-benefits collapsed across both noise levels

reaction times for valid, neutral and invalid trials all remain virtually flat as a function of position in a block. The reaction time data were examined in a three-way ANOVA (noise level x trial type x position in a block) and there was a clear main effect of trial type [F (2,22) = 31.72, p < .001] but no effect of position [F (3,33) = .45] nor any interaction between the two [F (6,66) = .77].

Another three-way ANOVA was performed on the cost/benefit data (noise level x cost/benefit x position). This showed that costs and benefits do not fall as position in a block of trials increases from 1 to 8 [F (3,33) = .51]. Costs are again significantly higher than benefits [F (1,11) = 9.93, p < .01]. In fact these results are exactly what would be predicted from a task situation where subjects are no longer forced to maintain selectivity over a sustained period but are instead constantly given a cue to re-orient their attention to a given location, just as they were in Experiments 1-3.

Berlucchi, Antonini, Chilozzi, Marzi and Tassinari (1986) report the results of an experiment where significant costs and benefits occurred in the absence of spatial cueing, but where subjects received an auditory warning signal prior to target onset. Targets could occur at one of five possible spatial locations, and subjects were given two types of blocks of trials. In one they were instructed to attend selectively to one specified position throughout a block of trials, and in the other they divided attention equally between each of the five locations. Significant costs and benefits accrued, suggesting the importance of an alerting signal in producing optimal controlled orienting of attention. This study makes a similar point, but it would be interesting to explore whether or not a neutral (alerting) cue would have a similar effect on performance to the specific locational stimuli used in this context, because in themselves they actually contain no new locational information. This point is returned to in Chapter 6.

Effects of Noise

There is no effect of noise on the execution of this task. In particular, as shown by Figure 5.27, noise does not result in an increase in reaction time to invalid trials in a similar manner to Experiments 5 and 7. Nor is there the corresponding increase in the measure of costs-plus-benefits (see Figure 5.29). The two analyses of variance confirmed these findings. There was no significant main effect of noise on reaction times: [F (1,11) = 1.18, p > .1], and neither were the interactions involving noise significant. The same was true for the effects of noise on costs and benefits, which were also non-significant: [F (1,11) < 1], as were both interactions involving the stressor.

These data bolster the conclusion that it is the presence or absence of the central warning signal in these tasks which will determine whether noise will affect performance or not.

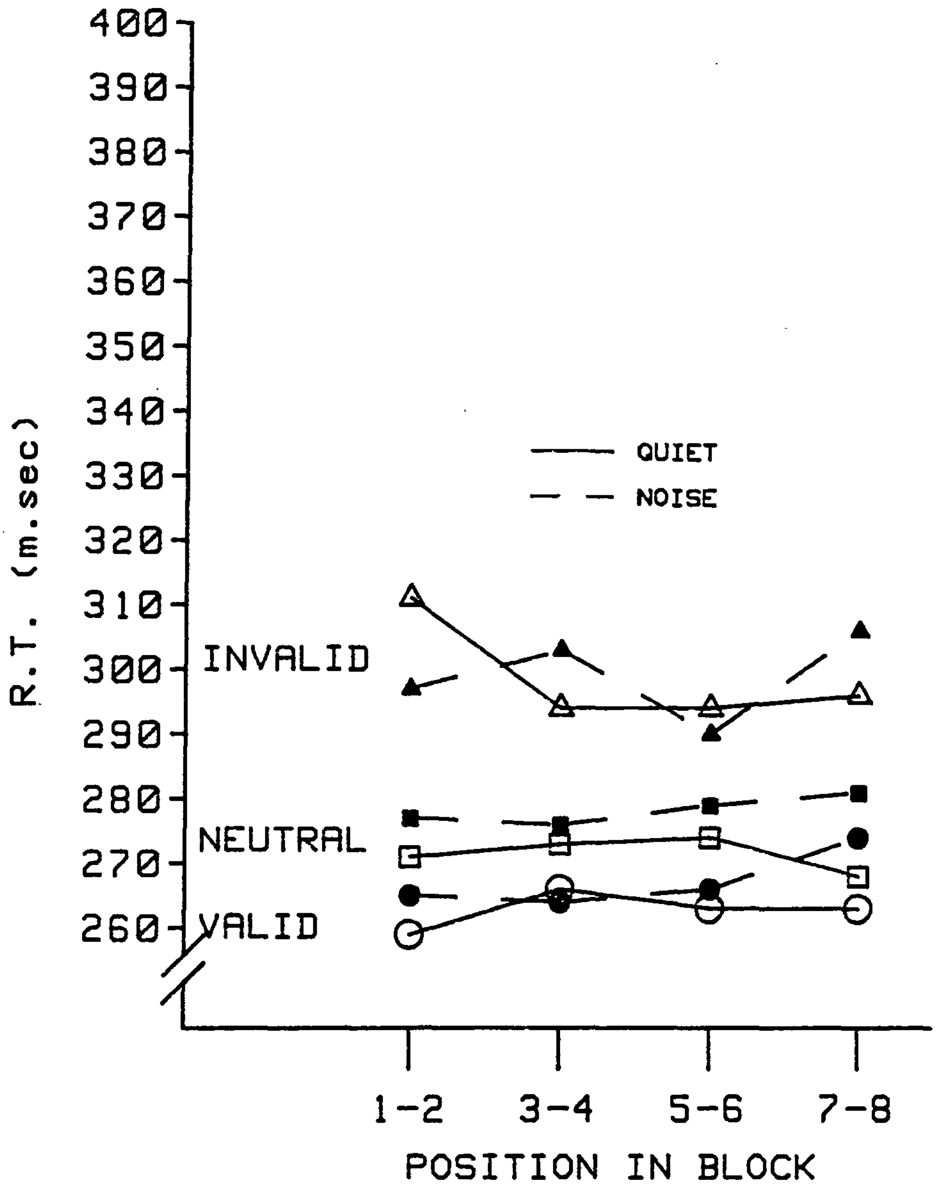


Figure 5.27 : Results from Experiment 8 - Effects of noise on reaction times

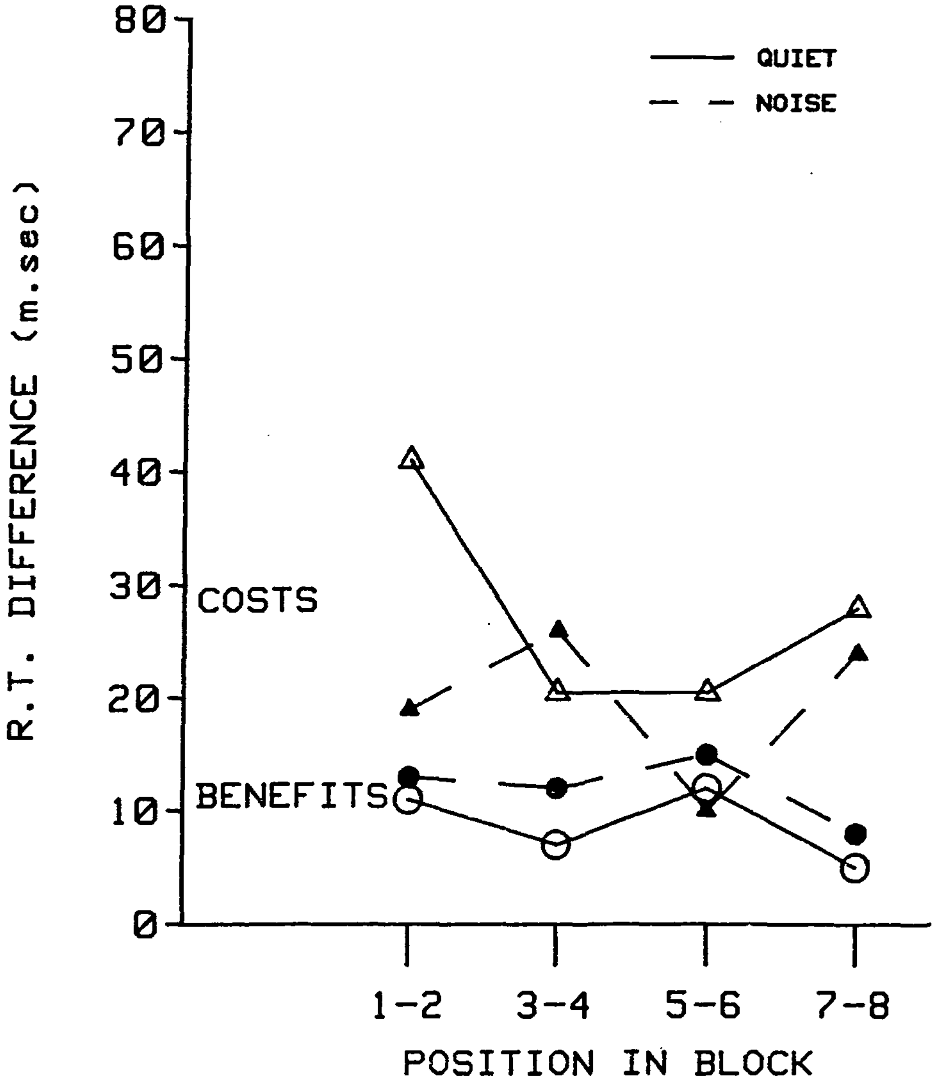


Figure 5.28 : Results from Experiment 8 - Effects of noise on costs and benefits

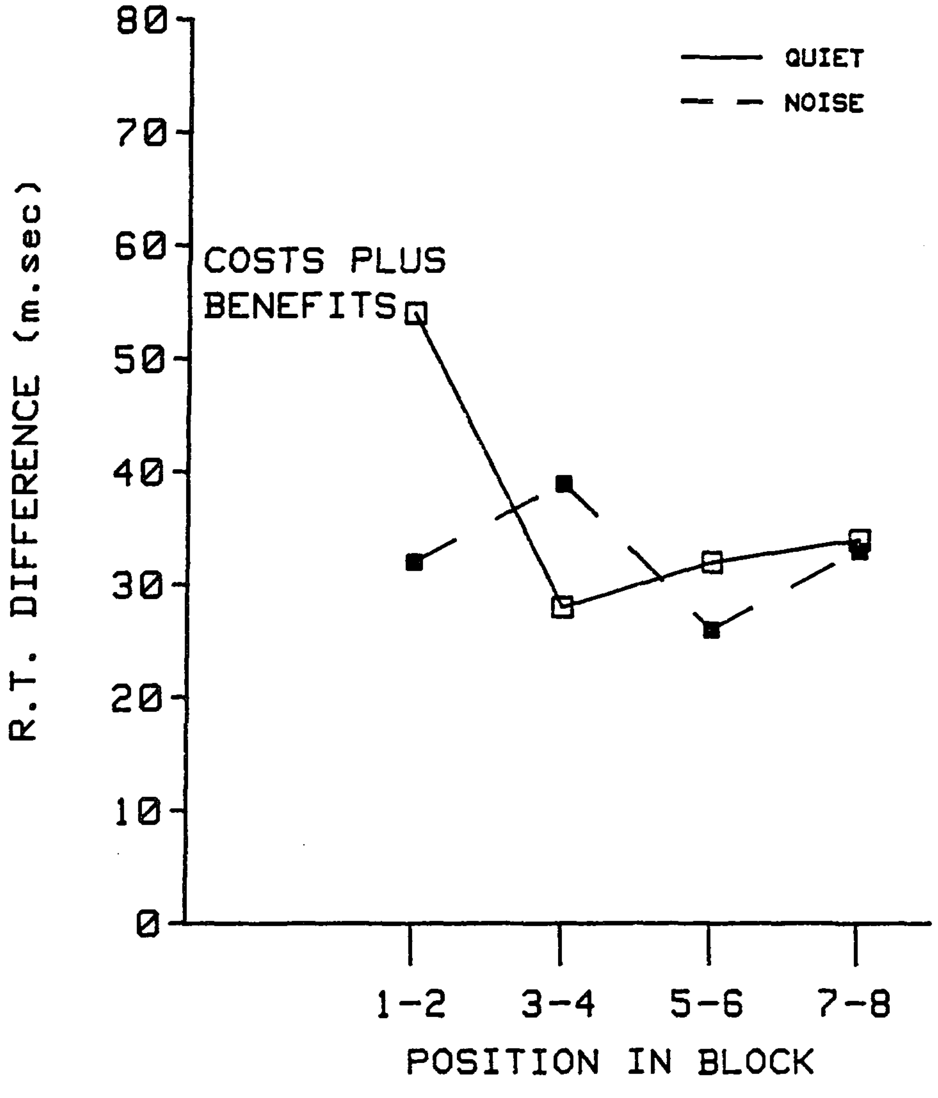


Figure 5.29 : Results from Experiment 8 - Effects of noise on costs-plus-benefits

There is certainly no reason why inhibitory effects cannot operate here whether or not there is further perceptual activity at another location. That would include the presentation of the central cue. As Maylor (1985) points out, two separate locations can be stimulated, and each will exhibit inhibition, and the inclusion of the central cue in this study does not therefore rule out the likelihood that inhibitory effects will be in operation. Adding together the maximum possible SOA and intertrial interval (500 + 1500 = 2000 msec), the temporal parameters of this task are such that inhibitory effects may be fading. An analysis of "same" and "different" trials similar to that conducted for Experiments 4-7 is presented in Figure 5.30.

These data were examined in a three-way ANOVA (noise x same/different x trial type). This revealed the inhibitory effect to be present as there was a significant main effect of location: [F (1,11) = 8.48, p < .05]. As reported in Experiments 4, 5 and 7, the effect appears to be greater for neutral trials, even though the interaction between location and trial type missed significance: [F (1,11), = 1.87, p < .1]. These data again form a strong argument against Posner et al's (1984) position on the reason for the loss of orienting over time. In this setting orienting does not diminish and yet the inhibitory effects which are supposed to result in this phenomenon are still present.

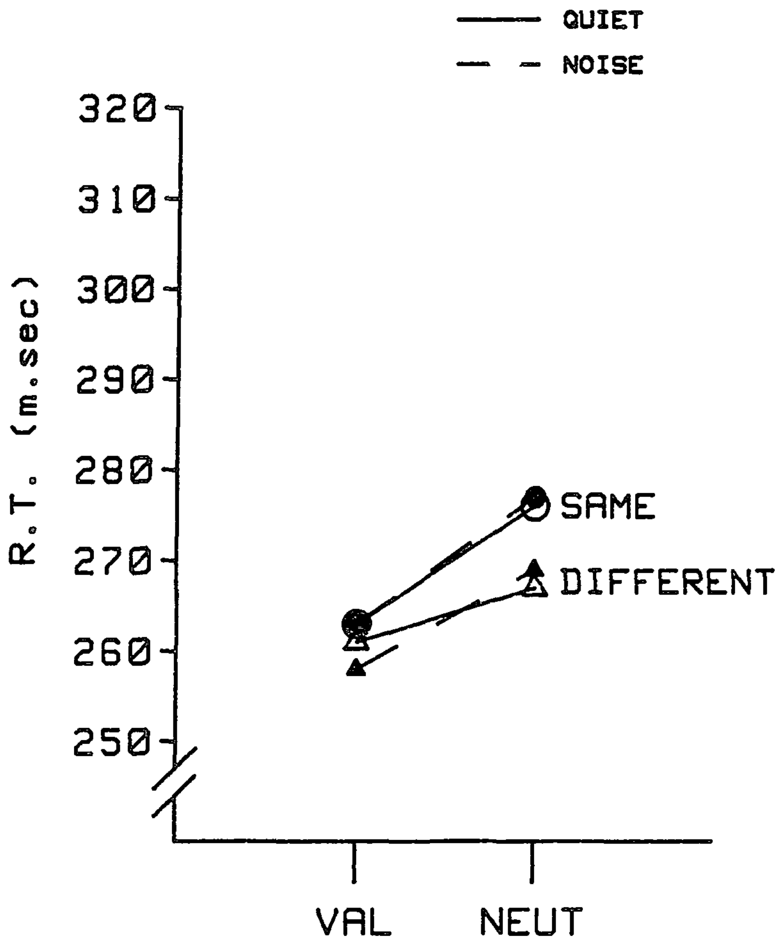


Figure 5.30 : Inhibitory effects in Experiment 8

5.7 General Conclusions From Experiments 4-8

5.7.1 Attentional Issues

Firstly the data from all the studies represent a clear replication of some of the attentional effects found in similar experimental situations by other authors, namely Posner et al (1980), Posner et al (1984), Maylor (1983, 1985) and Maylor and Hockey (1985). These effects are particularly those of the loss of spatial selectivity with presentation of targets without additional locational cueing, and a negative sequential dependency (inhibitory) effect arising from repeated stimulation at the same location.

The data also provide evidence against Posner et al's (1984) explanation of the loss of selectivity in terms of this inhibitory effect for the following reasons:

1) Experiment 6 showed a loss of selectivity in a situation where the inhibitory effect was not operating.

2) Experiment 8 showed a maintenance of selectivity in a situation where there was inhibition.

3) The inhibitory effect is consistently greater for responses to neutral rather than valid trials, an effect which does not fit with any explanation of loss of selectivity mainly affecting valid responses.

4) Costs also diminish with time. Further to point 3) above, this also indicates that loss of orienting cannot be attributed to any process thought to operate mainly upon responses to valid targets.

5) Noise gives an ability to overcome loss of orienting over time, but influences the negative sequential dependency effect in a manner opposite to that which would be predicted by Posner et al's (1984) contention. In particular it results in increased inhibition and orienting, where Posner et al (1984) would predict there to be a reduction in the amount of inhibition if orienting is maintained.

6) The specific prediction that there would be greater inhibition at later trials in a sequence (according to Posner's explanation) was tested and shown to be incorrect. The majority of the data indicated that the effect went in the opposite direction.

In all the conclusion favoured is similar to that put forward by Maylor (1983) who argues along with Sanders and Reitsma (1982) that orienting is simply something that is hard to do. Since it is a demanding cognitive process its effects will naturally decline in the absence of repeated cueing to a given location.

5.7.2 Effects of Noise

The experiments which demonstrate how noise can affect performance in this setting are important because of their implications for the selectivity hypothesis. There were indications from Experiment 5 that noise was enhancing the degree of attentional deployment in a differential way to invalid and valid responses. This effect was small but was taken as support for the view discussed in Chapter 2 that noise can induce a state of responding where sources of dominance or high priority will be attended to in a more selective manner. The suggestion of greater inhibition in noise (neutral trials) added weight to this position. However, the removal of the effects of noise on performance by a small change in task structure (Experiment 6) cast serious doubt upon the generalizability of the findings from Experiment 5. In addition to this fact, Experiment 7, which included the variables hypothesized to be of most importance in Experiment 5, provided only partial support for the selectivity hypothesis. It is true that there is no mechanistic or automatic narrowing of attention in this setting - Experiment 8 shows this too because of the removal of the effects of noise by the re-introduction of the alerting cue. Only a composite model for the effects of noise on performance is adequate to explain the data. In other words, the position outlined in Section 2.3 concerning the need for flexible and complex theories for explaining noise effects has been confirmed by the data. For this we need to appeal to models which allow for the cognitive patterning of performance we see in a complex situation. Models such as those outlined by Hockey and Hamilton (1983) or Fisher (1984b, 1986) seem most appropriate for this.

CHAPTER 6

MEMORY LOAD

SUMMARY

Three experiments are reported where task complexity is increased by the presentation of target information prior to a whole series of forthcoming trials. Subsequent orienting is achieved on the basis of items stored in short-term memory. The first two experiments differed from the third in the important dimension that target onset was preceded by a warning signal in the former case. The inclusion of this aspect of task structure continued to preclude the action of noise on performance, despite variations in memory load.

Noise affected attentional selectivity only when target onset was not preceded by an alerting signal. These results are discussed in the light of the way in which information processing is affected by noise only under certain task conditions.

6.1 Introduction

In reviewing the effects of noise on tasks containing a memory component it was seen that a loose analogy could be drawn between the effect of noise on stimulus selection from the external environment and the effect of noise on retrieval of items from memory.

In addition to this one of the more general points made in Chapter 2 was that when subjects were placed in situations which "strained" their information-processing capacity, noise was more likely to exert an influence on performance. This would probably be to bias behaviour towards the dominant or high priority aspects of any given task. With particular reference to changes in processing capacity on memory-load tasks in noise, Hockey (1984) argues that such changes in performance occur as a result of the commonality of processing resources which are required to cope with highly demanding tasks and noise stress. In simple terms, if noise is seen as producing a compensatory behavioural response of the type proposed by Teichner (1968), then when one places the human responder in a situation which loads his system heavily, then noise is more likely to push him beyond the point where all aspects of performance can be maintained to the same (optimal) extent. Therefore an alteration in the pattern of responding will emerge. The aim of the experiments reported in this chapter is primarily to create such a demanding situation as the above, whilst maintaining the experimental paradigm of orienting of attention, and therefore to investigate any resultant change in performance as a consequence of responding in noise.

In addition it is of interest in itself whether the introduction of a memory load will affect any particular facet of orienting behaviour. Jonides (1981) reported an interesting experiment which investigated this question. He required subjects to perform two types of orienting task (one involving central and the other peripheral cueing), whilst at the same time remembering a digit string which varied in length between three and seven items. His data demonstrated how the attention-capturing power of the peripheral cue was relatively unaffected by the increase in processing capacity demands resulting from memory load, whereas costs-plus-benefits from central cueing fell sharply as the length of the digit series was increased. From this he argued that automatic processes in attention were using less memory capacity than conscious ones.

Similar results to these are reported in an unpublished study by Shepherd (1982). He investigated the semantic priming effect on a lexical version of a Posner-type spatial orienting task (based upon Neely's (1977) design). The ability to use controlled processing resources was reduced when subjects were given the extra processing demand of counting backwards in threes.

There are a number of ways in which the effects of memory load upon orienting can be investigated. The design of the experiments reported in this chapter allowed the following two questions to be addressed:

1) What will be the characteristics of shifting attention on the basis of locational cues retrieved from memory as opposed to the sensory modality?

2) What effect will noise have on an orienting task performed under a situation of additional processing demands induced by memory load?

To investigate these issues an experimental design was adopted which might be described as a halfway-house between the two types of experimental design used in Chapters 4 and 5. Information was presented in a "passive" manner, similar to the technique adopted in Experiments 4-7, but instead of presenting a single cue, a number of cues were given to subjects prior to the onset of a small block of trials. The first one contained information relevant to the likely location of the first target, the second information relevant to the likely location of the second target and so on. Thus the design required subjects to remember a sequence of cues if they wished to benefit from the knowledge of positional information. To benefit from them maximally they also had to retrieve them from memory prior to each trial and maintain an accurate record of their position in a sequence of trials. Thus the task contained a passive presentation of information and required its subsequent active application.

This experimental design thus allowed for a variety of important issues to be addressed. Firstly there was the general question of the effect of processing load on orienting, which as has already been shown to be a matter of interest (Jonides 1981). Also, because of the manner of trial presentation, subjects would be required to constantly rehearse the sequence they had just learned - in other words make a great deal of use of the articulatory loop. As was discussed in Chapter 2, one effect of noise on memory performance is to enhance reliance on this aspect of the system. Mohindra and Wilding (1983) showed that noise both encourages articulatory rehearsal and slows it down, although this latter effect was mainly associated with items of long spoken length. Therefore one might well expect to see these effects demonstrated in an enhancement of some aspect of memory performance, presuming that any slowing of articulation will not happen in this situation.

On the other hand, the review in Chapter 2 pointed out that as in other areas the picture of performance effects on memory is by no means clear cut. For example, situations which require more central processing in noise may well be impaired, and those which do not, improved. It is not impossible to see both effects operating side by side within one task! (Hamilton, Hockey and Rejman 1977). It is hypothesized for the experiments reported in this chapter that the experimental setting used here will facilitate articulatory rehearsal (see Appendix 1 for instructions to subjects concerning this point).

In addition to these issues, because of the fact that subjects had to keep an accurate record of where they were in a particular sequence of trials, the task design allowed for the measurement of performance as the memory load unwound. The exact length of the sequence was a particular consideration in task design, with the degree of memory load obviously being heavily dependent on this factor, but it also varied as a function of the amount of information contained in each particular item and each whole sequence of items. For example, a run of arrows all pointing in the same direction would be far easier to memorize, recall and apply effectively than would a sequence of arrows in varied directions and so on. There are likely to be two factors at work here, both the effect of noise on short-term memory and the tendency for dominant aspects of a task to be given higher priority. This task design allowed for the study of a complex relationship between the amount of locational information provided by a cue (i.e. 80% or 50%) and its position in a sequence.

6.2 Experiment 9

6.2.1 Introduction

As this experiment was the first in this particular series and was therefore to some extent exploratory in its nature, it included a wide number of different variables. One such variable was that of the SOA between cue and target as used in Experiments 1-3. These studies showed that active orienting occurred optimally at one SOA in particular (i.e. between 250 and 500 msec) and that at other SOAs (i.e. 100 or 1000 msec) such orienting had either not had time to develop or was past its peak. It was hypothesized that if memory load were to affect orienting then because of its active nature, SOAs of the range 250-500 msec might be affected more heavily, and the same applied to the potential effect of noise on the task.

On the basis of pilot studies experimenting with 3, 5, and 8-trial sequences, a 5-trial presentation was decided upon for the first experiment in this series, on the basis that subjects showed a reasonable ability to perform on the task with this degree of memory load.

6.2.2 Method

Subjects

Sixteen subjects (10M, 6F) took part in this study, counterbalanced as described in Section 3.5. Each session took approximately 45 minutes to complete.

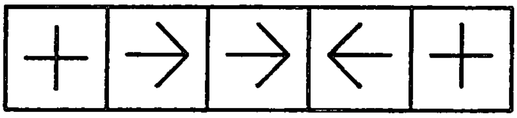
Apparatus and Stimuli

See Sections 3.4 and 3.6.

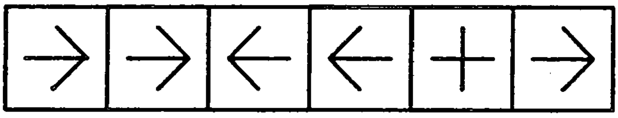
Design and Procedure

A typical sequence of trials was as follows: Subjects were presented with the series of five cues (see Figure 6.1) which remained on the screen for a period of 8 seconds. This was selected on the basis of results from pilot studies. During this time subjects were encouraged to memorize the sequence using any particular method of encoding they found useful, e.g. "left, left, right, right, neutral" or "L, L, R, R, N" and so on, and then to rehearse the sequence so learned. Subsequent to this a sequence of 5 trials would begin which would be in locations appropriate to the series just learned, with the caveat of the particular probabilities associated with each cue type. No checks were made to ensure that subjects were correctly memorizing the sequence, other than the post-hoc test of overall data inspection. This was a design weakness as checks could easily have been administered at the end of each block. Instead, it is presumed that subjects were obeying instructions because of the clear cut effects of cue type seen in the figures which follow.

A varied intertrial interval was used between the presentation of each target, and this ranged randomly between 1200 and 1500 msec. Once the five trials were completed, another series was presented to the subject. The experiment was divided into quarters, between each



Experiments 9 and 11



Experiment 10

Figure 6.1 : Presentation of cue information for Experiments 9 - 11

of which subjects were offered a rest period. Each target was preceded by a central warning signal - a plus sign presented for 80 msec - followed by one of four SOAs (100, 250, 500, or 1000 msec). These SOAs were "blocked" inasmuch as one SOA operated over a whole series of trials in each quarter of the experiment. Prior to each quarter, subjects were given a group of 6 practice trials to familiarize themselves with the particular SOA interval in operation. It was emphasized to subjects that although the plus sign was identical to the spatial cue signifying a neutral trial, it carried temporal information only.

Each sequence of trials was carefully calculated so that an even number of each particular trial type occurred at each particular position in a sequence. Subjects received 440 trials in all, 110 at each of the four SOAs. These 110 trials were proportioned across each of the 5 positions in every trial sequence, with 13 valid, 3 invalid, 4 neutral and 2 catch trials occurring at each position. The counterbalancing of these trials was complex and the appearance of each sequence was, to the subject observer, completely random. Thus the precise reliability of a valid trial was 81.25% as opposed to the 80% used previously. Such a minute difference in probability of target occurrence is unlikely to be important.

Trials on which subjects anticipated target onset were again penalized by a visual error message and removed from subsequent analysis. Subjects were encouraged to maintain central fixation throughout each block of trials, although they could move their eyes freely during the "learning" period.

6.2.3 Results and Discussion

General Effects

Error rates for this study were 1.02% (quiet) and 0.69% (noise). The data are presented in two different ways, as functions of position on a block of trials (Figure 6.2) and of SOA (Figure 6.3).

It is immediately clear from Figure 6.2 that there are effects of attention in the expected direction arising from prior cueing (i.e. valid RT < neutral RT < invalid RT). This result indicates that subjects were in fact remembering the sequences and using them as a basis for subsequent orienting. The three-way analysis of variance (noise x trial type x position in a block) performed upon these data confirmed this effect. There was a main effect of trial type [F (2,30) = 71.7, p < .001] and also a significant effect of position in a sequence [F (4,60) = 18.08, p < .001]. In addition the interaction between the two attained significance [F (8,120) = 5.42, p < .001].

Visual inspection reveals an effect in these data which is particularly intriguing. That is the increase in reaction time that is seen for all cue types at position 4 in the sequence of trials. It is difficult to suggest any explanation which can adequately account for this phenomenon. It cannot be due to the operation of a recency effect on trials at position 5 in a sequence. Such an effect would produce a relative

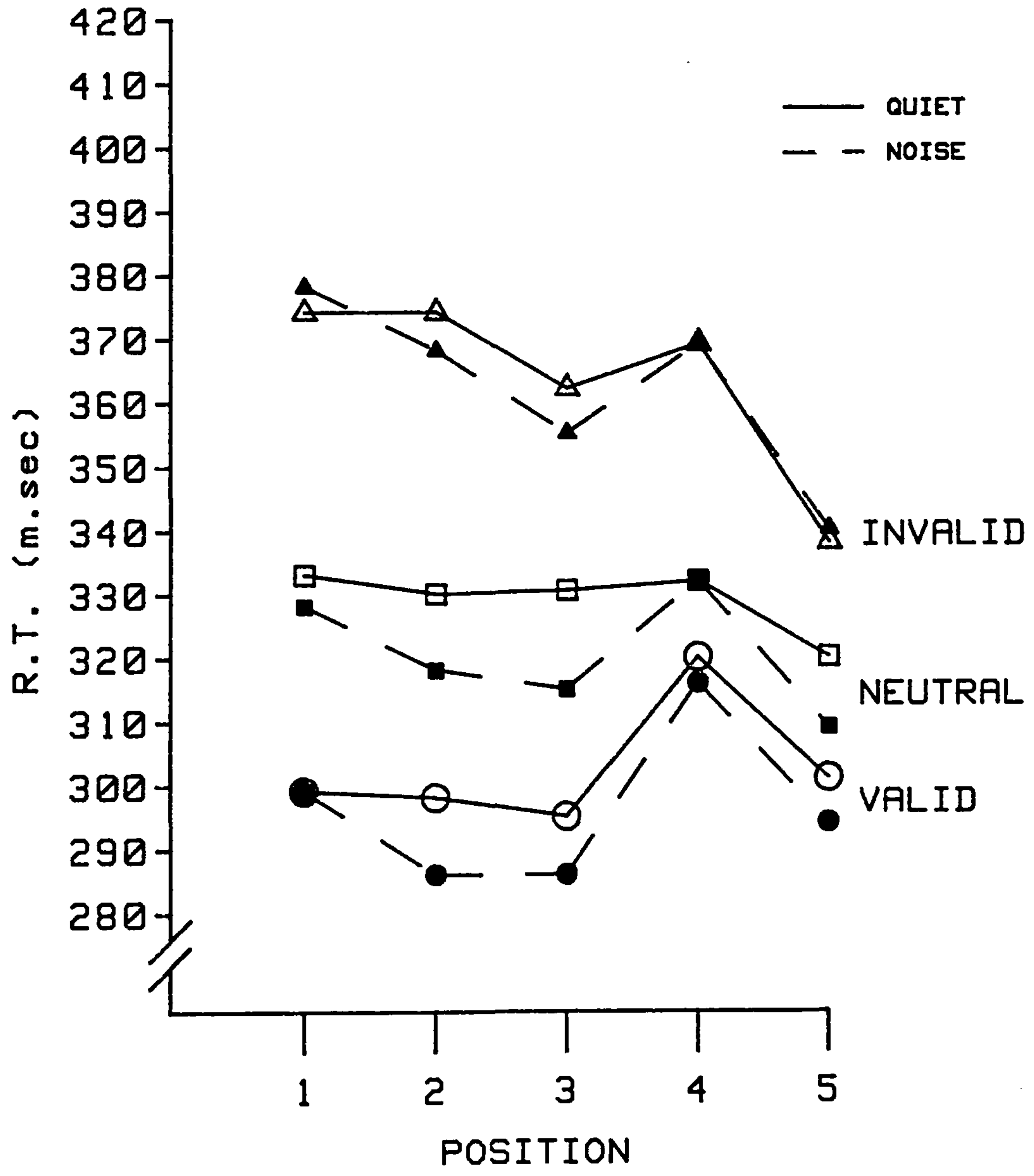


Figure 6.2 : Results from Experiment 9 - Reaction times as a function of position in a block of trials

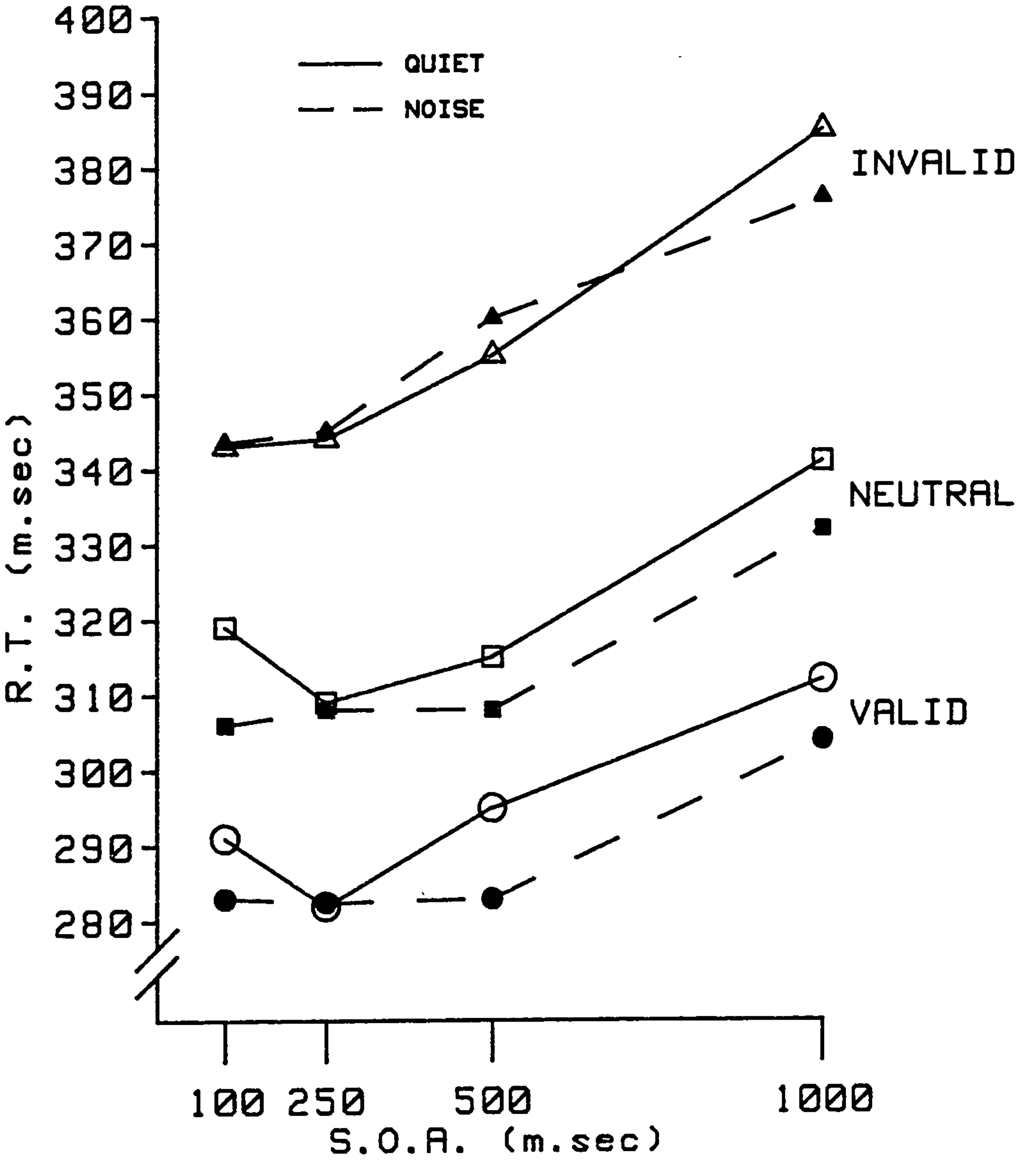


Figure 6.3 : Results from Experiment 9 - Reaction times as a function of SOA

speeding of response times for targets at that position but would also result in a sharp increase in costs-plus-benefits as cue use would be higher. This is not the case (see Figure 6.4).

In fact Figures 6.4 and 6.5 demonstrate clearly how all the measures of relative use of cue (costs, benefits and costs-plus-benefits) fall as a function of position in the sequence of trials. This was confirmed by a three way ANOVA performed upon the data in Figure 6.4 (noise x cost/benefit x position). The main effect of position was significant: [F (4,60) = 8.02, p < .001]. This is of interest because it suggests that as the sequence of trials continues subjects forget the type of trial which was relevant to that particular position. Invalid, neutral and valid responses are very close at the end of a sequence of trials and thus show the expected effects of attention in a less marked manner. Thus it seems that the memory load is affecting performance.

In addition to this general effect, there is also an effect of task structure which results in costs being significantly higher than benefits throughout a block (see Figure 6.4) [F (1,15) = 8.09, p < .05]. It is thus possible that the invalid trials are more affected by the imposition of the memory load per se. An explanation for this could be as follows: Subjects will not be expecting targets at uncued locations and thus reactions to targets occurring at such locations will be slowed relative to expected targets. In terms of neural facilitation, it is supposed that responses

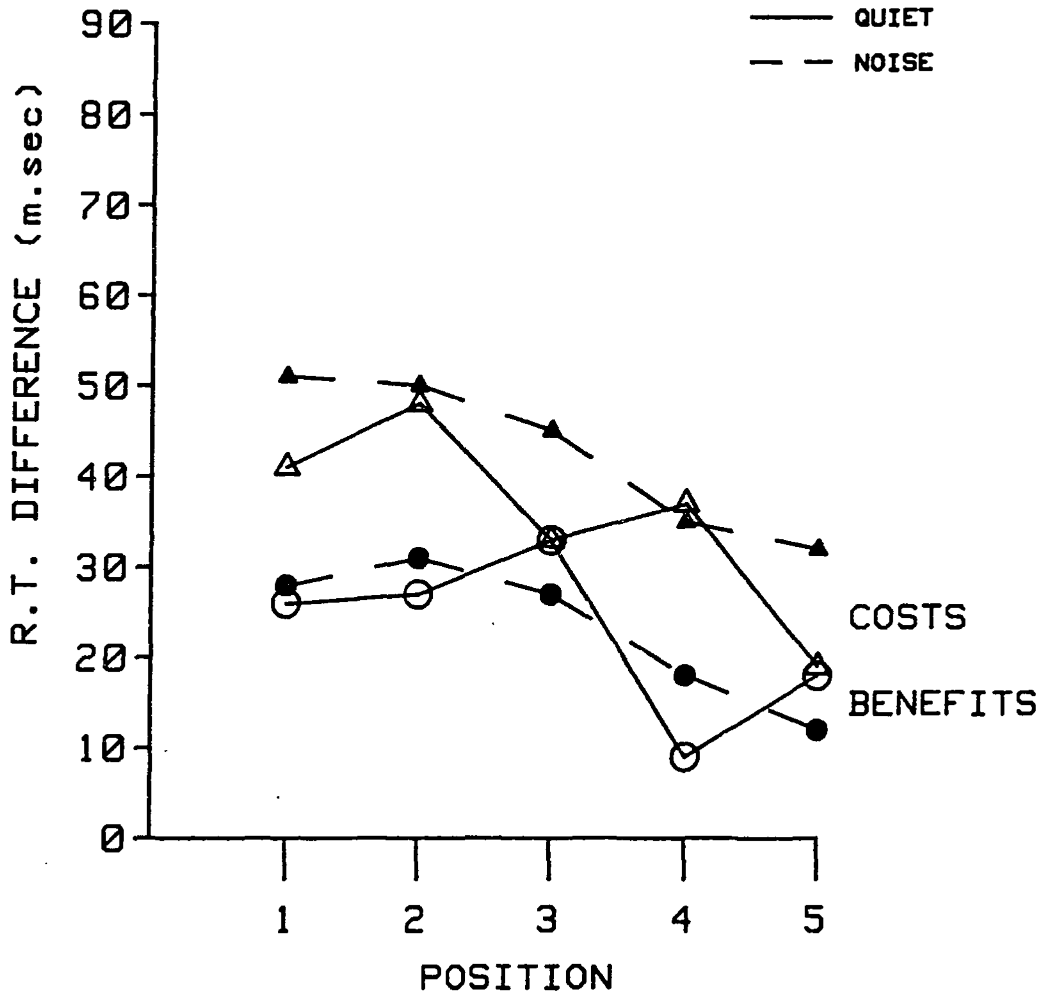


Figure 6.4 : Results from Experiment 9 - Costs and benefits as a function of position in a block of trials

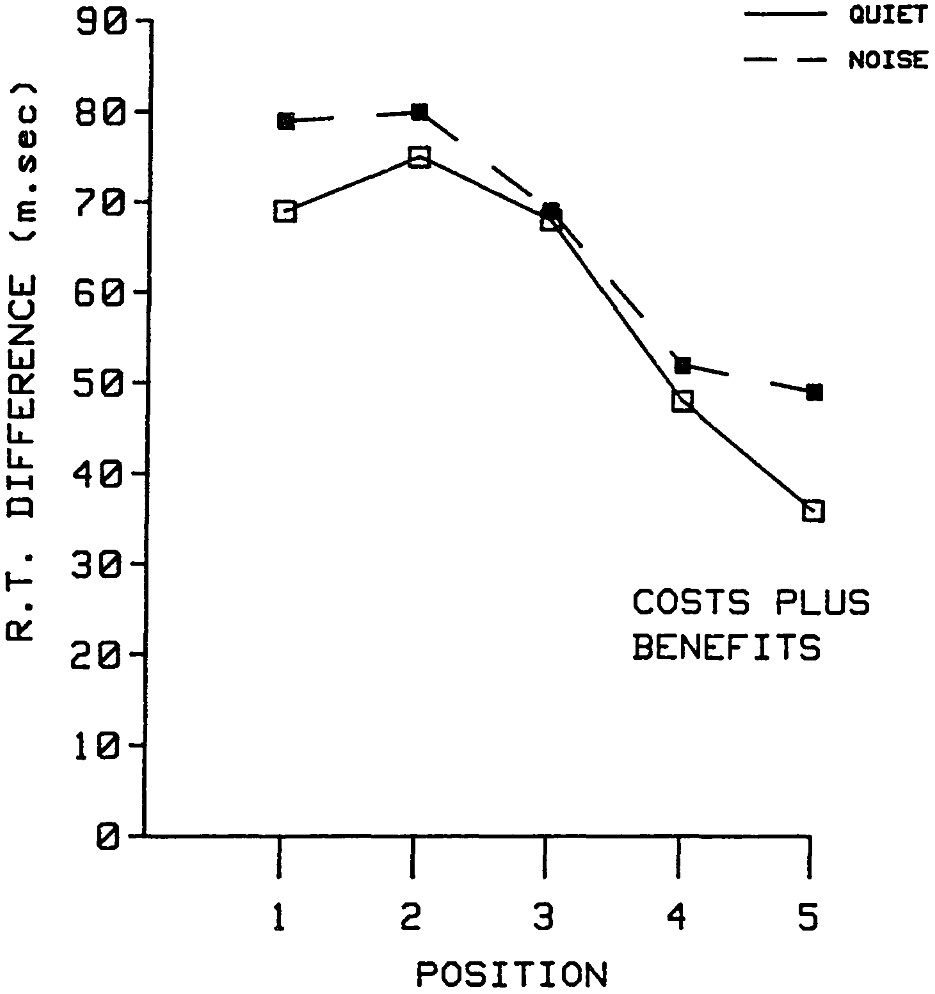


Figure 6.5 : Results from Experiment 9 - Costs-plus-benefits as a function of position in a block of trials

are slower because they require the use of unprimed pathways. The use of such pathways is therefore effortful and even more difficult when subjects are operating under memory load conditons. This would result in reaction times to unexpected tagets being especially affected at the beginning of a sequence of trials, where memory load is highest.

Another possibility is that these data are reflecting the operation of some sophisticated effects arising from subjective expectancy. At the beginning of a block of trials subjects are likely to expect that the first trial be valid and believe that an invalid trial, if it occurs at all, will come later in a sequence. Thus invalid trials which occur at early positions in a sequence result in response times far slower than those coming at later positions. A weakness in this argument is that the mixed pattern of trials occurring within each block would be likely to preclude the operation of such effects in a straightforward manner. In other words, subjective probabilities are likely to fluctuate wildly as a block of trails continues, reducing the likelihood of a neat fall in reaction time such as that plotted in Figure 6.2. However it is possible that both of the above two effects are in operation in this setting, and due to the experimental design used, it is impossible to disentangle the effects due to each.

These data are different from those reported by Jonides (1981), who found that costs-plus-benefits fell as a function of <u>increased</u> memory load. In other words in his case, when subjects' processing mechanisms were involved in the maintenance of the digit series, the attention directing power of the central cue was lessened considerably as a result of the resources taken up in digit rehearsal. In this situation however, costs and benefits fall as a function of decreased memory load, i.e. where memory load is lowest, so are costs and benefits. This leads to the conclusion that when subjects orient to a specific location in complete absence of additional processing demands (i.e. a straightforward orienting situation) they will show no costs or benefits at all! However, this argument ignores the exact nature of the experimental situation which faces subjects here. The important point is that both these data and those of Jonides (1981) demonstrate how resource-dependent the mechanisms which govern orienting are. In this task the cue itself forms the load on memory, and thus as it is first recalled and then acted upon it is being processed more deeply than would normally be the case, leading to the enhancement of costs and benefits. Jonides' (1981) study resulted in cues receiving shallower processing, because the memory component formed a separate processing load. In fact it could be argued that one problem in interpretation with the experimental situation used here is that memory load effects are always confounded with the period of time elapsed since the presentation of the locational cues.

Figure 6.3 presents the data from the experiment in terms of reaction time for each condition as a function of SOA. Once again the differences between the response to invalid, neutral and valid trials are very distinct. The three-way ANOVA performed on these data (noise level x trial type x SOA) confirmed this fact, there being a significant main effect of cue type: [F (2,30) = 71.02, p <.001]. There was also a main effect of SOA, with reaction time to all targets clearly increasing with it: [F (3,45) = 16.91, p < .001]. The interaction which commonly occurs between trial type and SOA (see for e.g. Experiment 1) only approached significance here [F (6,90) = 1.91, p < .1], which is interesting. There is an overall warning signal effect but no spatial attentional effect with SOA. However this warning signal effect does not resemble that found in previous experiments (1 and 3), but this is hardly surprising bearing in mind the differences that exist between the two designs. In fact there is an almost monotonic increase in reaction time with SOA. This is most likely to be attributable to the fact that subjects can begin orienting prior to the (uninformative) cue on the basis of the retrieval of the informative cue from memory. The same data expressed in terms of costs and benefits (Figure 6.6) demonstrate this point equally clearly, with the increase in costs (usually found as a function of SOA) seen to be relatively low, though still present. The three-way ANOVA performed on these data (noise level x cost/benefit x SOA) confirmed this fact, there being a main effect of SOA: [F (3,45) = 2.93, p <.05]. Costs

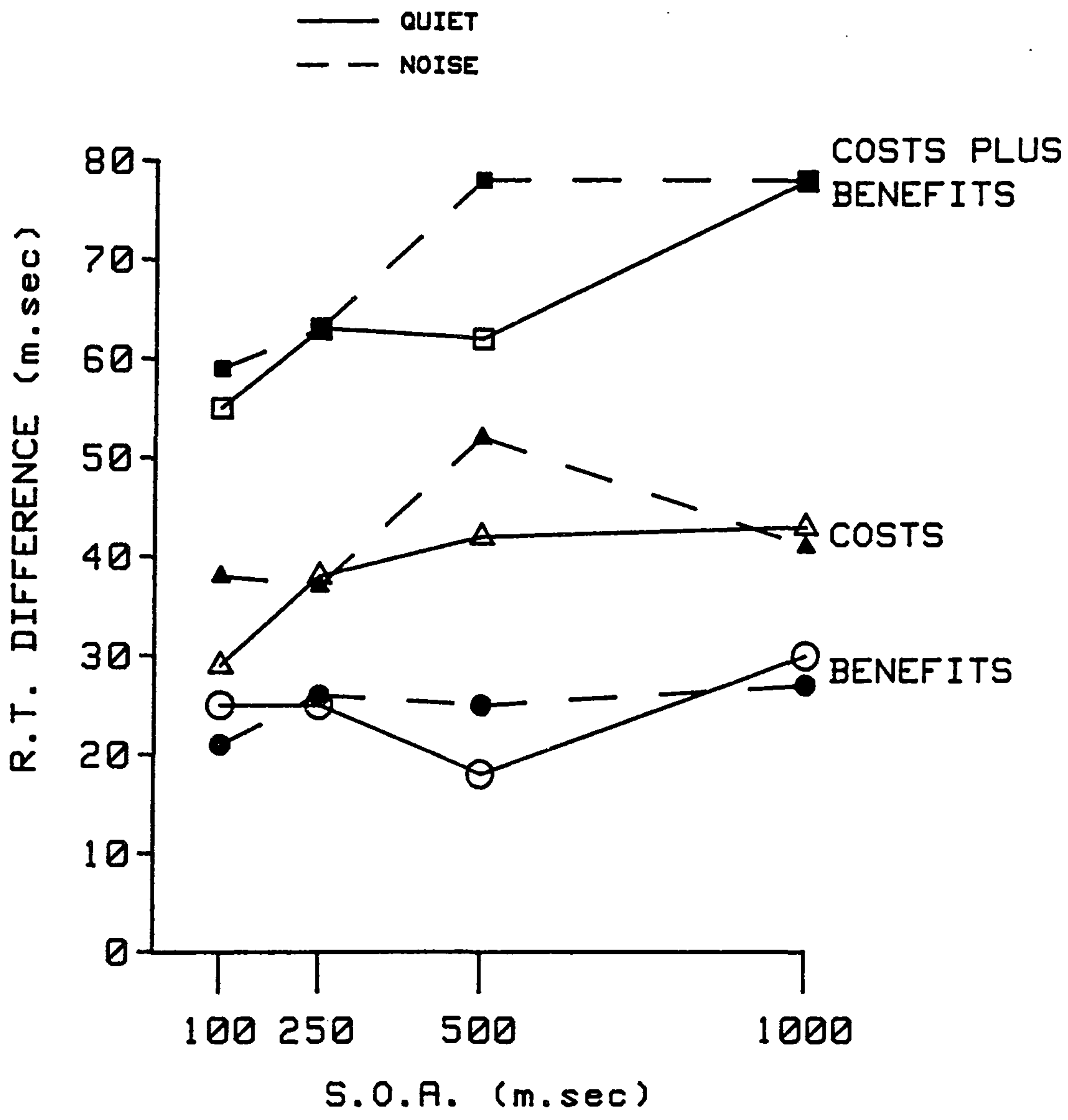


Figure 6.6 : Results from Experiment 9 - Costs, benefits and costs-plus-benefits as a function of SOA

were again significantly greater than benefits [F (1,15) = 7.16, $p < .05$].

Effects of Noise

Of the greatest interest of all though is that noise has no effect upon any dimension of the data presented from this task, either in terms of main effects or interactions with other variables. As discussed in previous chapters, the effects of noise on performance are often highly task and situation specific, and many of the elements of task structure known to preclude these effects are also present here.

The lack of any effect of noise on any particular aspect of performance could be for a variety of reasons. It could simply be that noise will not act upon cognitive processing of the kind manipulated here, and the stressor is not producing the kind of state change which will affect subjects' processing capacities in any demonstrable fashion. However, bearing in mind the discussion on the effects of noise presented in Section 2.3, which argued how noise tended to exert an influence of tasks which required effortful processing on the part of subject, this explanation does not seem likely. Another alternative is that a memory task of this nature is still a suitable experimental situation for the study of the effects of noise upon performance, but some specific aspect of task structure is preventing its demonstration.

Poulton (1979) argued that noise could affect performance by the impairment of rehearsal loops.

Although Millar's (1979b) criticism of Poulton (1979) was discussed in Section 2.2.6, it was acknowledged that such a position was still potentially tenable when interpreting the effects of noise on memory performance. In the situation described here, one would expect to see a memory decrement if Poulton's position was correct because he argues that "to show a reliable deterioration in continuous noise that can be attributed to the masking of inner speech, the task must involve both storage and processing" (p. 364). Certainly both of these essential task elements are present in this study, yet there is no noise effect.

In terms of failure due to task structure, two possibilities spring to mind on the basis of the experiments reported in earlier chapters, and in the light of other researchers work on noise and memory. This latter point is that the exact amount of memory load can be shown to affect performance quite significantly - e.g. Smith (1983b) has shown how quite varied effects of noise on a running memory task can be obtained by altering the number of items to be recalled from 5 to 8. Such a change completely altered the way in which the task was carried out. From Experiments 1-3 and 8 it was argued that the presence of the central alerting cue was pre-empting any effect of noise on policies of attention allocation, and such a cue was present in the design of Experiment 9. This is clearly another aspect of task design which may have been pre-empting the effects of noise on performance. Its inclusion in the original design was intended to help subjects summon the next relevant positional cue from memory prior to the occurrence of the next trial, in other words help them in the execution of the task. It is possible that this cue aided performance to such a degree that noise did not produce an increase in a cognitive state likely to demonstrate itself in a change in performance. (It could of course be argued that bearing in mind the strength of the conclusions drawn from the differences between the results obtained in Chapters 4 and 5, the inclusion of a warning signal in this experiment was a poor piece of experimental design. However the original order of the experiments was different from that reported in this thesis, Experiment 9 being conducted soon after Experiment 1).

The other major possible weakness in experimental design may have been simply that the memory load used in the study was not high enough, and that consequently processing demands were not sufficiently great to force any effect of noise on task execution. Experiments 10 and 11 set out to explore each of the above two possibilities.

6.3 Experiment 10

6.3.1 Introduction

The aim of this experiment was very simple: To provide an answer to the question as to whether loud noise would affect attentional orienting in the type of experimental setting used in Experiment 9 if the degree of memory load were increased, but the basic task design stayed the same. If noise did not affect Experiment 9 because of the alerting cue, then it would not affect it here either. However if the degree of processing demand was too low in Experiment 9 (see Hockey 1984) then noise would now induce a change in performance.

Pilot studies conducted prior to Experiment 9 had concluded that 5 items in a sequence were imposing sufficient demands upon subjects to make the memory load effectual, especially bearing in mind the relatively abstract nature of the task and the exact significance of each individual symbol to be remembered. However because of the failure of Experiment 9 to produce any effect of noise on performance it was decided for Experiment 10 to increase the length of each individual sequence to 6 items, whilst maintaining the presence of the central warning signal prior to target onset. This was to establish which of these two major structural variables (if either) was responsible for the results produced by Experiment 9. It was judged that the lengthening of the memory load to 6 items did not seriously violate the assumptions made on the basis of the pilot studies mentioned above as only one item was added to each sequence. It should be pointed out that Mohindra (personal communication) was in fact was consulted prior to making this change.

In addition to this change it was considered that it was possible that Experiment 9 had contained too many variables to allow enough trials per condition to provide a reliable test of any particular change in the pattern of attention distribution. So it was decided to remove the SOA variable from this study and keep the delay between cue and target fixed at 500 msec, which previous experiments had shown to be suitable in manipulating attentional orienting. This allowed an increase in the number of trials per condition without lengthening the experiment.

Another alteration in the overall design of Experiment 10 was the inclusion of a longer time period over which subjects could commit a sequence of trials to memory. This was because the pilot studies conducted prior to Experiment 9 had shown that performance on the task was very poor for any sequence over 5 items in length, and it was desired that subjects be given every opportunity to memorize the sequences.

It is acknowledged that these alterations in task design do render Experiment 10 open to the criticism that it does not form part of an exact or systematic progression from Experiment 9.

6.3.2 Method

Subjects

Fourteen subjects (8M, 6F) took part in this study. Sessions took approximately 25 minutes to complete and were counterbalanced as previously described.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

For the most part the overall design was similar to that used in Experiment 9. Subjects received a sequence of six cues which they were asked to memorize. In order to ensure that performance on this aspect of the task was maximal, subjects had as long as they wished to study each sequence rather than being given a period limited to 8 seconds as in Experiment 9. A single key press then initiated a block of trials.

In all there were 40 sequences of trials, with rest periods being offered to subjects after every five completed sequences. This gave 240 trials in all, which were again carefully balanced to present equal numbers of each particular cue type at each of the 6 positions possible. This meant 40 trials at each position, 24 valid, 6 invalid (= 80% probability) and 8 neutral. The remaining 2 trials were catch trials included to reduce the number of anticipatory responses. Despite this careful balancing, once again to the subject the

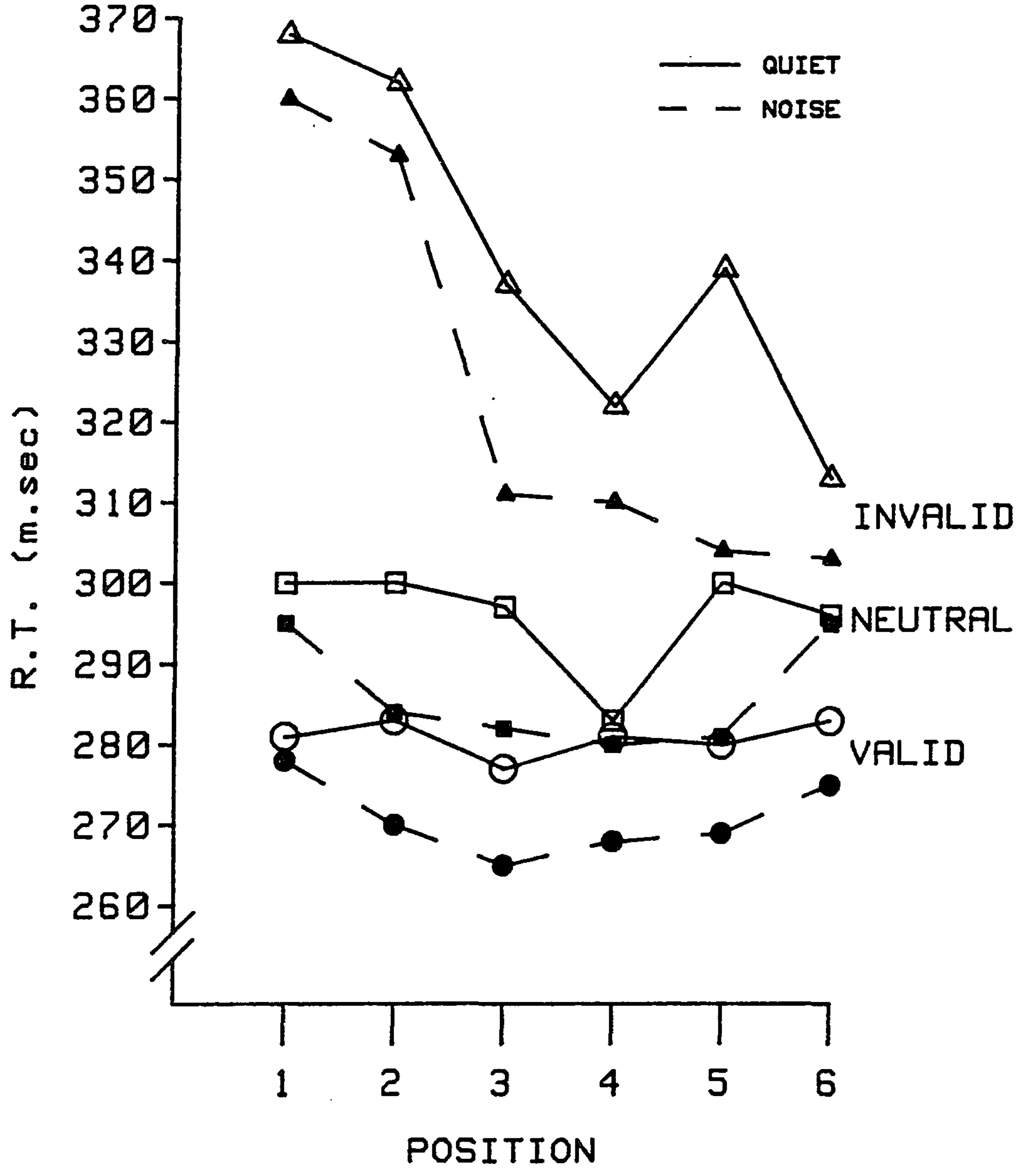


Figure 6.7 : Results from Experiment 10 - Reaction times

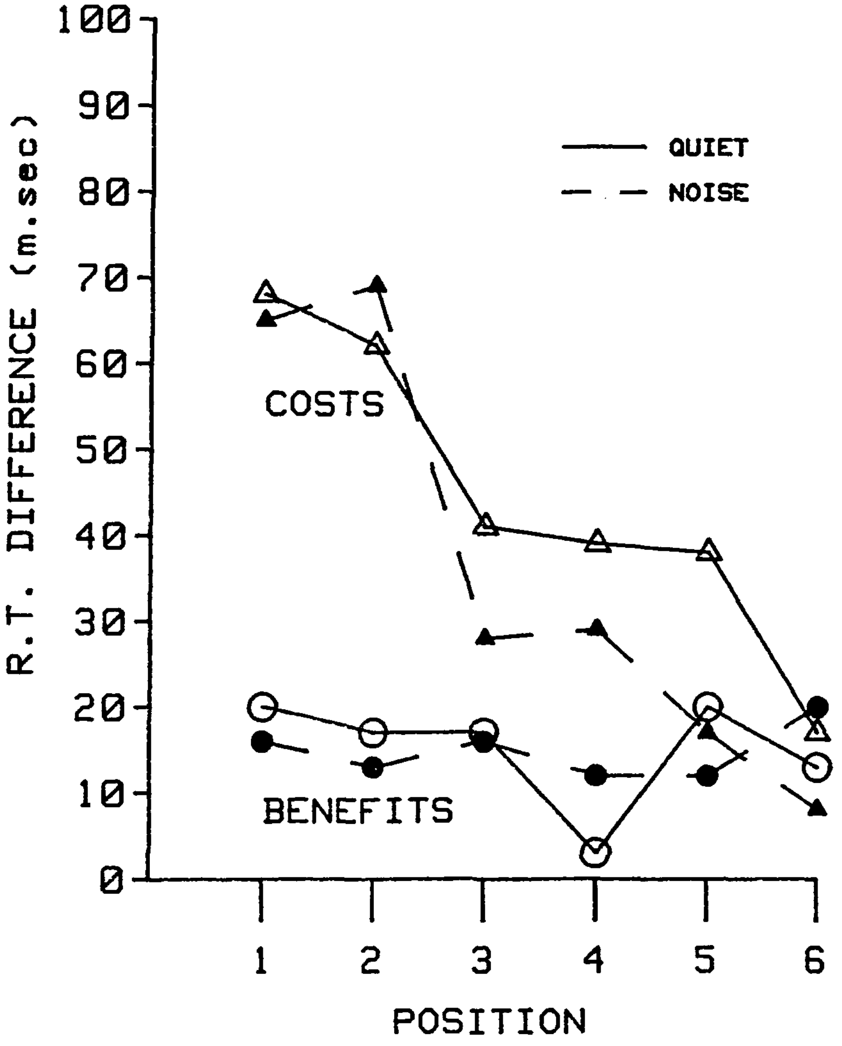


Figure 6.8 : Results from Experiment 10 - Costs and benefits

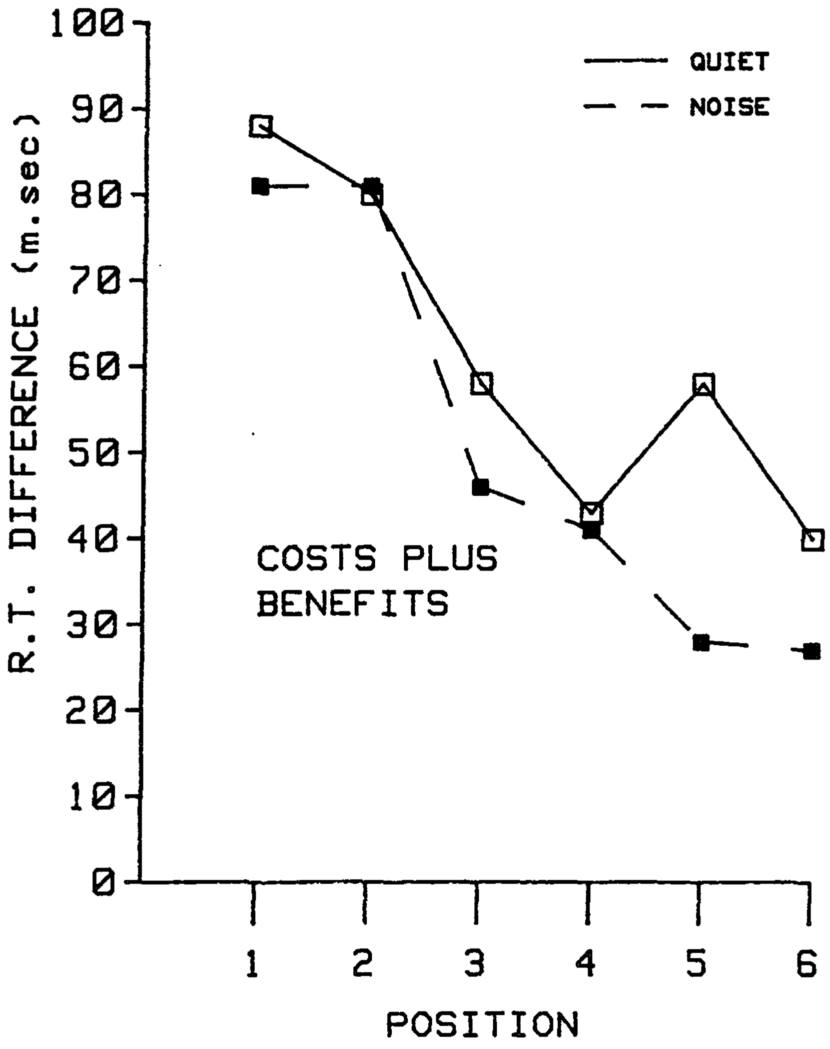


Figure 6.9 : Results from Experiment 10 - Costs-plus-benefits

appearance of the order of trials was completely random.

The SOA between the temporal warning signal and the target was limited to 500 msec for the reasons discussed above, and the intertrial interval was kept at between 1200 and 1500 msec.

6.3.3 Results and Discussion

General Effects

Error rates for this study were 1.35% (quiet) and 1.75% (noise). The overall reaction time data are presented in Figure 6.7, with the same data being expressed in terms of costs and benefits in Figures 6.8 and 6.9. It is clear that effects of controlled orienting are occurring in the expected manner (i.e. valid RT < neutral RT < invalid RT), and also that reaction times for the invalid condition fall rapidly as subjects proceed through a sequence of trials. This pattern in the data is similar to the trends observed in Figure 6.2 (Experiment 9), but is much clearer in this case. The reliability of these effects was confirmed by a 3-way ANOVA (noise x position x cue type) performed upon the data in Figure 6.7. There were significant main effects of cue type [F (2,26) = 30.91, p < .001], position [F (5,65) = 6.94, p < .001] and a significant two way interaction between the two: [F (10,30) = 4.88, p < .001].

This sharp fall in invalid response times could again be a reflection of the kind of subjective expectancy effect reported when discussing Experiment

9. In other words due to the nature of the experiment, it is possible that subjects regard invalid trials as being less likely to occur at the beginning of a block. However, as before, such effects cannot be disentangled from those which arise as a result of invalid targets bearing the brunt of the demands made upon general processing resources by memory load.

Figure 6.8 shows the consequences of these effects very clearly, with costs dropping sharply as a function of position in the sequence. It is interesting to note how low the measure of benefit is in this experiment, again a much clearer demonstration of the effect shown to a lesser degree in Experiment 9. Once again these effects are reflected in the significance of the relevant terms from the 3-way ANOVA performed upon these data (noise x cost/benefit x position). There were main effects of position [$F (5,65) = 9.04$, $p < .001$], cueing [$F (1,13) = 10.41$, $p < .01$], and a significant interaction between the two [$F (5,65) = 4.5$, $p < .001$].

However one feature of the above data remains obscure, and is of particular interest when compared to that obtained from Experiment 9. In that study there was an overall increase in reaction time across all expectancy conditions at the penultimate position in a sequence of trials. It was hypothesized that this effect was in some way due to the length of the memory load per se. Though there is a suggestion of a similar effect in operation in this experiment (see invalid and neutral trials, quiet) it is by no means as clear cut.

It must therefore be due to an aspect of experimental design absent in Experiment 10, and therefore be a specific result of the use of 5 items in the sequence. The precise reason for this is still unclear.

Effects of Noise

Visual inspection of Figure 6.7 would suggest that noise is exerting an effect on overall response speed on the task. However this effect does not reach significance [F (1,13) = 0.9, p > .1], and neither are any of the interactions involving noise significant. The main reason for the deceptive appearance of these data must lie in the large amount of variance that there is in the data - in other words although there may be a mean difference between the two groups, there is much variability. A variance ratio test comparing the amount of variance between performance in noise and quiet failed to reach significance [F (13,13) = 1.94, p > .05] showing the variability to be common to the data from performance in both noise and quiet.

There is still no effect of noise on this type of task and the stressor is exerting no additional effect on performance when subjects have 6 items to hold and recall then when they have 5. Coping with noise appears to be no more of a problem in this situation of relatively high memory load. In this case at least, whether or not there is some commonality in the physiological state resulting from noise and this kind of performance task (Hockey 1984), noise does not have an effect in a situation of this type. These data also argue against Poulton's (1979) explanation of noise effects in terms of masking, for the reasons discussed in Section 6.2.3.

It was suggested after Experiment 9 that the degree of the memory load might be one factor in preventing this effect, as might be the presence of the central warning signal prior to target onset. The data presented above suggest that the number of items to be remembered is not the crucial variable here, even though there was only a relatively small increase in memory load. This leaves the possibility that the latter facet of task structure is once again playing an important role in the overall pattern of the data, and Experiment 11 tests this hypothesis specifically.

6.4 Experiment 11

6.4.1 Introduction

Experiments 9 and 10 led to one of two possible conclusions - that loud noise would not exert any effect on performance on a task of this nature or that the particular task structure was not designed in a suitable enough manner. Experiment 10 suggested that increasing the demands made upon performance by lengthening the sequence of trials to be remembered was not a crucial factor in the experimental design. This leaves the other major alternative explanation which arose from Experiment 9, i.e. that the central warning signal presented immediately prior to target onset was the most relevant aspect of the task which was acting against the demonstration of any noise effect.

The review of the literature in Chapter 2 clearly showed how the distinction between alerted and non-alerted situations was often a critical consideration in evaluating the effects of noise on performance. In addition, the results from Chapters 4 and 5 taken together indicate that the experimental situations reported in this thesis are also highly sensitive to this aspect of task structure. Thus if it is also the case that the presence of the temporal signal in Experiments 9 and 10 is responsible for the maintenance of performance stability in tasks requiring the summoning of positional information from short-term memory, then the removal of the cue should result in a clear alteration of orienting under noise. This is of course presuming that the task is presenting subjects with sufficient information processing demands to create a situation where performance will be sensitive to overload caused by the presence of noise. If this is true, then the central cue, with its powerful effect in helping subjects to maintain their position in a sequence of trials, enabling them to prepare optimally for a forthcoming target, could easily be reducing the otherwise substantial processing load afforded by the task.

Thus Experiment 11 was designed with this question very much in mind: Would noise affect orienting under circumstances of a memory load but without the presence of a central alerting cue?

6.4.2 Method

Subjects

Sixteen subjects (9M, 7F) took part in this study, in each of two experimental sessions lasting approximately 30 minutes. These sessions were counterbalanced as described in Section 3.5.

Apparatus and Stimuli

These are described in Sections 3.4 and 3.6.

Design and Procedure

As in Experiment 9, subjects were presented with a series of five cues (similar to those shown in Figure 6.1) which remained on the screen for eight seconds. This time limit was re-introduced for two reasons. Firstly so that the experiment resembled Experiment 9 as closely as possible, and secondly in order to keep the length of each test session tightly controlled. During this interval subjects were again encouraged to memorize the sequence using any encoding strategy they chose. Then, as before, these cues would disappear and the sequence of five trials would begin in locations appropriate to the series of cues just learned. Once again a plus sign signified that a trial was equally likely to occur on either side of the fixation cross, and an arrow to the right or the left predicted target location with 80% reliability. This sequence continued for five blocks of trials after which subjects were offered a rest period which they terminated with a single key press.

In all there were 40 blocks of trials, giving 200 trials in total. Target presentation was again balanced so that an equal number of valid, neutral and invalid trials occurred at each position in the sequence with the ratios of trials occurring at each location being 24 valid / 6 invalid / 10 neutral. Each target was followed by an intertrial interval of between 1200 and 1500 msec (as in Experiments 9 and 10) but in this study the major departure in design from the above two experiments was the removal of the temporal warning signal preceding target onset. Thus essentially a target-target procedure was employed, and because of this there were obviously no catch trials.

6.4.3 Results and Discussion

General Effects

The error rates for this study were 0.05% (quiet) and 0.25% (noise). Overall data are presented in Figure 6.10. It can be clearly seen that there are effects of attention in the expected direction and that subjects are using the cue information to generate expectancies as to subsequent target location. The 3-way ANOVA (noise x trial type x position) performed upon these data showed this effect to be highly significant [F (2,30) = 13.27, $p < .001$] as was that of position in a block of trials [F (4,60) = 71.42, $p < .001$]. This latter effect presumably arises from the sharp overall fall in response times from position one in the sequence to position two. It is of interest to note how these data differ from those obtained from Experiment 9 - compare Figure 6.2 with Figure 6.10. It is possible that in the former case the central alerting cue warns subjects as to the impending onset of the first target in a sequence. This precludes the sharp fall in response times seen here because in this case, once the sequence of symbols to commit to memory has disappeared, subjects have no further cue to indicate when a block of targets will begin. Another point to note is that the increase in response times found at position four in the sequence of trials in Experiment 9 is absent here, suggesting it is either a result of something very specific to the cueing technique used, or is simply a type one error.

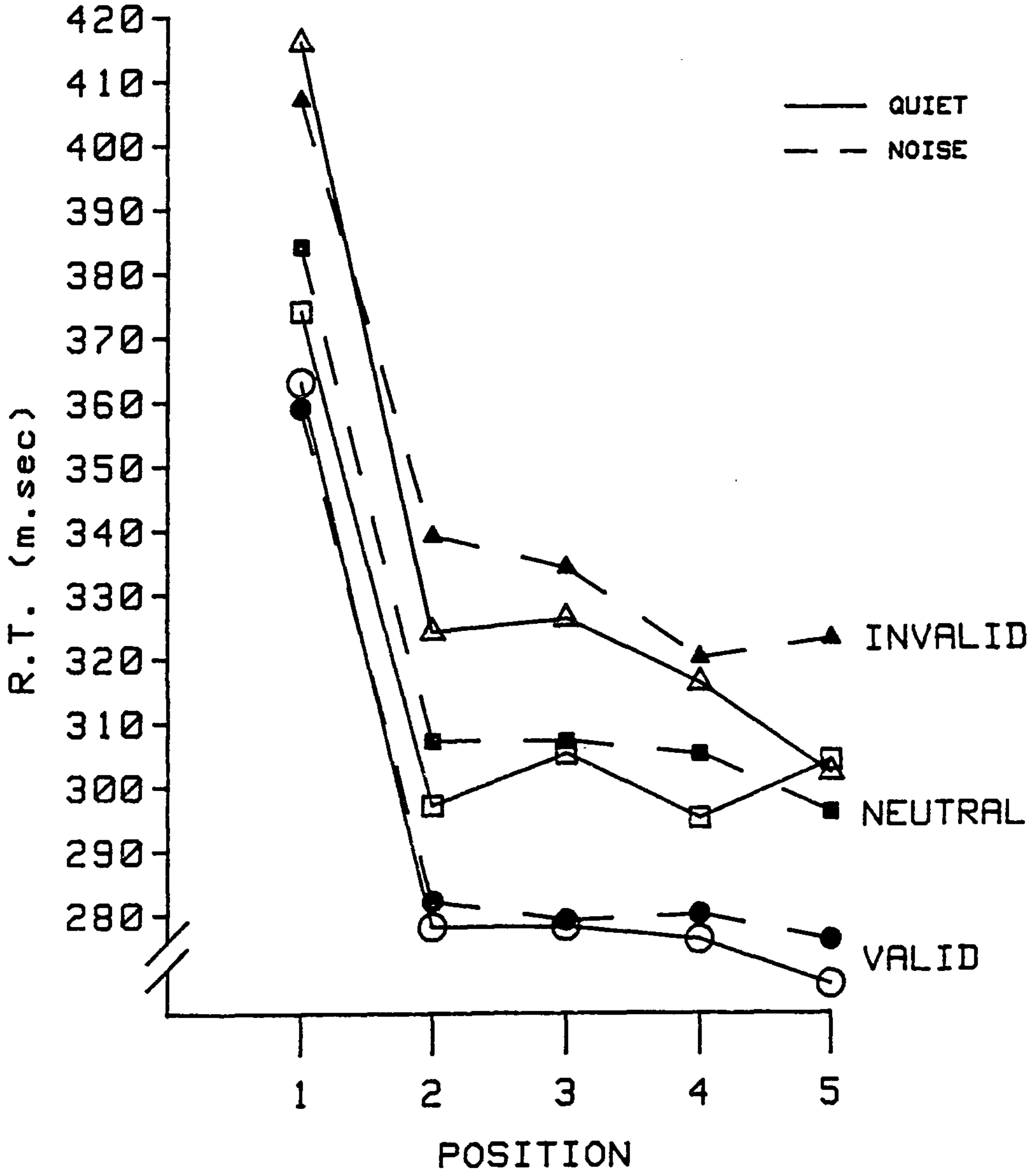


Figure 6.10 : Results from Experiment 11 - Reaction times

One additional question remains unanswered. If, as was argued above, the presence of memory load is contributing to the exaggerated fall in response times to invalid targets in Experiments 9 and 10, then why are such effects seemingly absent here? One would expect the processing demands made by a task devoid of alerting information to if anything be greater than in the earlier two experiments. However there is a straightforward explanation for the pattern of data expressed in Figure 6.10. It is most likely that any effects of the above kind are in fact masked by the already huge fall in response time (for all trial types) which occurs as a function of position in a sequence, the origin of which has already been described. In support of this it is interesting to note that responses to invalid targets are the ones which fall the most between positions 2-5 when compared with those for other target types.

Effects of Noise

Noise had no significant effect (or interaction) with raw RTs. However, the data discussed above but expressed in terms of costs and benefits are plotted separately (for the sake of clarity) in Figures 6.11, 6.12, and 6.13. It is clear from these data that noise is exerting a very specific effect on performance. Benefits remain constant across all positions in a sequence of trials in conditions of both noise and quiet, an effect very similar to that demonstrated in Experiment 10. Costs in quiet however appear to be far

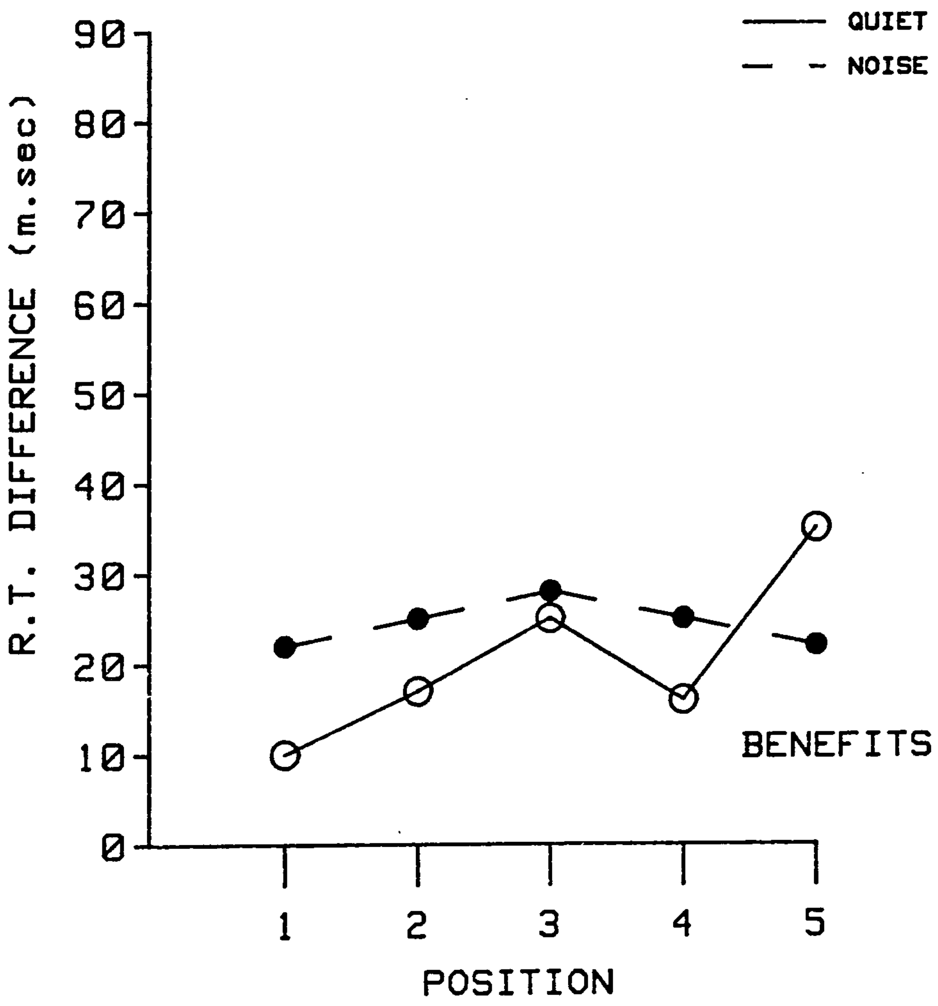


Figure 6.11 : Results from Experiment 11 - Benefits

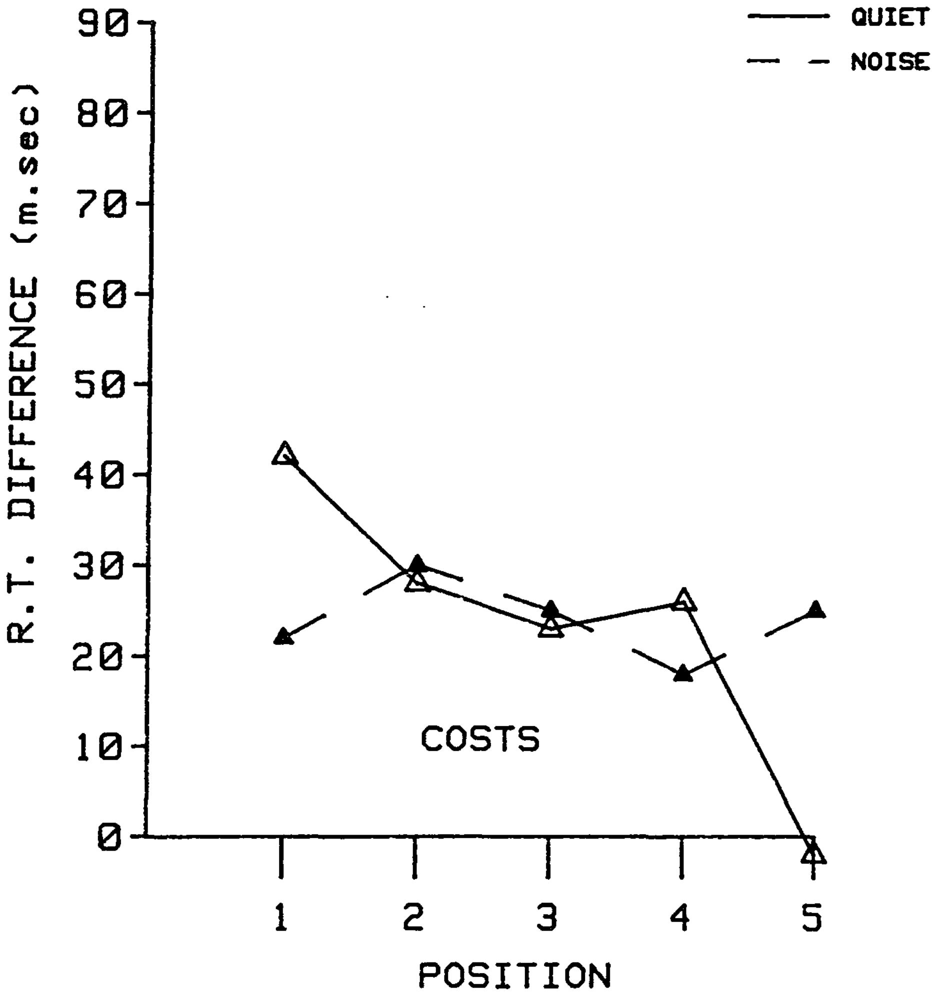


Figure 6.12 : Results from Experiment 11 - Costs

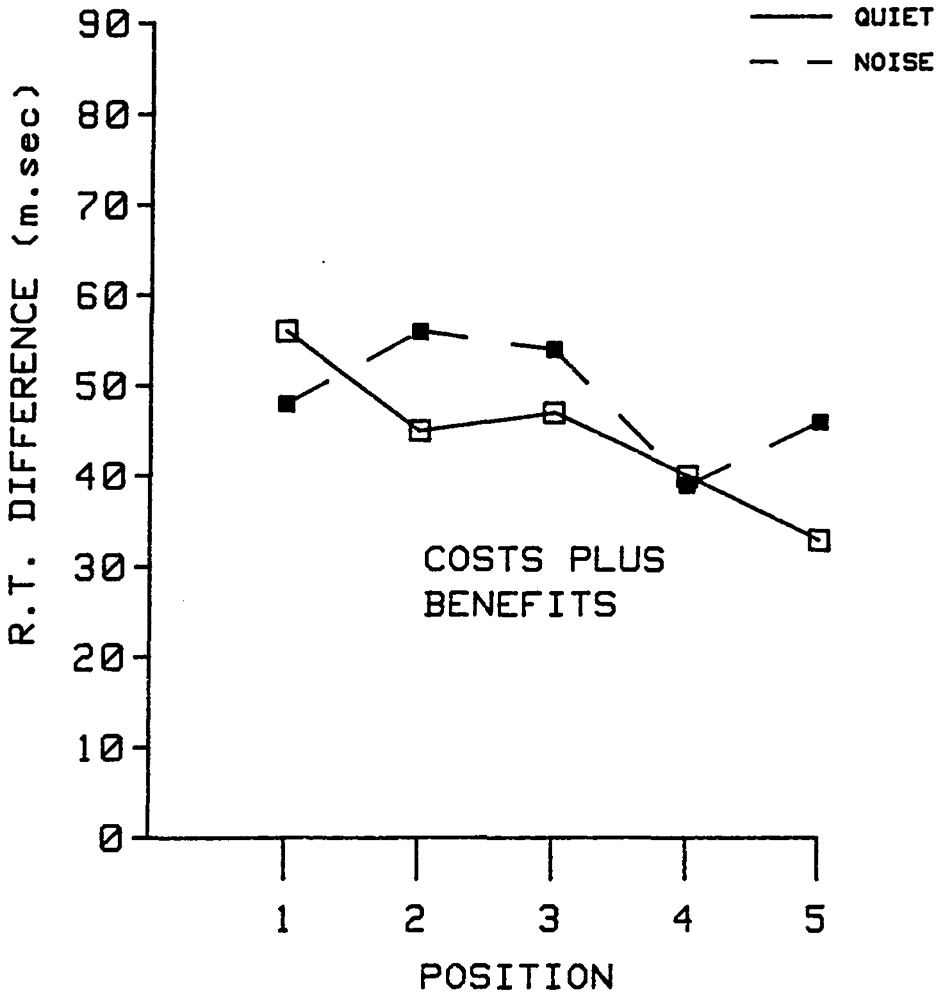


Figure 6.13 : Results from Experiment 11 - Costs-plus-benefits

more labile in this setting, whilst costs in noise remain stable across all positions. Costs fall in a similar fashion in Experiments 9 and 10, as a result of reaction times for invalid trials becoming increasingly faster with respect to neutral trials as a sequence continues. This is also the case for performance in quiet in this study, and is taken as a reflection of the previously discussed relative difficulty in responding to a target at an unexpected location at the beginning of a sequence. However, this is not the case in noise. Instead costs remain relatively flat as a function of position. A 3-way ANOVA was performed on these data (noise x position x cost/benefit) and only the three way interaction term proved to be significant [F (4,60) = 2.65, p < .05]. Visual inspection of Figure 6.10 would indicate that this interaction has its origin in the difference in RT to invalid trails at position 5 in a sequence of trials. A simple main effects comparison showed the difference between these points to be significant [F (1,120) = 6.86, p < .01].

One interpretation of this effect is that noise, in increasing reliance on the articulatory loop (see Section 2.2.4), is in fact resulting in better memory performance in this task. Thus for example a subject who can easily recall that a given trial is likely to occur on the left of fixation may commit more attention to that location. When the target does not in fact occur there, he suffers the consequences of having oriented more effectively to the source of expected input by demonstrating the increase in invalid reaction times shown in Figure 6.10. However there is clear evidence which argues against this explanation: Simply, the effect is absent from Experiments 9 and 10, which should not be the case if noise is increasing reliance upon the articulatory loop.

Another explanation would be that subjects are adopting a different type of processing strategy in noise which results in a more stable level of performance on invalid trials across the sequence. It could be that subjects are committing less processing resources to unexpected targets at the beginning of a sequence and adopt this relatively rigid form of responding irrespective of position in a sequence. This would account for the pattern of data seen in Figure 6.12. Such a rigid manner of responding could be a reflection of the same kind of effect shown by Dornic and Ferneaus (1981) where noise produced a reduced processing flexibility. Subjects were set a serial search task alternatively requiring the selection of target items with either physical or semantic similarity. Noise had the effect of increasing the time taken to switch between the two types of processing.

In the situation described here, this type of effect could be operating through a variety of means. The first could be the way in which the subjective perception of probabilities as to the occurrence of particular types of trial will build up as a sequence of five trials progresses. As discussed previously, because of the ratio of valid/invalid trials (80/20) used in an experiment of this type it is inevitable that subjects generate a subjective expectancy as to the likelihood of any given trial type occurring next in a sequence of trials. In a design of the kind used here, with five targets occurring in an individual sequence it is more likely that subjects will expect the majority of arrow cued trials to be valid, and only some to be invalid. As one progresses through a sequence of trials the subjective expectancy that an invalid trial will occur increases, and thus when one actually does occur, it is less of an unexpected event. Consequently reaction times to such targets will be faster than to invalid targets appearing earlier in a sequence. This has already been suggested as an explanation for the patterns of data seen in Figures 6.2, 6.7 and 6.10. Thus it is possible that prediction is the reason for the fall in costs seen in all the experiments reported in this chapter, and that in this particular study, noise is reducing this ability to predict, producing the flat costs function seen in Figure 6.12. However, as before, the major problem with this interpretation is that the above prediction no longer holds on blocks of trials where an invalid trial has already occurred at the beginning of a block. In fact, on such occasions, one would expect subjective probability to change dramatically for later trials in a sequence, with further invalid trials becoming highly unexpected events. As blocks of trials were carefully balanced so that each of the above two situations occurred with equal frequency (see Section 6.4.2), the specific trends observed in Figures 6.10 and 6.12 cannot be attributed to this cause.

However there is also a precise experimental as well as a theoretical method of testing this interpretation of the data. If it were true then it might be expected that such a change in levels of awareness would be manifested in other ways. If what we see in Figure 6.10 is a result of different levels of target expectancy operating in noise and quiet, then reaction times for valid trials which immediately follow invalid ones should reveal that response times for noise are slower than for quiet. This is simply because, according to the prediction, subjects are less aware of the type of trial to expect next in noise, and the (subjective) probability of a valid trial following an invalid one is high. In addition, and by the same argument, one would expect response times to the second of two invalid trials occurring in succession to be similarly affected, i.e. in noise the second trial in such a pair should be slower than in quiet.

An examination of such trials was carried out. In the original balancing so that each trial type occurred an equal number of times at each target location, it was not deemed important to ensure that valid trials followed invalid ones in any specific pattern. Thus an equal number of valid trials following invalid ones did not occur at each position. There were no such trials at position two, allowing an examination only of positions 3-5 as shown in Figure 6.14. Visual inspection of the data seems to confirm the prediction

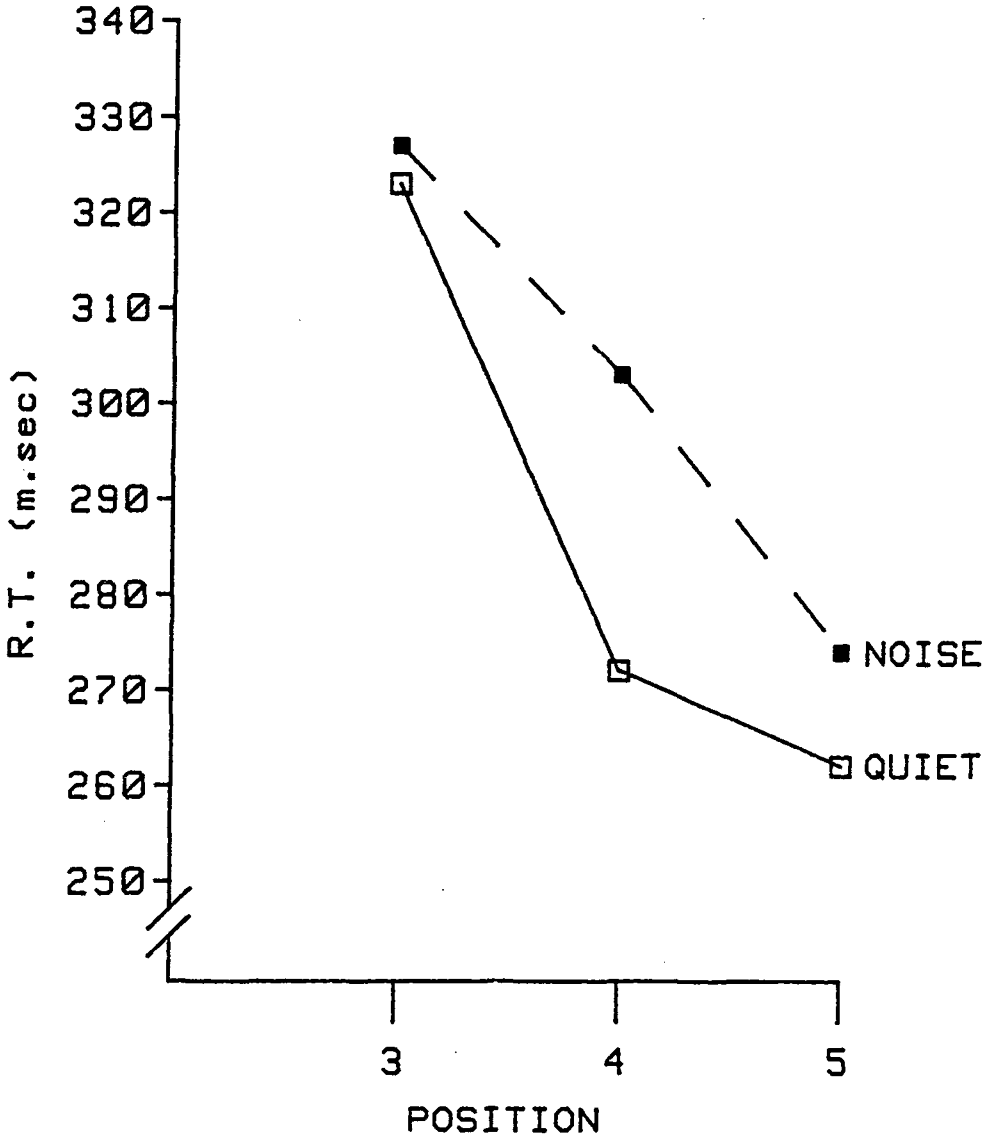


Figure 6.14 : Results from Experiment 11 - Reaction times to valid trials which immediately follow invalid trials

stated above that reaction times to these valid trials are slower in noise than in quiet, but the two way ANOVA performed on these data revealed that there was not a significant main effect of noise [F (1,15) = 2.91, p > .1]. The effect of position was however significant [F (2,30) = 13.03, p < .001]. This suggests that subjects are <u>not</u> biasing their intake of information in noise in such a way that they are losing their overall sense of the likelihood of a forthcoming trial at a particular point.

The data from invalid-invalid trial pairs confirmed this finding. They are plotted in Figure 6.15, and as can be clearly seen, the difference between the two lines are very slight. This observation was borne out by the two way ANOVA performed on these data, the critical main effect being nowhere near significance [F (1,15) < 1].

Another explanation needs to be found. The data in Chapter 5 led to the tentative conclusion that under certain circumstances, noise was increasing orienting. In other words the amount of attentional resources committed to a source of expected input was greater when the subject was in a stressed state. Such a phenomenon could to some extent also account for the pattern of data obtained from Experiment 11, and has the advantage of being a more parsimonious explanation than the alternatives discussed hitherto. Certainly when compared with Experiments 5 and 7 it can be seen that the data expressed in Figure 6.10 reveal a corresponding increase in reaction time to invalid

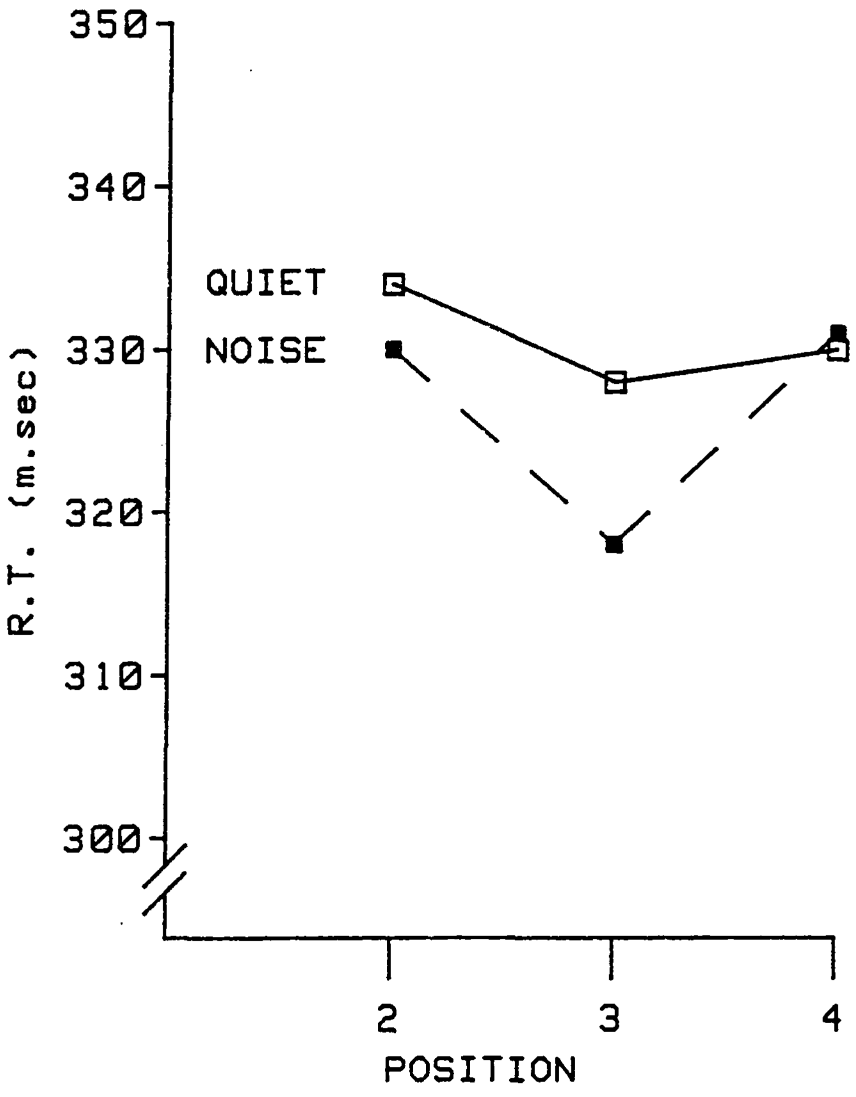


Figure 6.15 : Results from Experiment 11 - Reaction times to invalid trials which immediately follow invalid trials

trials in noise. However, once again, this effect is very slight. If noise is producing a greater commitment of attentional resources, then it is doing it in a very slight and subtle manner. Even if one does conclude that there is an attentional effect present here, its origin could equally be that responses to invalid trials fall dramatically at the last position. This could be a type one error, especially as the effect depends upon one data point!

If this conclusion is correct, then the introduction of the factor of memory load has made no appreciable difference to the pattern of noise effects already produced in a setting where it is absent. As discussed in Section 6.1, Hockey (1984) argues that one might expect performance to deteriorate on a high memory load task in noise, but as can be seen, this does not apply here. That noise can and does affect certain types of memory task was made clear in Chapter 2 (Section 2.2.4) and therefore it must again be concluded that it is the precise kind of memory load combined with exact situational factors that contributes to the effects of noise on performance. The results presented here also argue against any other explanation of the effects of noise on short term memory (e.g. Poulton 1979).

What do these results tell us about attentional selectivity in noise? It is possible that noise is manifesting itself in a relatively subtle manner in terms of a change in performance, and narrowing the range of task relevant cues which are used to regulate performance. As was suggested in Section 6.4.1 above, the central alerting cue could be assisting performance on this type of task, so that when it is removed subjects are left devoid of the support it offers. The demands made upon general processing capacity could then increase to the point where it is impossible to maintain the same pattern of responding in noise and in quiet. But this is a far cry from the clear pattern of data found from multi-component task studies (e.g. Hockey 1970a, b) discussed in Chapter 2. It points again to the frail nature of noise effects and to the fact that only a complex model will adequately allow for the "now you see it, now you don't" nature of the effects reported thus far. This point will be developed in the next chapter.

6.5 General Conclusions from Experiments 9-11

From all three experiments reported in this chapter it is possible to draw several specific conclusions.

The first and most clear cut is the simple observation that orienting can be repeatedly produced by the alignment of attention with a succession of items stored in short-term memory. Other research (e.g. McClean and Shulman 1978; Neely 1977) has shown orienting from semantic memory structures but is dissimilar to the visual manipulations reported in this chapter. All three studies showed there to be clear effects resulting from the alignment of attention with expected input, resulting in distinct costs and benefits.

An extension of the memory load from five to six items failed to produce any significant effects of noise upon task performance, leading to the possible conclusion that despite the appropriate nature of tasks of this type for measuring the effect of noise on performance (Hockey 1984), the specific structure employed here was insensitive to changes in performance efficiency.

The removal of the central (temporal) alerting signal employed in both Experiments 9 and 10 resulted in a change in the level of costs in different noise levels in Experiment 11, and three possible explanations for this effect were put forward. It was concluded that subjects might be operating in a different manner in noise as opposed to quiet, resulting in an increase in invalid RT at late trial positions. This effect was, however, very small, and is shaky evidence upon which to build any far-reaching theory of the effects of noise on performance. This fits in clearly with the theoretical interpretation of the effects of noise on performance discussed throughout much of this thesis, and emphasizes once again the frail and perhaps transient nature of noise effects.

CHAPTER 7

CONCLUSIONS

SUMMARY

This chapter contains a discussion of the issues raised by the experimental work presented in Chapters 4-6. The chapter is divided into two main sections. The first deals primarily with attentional mechanisms. The data showing how attention can be covertly oriented to a location in space and showing that such orienting cannot be passively maintained over a block of trials are discussed. The nature of inhibition and its consequences are given detailed discussion. Finally, the way in which locational expectancies can be generated from memory is examined.

The second part of the chapter focusses on the effects of noise on the above three situations. These data are considered in the light of five alternative models which seek to explain the effects of noise on performance. These are perceptual failure, reduced capacity, masking, arousal and strategy change. It is concluded that the last of these models forms the best overall explanation of the data. It is pointed out how the inclusion of a minor experimental variable can alter performance in noise. It shows how attention must be paid to such details if any predictive theory of the effects of noise on performance is to be formulated.

7.1 Introduction

The aims of this chapter are to summarize the experimental findings, relate them to previous work in the areas of attention and stress, and finally examine their implications for theories of noise upon performance. The effects of noise upon task execution will be discussed separately from the issues relating to theories of attentional orienting.

7.2 Attention

7.2.1 Experiments 1-3: Central Cueing

Experiments 1-3 all demonstrate how attention can be covertly aligned with a source of sensory input (Posner 1978, 1980). The direction of attention was manipulated by a central warning signal which acted as an instruction as to the likely subsequent target location. Changes in the speed of detecting events which occurred at various spatial locations with certain probabilities were examined and revealed that attention was being directed by a central decision to one of two peripheral locations. Such shifts in attention were identical to those found by other researchers using a similar experimental technique, (e.g. Posner, Nissen and Ogden 1978; Shulman, Remington and McLean 1979). Chapter 3 contains the arguments which justify the conclusion that these occurred, as in the other situations, in the absence of eye movements. Such changes in the alignment of attention are termed "covert" (Posner 1978, 1980) to separate them from "overt" attention movements involving the head and eyes, and result in a benefit in processing expected information and a corresponding cost in processing unexpected information.

Posner and Snyder (1975a, b) present a theory of attention which specifically deals with the processes underlying these two effects. It was argued that the data from Experiments 1 and 3 fitted well with the attentional mechanisms embodied in this theory. It was interesting that the benefits arising from target occurrence at a cued location accrued more rapidly than the costs which occurred when targets appeared at an unexpected location. This was attributed to variations in responses to the neutral condition. Other than this, the data presented in Experiments 1 and 3 seem to provide similar support for Posner and Snyder's (1975a, b) theory of attention as the data originally reported by Posner, Nissen and Ogden (1978) where costs and benefits were symmetric (see Section 1.2.2).

Certainly the data from Experiments 1 and 3 reflect the operation of attentional mechanisms that are closely time-locked. This is seen firstly in the differential time course of costs and benefits discussed above and also in the way in which the data show a U-shaped function relating reaction time to interval following the cue for all positions. This is a reflection of the alerting effect well documented in the reaction time literature and discussed fully in Chapter 1 (Posner and Boies 1971; Niemi and Naatanen 1981). The cue is not only providing the subject with selective information regarding the probable location of the target, but is also acting as a temporal warning signal. The optimum SOA for predicting the moment of target onset in Experiments 1 and 3 lies between 250 and 500 msec. After this point it is possible that subjects become poorer at estimating the length of the SOA, as argued by Rabbitt (1981), resulting in longer reaction times regardless of cue type.

Both the warning signal and the attentional orienting effects remain consistent across the two differing experimental conditions used in Experiments 1 and 3. In other words both effects occur despite variations in intertrial interval and regardless of whether SOAs vary randomly across trials or are presented in a blocked design. Thus the latter design used in Experiment 1, which would result in a greater degree of predictability of target occurrence, did not produce any demonstrably different effects from Experiment 3. This is consistent with other data from the literature where blocked and mixed SOA designs produce the same patterns of effects resulting from alerting and orienting. For example closely comparable effects were found by Posner, Nissen and Ogden (1978) using a blocked SOA design and by Shulman, Remington and McLean (1979) who used randomly varying SOAs. The difference between the two task designs does produce evidence which suggests that blocked SOAs will result in faster overall reaction times than random mixing. Mean overall reaction time for Experiment 1 was 324 msec compared with 363 msec for Experiment 3. It is acknowledged that these effects might be attributable to subject differences or other variations in task design. Other than this, performance is remarkably stable when compared across the two situations.

Another indicator of the invariant properties of orienting is the analysis of the stability of performance in all four blocks of Experiment 3. Apart from the operation of a general fatigue effect resulting in a slight increase in mean response times, performance in the last quarter of the experiment was highly similar to that in the first. The data still showed the general U-shaped function associated with alerting (Posner and Boies 1971), and demonstrate how powerful are the changes in overall pathway activation that result from the presentation of a clear warning signal. This point is developed further in Section 7.2.

But within this overall invariability of orienting behaviour over time there are some subtle and interesting interactions between specific indices of attentional allocation and time on task. Of particular interest is that the overall use of cue information (costs-plus-benefits) falls with time on task when the SOA is short (100 or 250 msec), but increases when it is longer (500 or 1000 msec). Overall, cue use is always greatest at the longer SOAs as target detection will be affected maximally by both facilitatory and inhibitory processes by this time (Shulman, Remington and McLean 1979), but Experiment 3 clearly shows how more general changes in state (caused in this case by time on task) can interact with the commitment of conscious attentional processes. This point is of particular interest when one considers that noise has no overall effect in this experiment, perhaps a typical example of the diverse changes in the pattern of performance that one can expect to see under different situations of environmental stress (see Hockey and Hamilton 1983).

Responses for SOAs of 250 and 500 msec are consistently the fastest for all cue types, irrespective of time on task - a reflection of the general alerting properties of the cues discussed above, but there are other specific changes which reflect the operation of the type of limited-capacity conscious attention mechanism suggested by Posner and Snyder (1975a, b). In particular the rise in costs-plus-benefits over time on task for the longer SOAs shows the interaction between attentional mechanisms and overall levels of awareness. As subjects become increasingly fatigued costs and benefits are greater at longer SOAs because of the increase in time taken to process an unexpected target event. The steady increase in response times to all targets, especially invalid ones, is a reflection of the same process.

Up until now little has been discovered about the way in which processes concerned with internally controlled covert orienting alter with fluctuations in tonic state arising from task demands such as those applied here. This situation has not altered a great deal since Moray (1969) bemoaned the lack of knowledge about the relationship between the processes that govern selective attention and tonic arousal. Certainly there is much scope for the development of work in this area, though such research is likely to be complicated by the fact that, as discussed in Chapter 1, phasic and tonic alerting effects operate at least in part through similar mechanisms. This would explain the difficulty that exists in obtaining effects of time of day or sleep deprivation during short task sessions where phasic alertness will be quite high (see Wilkinson 1967). One solution to this problem and a fruitful avenue for further research is the greater development of tasks which allow for the separation of effects of cueing from shifts in attention. One example of this is the blocked cueing designs used in Chapter 5.

Conclusions from Experiments 1-3

1) Attention can be covertly oriented to the periphery by means of a central warning signal. There is a "benefit" in processing subsequent targets which appear at the attended location, and a "cost" in processing targets which appear at unattended locations. In line with previous research, these effects have differing time courses depending upon the degree to which automatic or controlled attentional mechanisms have been activated.

2) A second major effect of the central signal concerned its temporal warning properties. These resulted in maximal alerting effects when targets occurred at approximately 250-500 msec after cue onset. This feature of the data remained consistent across different task designs and time on task, there being no

suggestion that the optimum warning interval gets longer as subjects become fatigued.

3) Cue use is greater at longer SOAs, a difference which becomes more marked as time on task increases. This was taken as a reflection of the active nature of orienting: Fatigue highlights the difficulty subjects experience in using positional information optimally when SOA is short.

7.2.2 Experiments 4-8: Blocked Cueing

Knowledge of the spatial position of a target does not always decrease the speed of its subsequent detection. If, instead of cueing on every trial, one spatial position is made likely for a whole block of trials, the pattern of results discussed above alters dramatically. Under such circumstances subjects do not continue to set themselves for the location at which the environmental signal is most expected (Posner, Snyder and Davidson 1980; Posner, Cohen, Choate, Hockey and Maylor 1984). This results in reduced orienting effects over a block of trials.

Data reported in Experiments 4-7 clearly reproduce similar effects where subjects rapidly lose spatial selectivity over a short block of trials. In a similar blocked design, Posner et al (1980) reported that benefits fell dramatically whilst costs tended to remain. In two separate experiments Posner et al (1984) demonstrated a similar reduction in costs and benefits. As discussed in Chapter 5, they claimed that this failure to show strong selectivity was due to the inhibition that occurs when the same stimulus is presented twice in succession on the same side. They argued that whatever benefit might be obtained by the allocation of attention to a cued location is counteracted by this inhibition. This indeed seemed an elegant suggestion as it takes into account the probabilities of the occurrence of particular trial types, i.e. the greatest effects of loss of orienting are seen in responses to valid trials which frequently occur at the same location twice or more in succession. However the experiments reported here show this to be inadequate as an explanation for reduced selectivity under such conditions.

Firstly the failure to establish or maintain selectivity as a result of a central cue (as shown by Posner et al 1984) may be produced without a corresponding occurrence of inhibition. This inhibition refers to the slowing of responses to targets which appear successively at the same location. Its presence was tested for by comparing reaction times to the second of two targets appearing at such locations with those appearing at the opposite location. Inhibitory effects are generally accepted to operate over a time scale of around 1500 msec (Posner and Cohen 1984; Maylor and Hockey 1985). In Experiments 4 and 5 significant inhibitory effects were found to last up to 2000 msec. However, when response-stimulus intervals were lengthened even further (between 2500 and 3500 msec in Experiment 6), inhibitory effects were absent but subjects still showed reduced attentional selectivity.

Secondly, it was found that selectivity could be maintained in a situation where there was also inhibition (Experiment 8). The view taken by Posner et al (1984) that there is an intimate causal link between inhibition and loss of selectivity seems untenable in the light of these findings.

The next two objections to the Posner et al (1984) explanation of loss of orienting centres on their argument that inhibition affects responses to valid targets most strongly (resulting in reduced benefits rather than costs). It was argued that even their own data did not support this point. (In one experiment the inhibitory effects for neutral trials were almost twice the size of those reported for valid trials). Similarly in the experiments reported here, inhibitory effects were greater for responses to neutral trials as opposed to valid trials.

In addition it was shown that costs also tend to decrease across a block of trials, arguing against Posner et al who claimed that negative sequential dependency will mainly affect reaction time on the cued side where target probabilities are high. Also, in Experiment 2 of Posner et al (1984) costs and benefits were extremely small. In all the experiments using a target-target procedure reported in Chapter 5 costs are less for positions 7-8 in a sequence than they are for positions 1-2. In all the studies except Experiment 4 this fall as a function of position is both steady and significant. Benefits consistently fall with repeated target presentation, (Experiments 4, 5 and 7) or remain consistently low from the outset (Experiment 6). Posner et al (1980) report that relative to cueing on every trial benefits are virtually removed by block cueing, but it is clear from their data that costs are also affected in the same manner (but not to the same extent) as benefits.

Another objection to their explanation was that there was no greater inhibition for trials occurring later in a sequence. This would be a logical prediction from the argument which says that the longer a sequence continues, the more inhibitory effects can build up and therefore result in reduced selectivity.

Finally, noise tended to produce greater levels of inhibition <u>and</u> orienting. Posner et al's position would lead to the argument that the stressor would result in <u>less</u> inhibition coupled with greater orienting, given that any increase in inhibition should reduce selectivity.

Maylor (1983) also argues that the inhibitory effect explanation put forward by Posner et al (1984) is inadequate as an explanation for any inability to maintain orienting. One of her contentions is that because Posner et al's (1980) experiment contained R-S intervals of at least 2000 (and sometimes over 4000 msec), there would be no effect on reaction time of the location of targets on previous trials. However this argument is weakened by the fact that the inhibitory effect is found here to last up to 2000 msec (see later discussion). Having said this, Posner et al's (1984) first experiment, in which a similar R-S interval was used, produced a trend (of inhibition) in the expected direction (corresponding to the reported failure to maintain selectivity), though the effect was not significant.

Sanders and Reitsma (1982) investigated the effects of lack of sleep on covert orienting of attention using a design where R-S intervals varied between 6 and 24 sec. They found an expected cost-benefit function for targets which appeared at fixation, but no effect of target probability on reaction time to targets presented in the periphery. Sanders and Reitsma suggest that internally controlled orienting may be "so demanding that it can only be maintained for a short period of time" (p. 144). In discussing the same topic Maylor (1983) concludes that "the inability of subjects to maintain a constant expectancy over a block of trials must be attributed to some other factor" (p. 287), i.e. not inhibition.

There is general agreement from a variety of sources that orienting is heavily resource dependent. Posner (1980) himself argues that the failure to maintain selectivity is a reflection of the active nature of orienting and that "orienting does not seem to involve a passive filter that can easily be set in place and left. Rather, an active process of maintaining the orientation seems important" (p. 8). This is also at the centre of the arguments put forward by Posner et al (1984), the effects of inhibition being the precise mechanism underlying their explanation of the way in which active maintenance of orientation is prevented. Maylor (personal communication) similarly argues that orienting is an active cognitive process which is difficult to maintain without repeated locational cueing to re-direct attention to a source of expected input. But she reasons that subjects show a loss in selectivity not because of inhibition, but rather as a direct result of the difficulty experienced in maintaining orienting. This is the view favoured on the basis of the data presented here.

In considering the behavioural significance of orienting it would be strange to propose the existence of any kind of attentional mechanism which failed to prepare observers for expected events but which still resulted in an impairment in the processing of unexpected ones. This however is the position one is forced into if Posner et al's (1984) view is adopted. For this reason and on the basis of the findings reported here it is concluded that although subjects will show a failure to maintain selectivity to one location, this will be manifested in a loss of costs as well as of benefits. The reason that the former measure at times appears not to be affected in the same manner as benefits may be partly attributable to the fact that costs tend to be greater than benefits anyway. In addition, there may be errors in the estimation of costs and benefits relating to the measurement of the baseline neutral condition. Jonides and Mack (1984) argue that the unthoughtful application of cost-benefit analysis can result in serious errors in theorizing in this field, pointing particularly to the fact that neutral cues are often very poor at producing a truly "unbiased" measure of performance. As discussed in Chapter 1, in essence they say that this is because the rationale hinges on the assumption that neutral and informative cues must be identical with respect to all their effects except that of information specific to the target - which is not necessarily always the case. They recommend that, if possible, researchers leave neutral trials out of their experimental designs and instead measure changes in use of cue information from the differences in reaction times to invalid and valid trials only. If this measure of performance is the one relied upon most strongly as an overall indicator of cue use - as recommended by Posner (1978) - then all the reported experiments using blocked cueing, including the ones described here, would show an increasing loss of orienting as trials continue. In fact if this had been the method of measurement adopted by Posner et al (1980) and Posner et al (1984), then their proposed explanation in terms of the effects of inhibition would be less convincing from the outset.

An additional issue of interest, addressed particularly by the blocked cueing experiments of Chapter 5, is the length of time over which inhibitory effects can last. Significant negative sequential dependency effects lasting up to 2000 msec (neutral trials, Experiment 4; valid and neutral trials Experiment 5) were found. This length of time exceeds the hitherto published data concerning the temporal characteristics of inhibitory effects by 500 msec. It is acknowledged that this may be a result of factors which vary across these experimental situations, e.g. display luminance, contrast etc. Maylor and Hockey (1985) report data where inhibition is clearly present at 1300 msec, and Posner and Cohen (1984) report inhibition to last at least 1.5 seconds (p. 549). The effects described here confirm the reported non-significant trend described by Posner et al (1984).

Thus, the inhibitory effect associated with externally controlled orienting (Posner and Cohen 1980, 1984), and identified to be operating in other experimental situations (Maylor 1983, 1985), can be seen to be an important consequence of attention having been oriented to the periphery. The experiments reported here not only point to the widespread occurrence of the phenomenon but provide additional information as to the possible extent of its time course (up to at least 2000 msec after stimulation, but probably not longer than 2-3 seconds; Experiment 6). Further research will be valuable in this area in order to unravel more of the temporal properties of these effects.

Conclusions from Experiments 4-8

1) Without repeated cueing to an expected location, orienting to that location is rapidly reduced over a short block of trials.

2) When targets occur at the same location in succession, inhibitory effects retard subjects' response speed.

3) These inhibitory effects cannot be the cause of loss of orienting. Instead the loss is more likely to be due to the fact that orienting is a demanding cognitive process and decays over time.

4) These effects can operate over a longer time course than previously thought.

7.2.3 Experiments 9-11: Memory Load

The inability to maintain covert orienting to a specific location over time was demonstrated clearly in Chapter 5. The experiments described in Chapter 6 represent a further extension of the blocked cueing technique. In these experiments a sequence of 5 or 6 locational expectancies were cued prior to a complete block of trials, and subjects were required to store this information in memory. There is already limited evidence which suggests that attentional processes can operate in a broad variety of circumstances (McLean and Shulman 1978; Neely 1977; Shepherd 1982). Thus the findings that subjects are able to summon and orient their attention on the basis of a series of spatial cues stored in short-term memory, although original, is not perhaps surprising. In itself such an action is a fairly straightforward mental operation, but of more particular interest is the way in which the changing memory loads interact with attentional mechanisms.

As was discussed in Section 6.1, Jonides (1981) conducted an experiment where subjects were given two types of orienting task (central cues and peripheral cues) under three different levels of memory load. On the basis of data obtained from this study he concluded that "the processing of a central cue is a more capacity-demanding task than processing the peripheral cue" (p. 199). Although the pattern of data reported for Experiments 9 and 10 in particular differed greatly from Jonides', both studies also show how the processing of central cues draws heavily upon general cognitive resources.

The data presented in Experiments 9 and 10 clearly fit with what is known about the active nature of orienting. This is reflected by the way in which response times for invalid trials are the ones most affected by memory load. The limited capacity attentional mechanism at work here cannot operate without intention and conscious awareness and will inhibit pathways that are not primed or facilitated. Thus an invalid target is processed even more slowly than usual because of the already high level of demands being placed upon the system and the depth to which the symbolic cue has already been processed.

It is interesting to note that the situations in which subjects are cued as to impending target onset (i.e. Experiments 9 and 10) are the ones in which the fall in both costs-plus-benefits and invalid reaction times (as a function of the unloading of memory) are most striking. This is evidence that the alerting cue facilitates the summoning of the next trial-relevant cue from memory - this is not the case in Experiment 11. Certainly the mean level of costs-plus-benefits is lower for Experiment 11 (47 msec) as compared to 62 and 56 msec for Experiments 9 and 10 respectively. This is a further indication that a greater commitment of attention is being brought about in the earlier studies as a result of the presence of the warning signal.

The usual U-shaped function (see Shulman, Remington and McLean 1979) found as a result of alerting is not as clear in the data from Experiment 9 (see Figure 6.3). Nevertheless the alerting power of the central warning signal is likely to be responsible for the differences between the overall pattern of results between Experiments 9 and 10 and Experiment 11. Without the alerting cue, the design of Experiment 11 resulted in a dramatic fall in reaction time for all trial types across the first two positions in a sequence. It was argued that this effect obscured the more subtle effects of unwinding memory load on spatial attention processes. These effects were in addition to the alerting cue's role in rendering the experiment susceptible to the effects of noise (see Section 7.3).

It has already been argued, both here and elsewhere, that the absence of such signals produces a situation where spatial selectivity cannot be effectively maintained. Although there are clear effects of attention in the expected direction in Experiment 11, it is nonetheless true that the alerting signal present in Experiments 9 and 10 is activating attentional allocation both more readily and optimally. On the basis of this fact, the results of Experiment 8, and the data presented by Berlucchi et al (1986) (see Section 5.6.3), it is concluded that a central warning signal presented shortly prior to target onset in experimental situations devoid of other cues, would help subjects orient their attention to the expected location, despite the fact that the signal itself carried no spatial information. If orienting is an active process that is hard to maintain under certain circumstances (Maylor 1983) then a temporal warning signal would provide sufficient information for renewed activation of previously primed pathways to occur. This effect would not depend on the alerting cue providing fresh information; merely on the triggering of previously primed actions. The cue causes subjects to re-orient on the basis of what they remember the most likely target location to be. This fact is of particular interest when considered alongside the findings of Posner and Boies (1971). Their priming studies suggested that the alerting effect of a warning signal is totally independent of specific pathway activation. However such a strong view of this separation is probably not correct, and this study emphasises the fact that there can sometimes be a close connection between general alerting effects and specific pathway activation.

Conclusions from Experiments 9-11

1) Orienting can occur on the basis of target information held in short-term memory.

2) Responses to invalid targets are most heavily affected by the imposition of memory load, probably as a result of the greater demand responding to such events places upon the subject.

3) Cueing aids the retrieval of target locations from memory. The alerting property of the cue rather than its specific information content is likely to be more important in this respect.

7.3 Performance under Noise

7.3.1 Alternative Models

As Fisher (1986) points out, it is easy to look at the history of noise research and find a continuum of new theories and models which are proposed to account for an ever increasingly complex pattern of data. These models have fallen into five broad categories, and each one will now be discussed below in the light of the data reported in this thesis.

Perceptual Failure

This position, frequently referred to as the "distraction hypothesis" was proposed by Broadbent (1958a). He argued that as filtering took place in all situations, efficient work could only be carried out by the selection of stimuli from the task and the exclusion of irrelevant information. Novelty was deemed to be an important factor governing stimulus selection, and thus when a task was continued for some time, stimuli from that task would gradually lose priority. This would lead to perceptual failure due to the filter selecting irrelevant stimuli rather than task stimuli. As physical intensity of a stimulus was another factor governing its selection, the presence of noise would increase the frequency of such failures. Arguments for and against this position are discussed more fully in Chapter 2. Despite the fact that such a model is no longer considered viable (Broadbent 1971), it is interesting to consider the predictions that such a position would make in the experimental situations reported here.

One would predict from the perceptual failure hypothesis that noise would firstly increase the number of errors on a task, and secondly that these errors would be more pronounced towards the end of an experimental session. The first of these predictions has not been held up by the data reported here, as can be seen from an examination of the error rates reported for each study. They are consistently low in both noise and quiet, and this is also the case for Experiment 3, the longest of the studies reported. The method used for the extraction of error rates did not allow for any further comparison of noise-quiet differences as time on task progressed. However, as Broadbent (1958a) emphasised the importance of novelty in allowing successful perceptual selection, one would expect a general increase in RT (noise) in Experiment 3 as time on task progressed. As was shown in Chapter 4, the increase in RT which was present in this study was common to both conditions. No other experiment was long enough to be a sensitive test for the effects of noise on time on task (see Jones 1984) and thus it is concluded that the distraction hypothesis has little to offer in interpreting the effects reported here. It would only be of value if changes in RT were present for all three trial types, which is not the case in any of the experiments where noise affects performance.

Reduced Capacity

One popular notion concerning the effects of stress on performance is that such conditions create additional demand on general resources leading to lowered competence. Such a general view would go a long way to explain much of the experimental evidence reviewed in Chapter 2. In its most simple form this theory argues that performance impairment will occur when demand exceeds available capacity. Experimental evidence in support of this view comes from a variety of sources. Boggs and Simon (1968) found that the introduction of noise to a multi-component task resulted in an impairment of subsidiary task performance. The two tasks could be successfully completed without noise, but capacity was exceeded when noise was introduced. These authors concluded that "the introduction of noise used up some of S's reserve capacity, that is, S had to draw from his reserve so that primary task performance would not suffer as a consequence of noise" (p. 152). Finkleman and Glass (1970) interpreted their data which showed a noise induced impairment on a secondary task (see Chapter 2) in a similar way. In addition, Millar (1980), using a letter matching task paired with a probe reaction time task, found probe latencies to be lengthened in noise. He concluded that delays were occurring on the secondary task as a result of loss of spare capacity.

However, as discussed in Chapter 2, the same data have been appealed to by supporters of the selectivity hypothesis as evidence of noise resulting in the shifting of performance away from low priority elements of task structure. Indeed, the reduced capacity model can be seen as a cruder version of the selectivity hypothesis as it is far less predictive. As will be argued in Section 7.3.2, the positions are not necessarily mutually exclusive.

Data reported by Weinstein (1974) points to the value of a somewhat broader position than that taken by selectivity theorists. He examined the detection of errors on a proof reading task and found that in loud noise subjects maintained comprehension ability but failed to detect errors which depended on reading context. They remained able to detect errors not dependent on context. He concluded that arousal theory could not account for the "relatively complicated pattern of heterogeneous effects observed in this experiment" (p. 552).

How would a breakdown in capacity account for the data reported here? One would imagine that if noise were responsible for such a general change in performance, then there would be a reduction in the amount of attentional orienting to a target resulting in an opposite pattern of data to that predicted by the selectivity hypothesis. The small effect of noise on performance reported in Experiment 5 would clearly not fit with this position, as would the suggestion that noise increased inhibition in Experiments 5 and 7. Although the effects of noise in Experiments 7 and 11 were small, the reduced capacity model would only account for the reduction in invalid response times seen for positions 1-2 in Figure 5.20. As much as the selectivity model failed to account for this aspect of the data (see Section 5.5.3), the capacity model cannot explain the rise in RT to invalid targets as a block of trials continues. Thus it is concluded that although this model has the advantage of simplicity when compared to the selectivity position, it cannot adequately account for the effects of noise on orienting.

Masking

As was discussed in Section 2.2.6, Poulton (1977a, 1979) re-examined a number of existing experiments purportedly demonstrating negative effects of noise and he proposed alternative explanations in terms of the masking influence of noise on feedback and memory. He argued that noise could heighten arousal and improve performance, but that any deleterious effect of noise was due to these other factors. Section 2.2.6 showed that there are strong theoretical (Broadbent 1978) and experimental (Millar 1979b; Jones 1983a) criticisms of the masking hypothesis, and much of the data in this thesis adds weight to these arguments against Poulton's position.

Firstly, Poulton (1977a) argues that effects of noise attributed to changes in attentional selectivity (e.g. Hockey 1970a, b) in fact arise as a result of suppression of feedback from responses switches. Jones (1983a) has already demonstrated a typical pattern of noise effects on a silent serial reaction time task, and the equipment used in the experiments reported here allow a similar point to be made. Firstly, the response bar was identical for all types of target. It is impossible for feedback from this to be masked in such a way as to differentially affect responses to invalid and valid targets, as was the case most clearly in Experiment 5. In addition, the quiet condition (50 dB(A)) masked the soft tap made by the response bar, precluding any additional masking by the higher noise level.

Poulton's position also makes specific predictions about how performance on a memory task will be altered by noise, because of the effects upon the masking of internal speech. He argues that noise will affect memory in situations which require the storage and processing of material. Both these factors are incorporated into the designs of Experiments 9-11, yet there is no significant effect due to noise. It is possible that the alerting cues present in Experiments 9 and 10 aid recall in such a way as to counteract any effect of noise due to masking, but this is unlikely as there is no effect present in Experiment 11 either. It is safe to conclude that the experiments reported here offer no support to Poulton's position, and in fact effects are present which run contrary to any prediction made by the masking hypothesis.

Arousal and Selectivity

As was discussed in Chapter 2 it has often been useful to appeal to the type of state analysis suggested by Hockey and Hamilton (1983), which considers the overall constellation of behaviour changes brought about as a result of a particular stressor. As these authors point out, alterations in responding are better considered in terms of changes in style rather than competence, and there are a number of component features which characteristically identify performance under noise. The features of this "noise state", detailed very accurately by Broadbent (1978) (and reported in Section 2.1) can be described in terms of an alteration in the balance of a predisposition towards certain forms of mental activity and away from others. The most relevant example to the issues addressed by this thesis is an increase in the selectivity of attention.

This alteration in attentional selectivity under noise was originally and most clearly identified by Hockey (1970a, b), who argued that the phenomenon was best described as an enhancement of attention paid to sources which were being given highest priority, and a resultant withdrawal of attention from low priority sources. Thus it is hypothesized that noise will produce a particular alteration in the allocation of attention so that a higher proportion of processing effort is given to the intake of information from dominant sources, and less from relatively minor ones. Much of the evidence for this viewpoint comes from multi-component tasks of the type discussed in Section 2.2.3, where the experimental design contains a built-in hierarchy of response priorities. As was discussed in Section 2.4, this tendency of noise to result in a bias in favour of one response rather than another, poses interesting questions about the possible effects of noise on internally-controlled orienting tasks, where attentional priorities are clearly set up by means of locational information. A hierarchy of priorities exists, not between various separate components of tasks, but in terms of differences between expectancies governing the likelihood of target occurrence at a particular location.

An overview of all the experiments reported in Chapters 4-6 reveals that noise does not affect the selectivity of attention allocation when the alignment of that attention has been focussed by a central warning occurring immediately prior to target onset. This was the case in Experiments 1-3 where subjects received a cue which precisely governed their expectations as to subsequent target onset. Similar data were also obtained in Experiment 8, where the introduction of the central cue removed the effect of noise on orienting produced when trials were blocked together in groups of 10. Even when the central cue contained no specific locational information (Experiments 9 and 10), it was seen to marshall resources sufficiently so that performance on an otherwise highly complex task remained unaffected by noise. This was not the case when the cue was removed in Experiment 11.

In Chapter 1 a clear distinction was drawn between general and specific states of alertness. The former, defined by Posner (1975, 1978) as "tonic", refers to an overall state of activation which governs subjects' general baseline state of preparation. Although such a concept has in the past led to the erroneous assumption that changes in the general level of arousal or reactivity will either enhance or have a deleterious effect upon overall performance efficiency (see Hockey and Hamilton 1983), it is the state of this global condition that researchers are manipulating when examining the effects of sleep loss, drugs, anxiety (etc) on performance. Such a concept of alertness contrasts sharply with the notion of some kind of unique state of preparation associated specifically with preparation for an incoming stimulus. Such a state of readiness for external signals is defined by Posner (1975, 1978) as "phasic". In simple terms the differences between the two concepts of alertness can be usefully compared to the situation of an athlete preparing to run an Olympic 100 metres final: His general state of preparedness on the day, whether he is sober or intoxicated, sleepy or awake and so on is one measure of his alertness, and obviously such a general condition will have a considerable effect on the highly specific state of readiness he will be in whilst waiting to come off his blocks.

In Section 2.2 one of the most important aspects of vigilance tasks seen to influence the nature of the effects of noise on selectivity was the presentation of information in a clear, unambiguous fashion. Tasks containing a high element of ambiguity - and therefore exerting considerable demands on processing resources - often created a situation sensitive to effects of noise, but clear signals which are maximally informative do not push subjects to the limit of their responding, and so may not be sensitive to effects of noise.

Broadbent (1979) argues how noise produces a general alerting or awakening effect and that the effects of noise are similar to those induced by some other methods of changing the general state. He also argues that "any task in which a person has to react only at certain definite times, receives a clear warning signal of the need for reaction, and receives an easily visible stimulus will show no effect in continuous loud noise" (p. 17-4). These arguments are particularly applicable to the pattern of results reported in this thesis. A specific warning signal will change the condition of an internal alerting state and affect the response made to any following signal. This is because it is a specific temporal event which tells subjects to get ready to attend closely to a forthcoming external stimulus. Broadbent (1958a) makes a similar point, arguing that in RT tasks, the rate of transmission of information is low, thus making such tasks "precisely those which we would expect to minimize the effects of noise" (p. 88).

The alerting effects of cues in reaction time tasks such as those used here are well documented (see Shulman, Remington and McLean 1979; Posner, Nissen and Ogden 1978). It is undeniable that such cues affect reaction to following stimuli in a very specific and powerful way. The main contention here, based upon the stability of performance in noise in Experiments 1-3 and 8 and its variability in Experiments 4-7 (as well as the comparison between Experiments 11 and Experiments 9-10) is that subjects are operating under conditions of high phasic alertness when they have received a central warning signal. The signals used here were clearly visible and provided specific information concerning subsequent target onset, a situation argued by Broadbent (1979) as being likely to preclude the action of noise on performance.

One possible future avenue for research in this area would be to investigate the effects that noise bursts have on this specific state of alertness. As was mentioned in Section 2.1, such issues have not been focussed on by this thesis, but the distracting effects that sudden bursts of noise can have on performance are well documented (see Jones 1984; Fisher 1984b for overviews). Fisher (1972) found that such bursts produced a slowing of response in a serial reaction task when they arrived during the execution of a response. Similarly, Woodhead (1964) found that bursts arriving during the intake of information in a mental arithmetic task were particularly detrimental to performance. It is possible that such events may interact with specific effects of alerted attention to either heighten or lessen the ability to benefit from pathway activation.

It is argued along with Broadbent (1978) and Hockey and Hamilton (1983) that the effects of noise on selectivity of performance are associated with a bias in the intake of information from dominant or high priority sources, and that noise increases the tendency to direct activities towards the more dominant aspects of an overall goal. This last phrase is given particular emphasis because it is quite apparent that when the goal of directed behaviour is unique, specific, and clear, as in the experiments here which include central cues in their design, then noise does not usually bias performance in this way. This is returned to in the section which follows. Thus if a task contains an element of its structure which results in a state of extremely high preparation in the observer then any more general alerting effects arising from changes in the environment become less influential in determining behavioural efficiency.

The stability of performance seen over time in Experiment 3 and already described above is a testimony to this fact. Irrespective of the length of time spent on the task, the alerting effects arising from cue presentation (Posner and Boies 1971; Niemi and Naatanen 1981) are equally present in each quarter of the task. Some aspects of performance reflected the general fatiguing processes caused by time on task (specifically the measure of costs-plus-benefits discussed in Section 7.1.1). This indicated the way in which a change in tonic alertness level was interacting with the processes of pathway activation. This result agrees with the view discussed above (Posner 1978) that non-selective alerting and specific pathway activation can go on with little or no interference. Alerting and specific preparation for particular signals can be relatively separate processes.

An important result is that the change in tonic state (i.e. fatigue) affects the particular levels of costs and benefits but does not interact with the nonselective activating properties of the cue. This is further evidence for the necessity of a view of changes in performance under stress which expects a particular <u>pattern</u> of responding from a certain stress state (e.g. Hockey and Hamilton 1983). If we expect a particular qualitative pattern of performance changes to accompany a particular change in state, then rather than arguing that one particular stressor will alter performance in only one way along some unidimensional notion of efficiency, we should be expecting both subtle and complex alterations in performance to be indicative of the influence of any given stressor on task performance.

In real terms the presence or absence of the alerting signal is a relatively minor feature of task design. The original conception was that an experimental situation which allowed the manipulation of internally controlled orienting would be a sensitive test-bench for examining the effects of noise on performance. Although the possible alerting properties of the central cue were recognised, their potential for altering patterns of performance was not realised. It is widely agreed that the effects of noise on performance and their interpretation is a particularly complicated field of study (see Smith 1983a; Jones 1984). Such factors as task demands and the way in which they are subjectively perceived can vary from one experimental situation to another and affect the overall outcome of a task. The finding here that alerting cues can play a crucial part in task performance highlights the crucial importance of experimental design and the need for attention to be given to the possible implications of what might seem on the surface to be a minor alteration in task structure.

Strategy Change

Experiments 5 and 7 offer some support to the notion that noise can result in a bias in favour of a high priority source and away from a low priority source, so long as the task design is both suitable and sensitive. Without the alerting cue, subjects' locational priorities had to be maintained over a whole series of trials, and noise was shown to reduce the tendency for selectivity to be lost as a function of position in a sequence of trials - a typical feature of orienting tasks using blocked designs of this sort. In particular costs-plus-benefits did not fall so sharply in noise as they did in quiet. This result was contributed to in Experiment 5 by differential and opposite effects on valid and invalid trials, and in Experiment 7 by an increase in reaction times to invalid trials only. Both experiments reflect the changes in speed of responding to expected and unexpected targets already demonstrated in other experimental situations (Hockey 1969, 1970b; Hartley 1981a; Smith 1985).

Recently Maylor (1983, 1985) and Maylor and Hockey (1985) have shown how the occurrence of inhibition is actually dependent on prior orienting having taken place, rather than the inevitable result of sensory stimulation in the periphery per se. This fact makes the findings of Experiments 5 and 7 even more interesting, because the increase in the degree of inhibition found in noise (for neutral trials in particular) would suggest that the stressor is resulting in a greater degree of attentional commitment to the periphery. Although these results are significant, they are of course very small. Noise can be seen in these experiments as enhancing the amount of resources directed to high probability environmental signals. As discussed in Section 5.2.2, the fact that the effect is limited to neutral trials is not contradictory to the hypothesis that noise biases attention towards high-priority sources. This is because neutral trials produce a greater and more consistent amount of inhibition in quiet conditions too, and thus form a better baseline for the study of such effects. Clearly though, as this is a relatively minor aspect of performance it would benefit from further research. In fact the size of these effects underlines the need for the use of sensitive experimental techniques to detect effects of stress on performance.

However, as was discussed in Section 2.3, an equally valid interpretation of the above effects is that they are related to a perceived change in salience and strategy, rather than arising out of some kind of unavoidable attentional restriction. The issue is whether changes under noise occur in some kind of mechanistic or "automatic" manner or as a result of some kind of higher level decision making process. Fisher (1986) makes a distinction between the two approaches by giving the example of driving too close to the car in front in conditions of fog. A direct-hit model would assume that fog changes driving behaviour directly by, say, increasing arousal resulting in faster driving. A strategic model would argue that the driver travels faster because he has the goal of getting home before the fog worsens.

Many researchers in the field have welcomed the notion of strategy change (e.g. Broadbent 1983; Smith 1983a; Jones 1984; Fisher 1986) generally because experimental studies have shown that factors such as changed level of task difficulty, changed probability of the need for action and changes in prior experience may reverse or abolish effects. However, as will be discussed below, it is not always easy to decide whether an effect is strategic or mechanical in origin (see Smith 1983b).

Posner (1978) likens orienting to "set" (Gibson 1941) and defines it as "an active process that arises from the subjects' knowledge about the nature of the input they will receive." (p. 186). In a similar manner Posner (1980) describes orienting as an active alignment of attention. Despite these definitions, it was argued in Section 2.4 that orienting would not be subject to strategic changes in performance under noise. This was because it was not thought likely that orienting operated on a level which would be affected by policy decisions concerning target salience. Thus if noise affected orienting, it would suggest that the effect of the stressor was, if anything, mechanical in nature rather than strategic.

The fact that many of the results in this thesis are either small or negative would support this view. If noise affects attentional selectivity by unavoidably restricting attentional scope then a strict mechanistic view of the effects of noise on performance is untenable. Otherwise, noise would have resulted in a greater degree of commitment of attentional resources to a probable location in the experiments using alerting cues. Only when these cues are absent perhaps does the subject have to adopt a strategy which is susceptible to noise.

Whatever the case, such changes in responding must be a reflection of a subtle and complicated alteration in some of the components of performance rather than a simple increase in attentional efficiency per se. It is clear that no simple model of the effects of noise on performance is sufficiently robust to account for such a pattern of changes.

7.3.2 Concluding Discussion

The effects of noise upon human performance have led to controversy, disagreement and confusion over the years. This is the all too constant and pessimistic conclusion of most reviewers. Gulian (1973) stated that "no firm conclusions can be drawn" from research in the area (p. 363), and later, Loeb (1980) arrived at a similar position, arguing that he doubted whether things were much better seven years on (p. 317). All reviewers agree on this one fact, that nothing except inferences of the most general kind can be drawn from the majority of research in the area of noise and performance. This is because the effects of noise vary widely under the influence of three important variables: The type of noise used, the multiplicity of tasks upon which performance has been measured, and subject factors. Because of this, Broadbent (1981) argues that the majority of work in the area has been "critical and destructive" (p. 182) and has not helped in the advance towards a general theory. The data presented in this thesis have gone some way to outlining the importance of one aspect of task structure in particular and relating it to the way in which environmental stimulation may affect performance. Systematic investigations of the effects of individual variables must be conducted if a more detailed pattern of the "noise state" (Hockey 1984) is to emerge.

Some recent broad-based models have been put forward in an attempt to bring together the many disparate results that have emerged from noise research. As discussed in Chapter 2, Smith (1983a) has recently presented one such formulation. He argues that in noise the allocation of effort will move towards the particular operation that appears to repay best the investment of effort. In other words he suggests that noise will alter the mechanism used for selecting strategies of performance, so that the strategy more likely to be adopted becomes almost certain to be so in noise. Such an explanation would go a long way to account for the type of selectivity effects discussed in Chapter 2, which often show how non-dominant or secondary parts of a task are more likely to be impaired in noise. For its predictive power such a theory relies upon the fact that the most likely strategy of performance can be identified prior to task onset. Because it rightly admits the possibility that a subtle (and sometimes unforeseen) combination of task factors, the perception of those factors, <u>and</u> the sets of priorities under which subjects work can affect the particular strategy adopted, this can be rather weak.

Fisher (1986) explains how in any theory of the effects of noise on performance it is difficult to distinguish between variables of "choice" such as the above, and more mechanical or "direct hit" variables as being the major sources responsible for alterations in performance. Hockey and Hamilton (1983) make a similar point, defining strategic performance variables as those which are peculiar to the task situation and its demand characteristics, and structural variables such as changes in the operating parameters of the human information processing system. At the same time they point out that any such distinction as this is difficult to sustain in practice because people are interactive and flexible processors of information, where intake and output are subject to both strategic and structural factors. Fisher (1986) argues that strategic responses, characterised by policy and style decisions, provide the base features of all behaviour in stress, while mechanical effects directly overlay and colour these decisions.

It is clear that to a large extent such variables are open to individual interpretation. Hockey and Hamilton (1983) suggest that attentional selectivity and changes in the balance of the speed/accuracy trade off are reflections of strategy changes, whereas, for example, changes in the capacity of short-term memory are indicative of alterations of a more structural nature. It is equally likely though that strategic factors are involved in affecting the action of noise on memory. This possibility was raised by Smith (1983b). He showed how performance on a running memory task of the type used by Hamilton, Hockey and Rejman (1977) could be interpreted either in terms of the direct effect of noise on storage, or changes in the precise strategy used to do the task. As Fisher (1986) points out, it is difficult to see how any experimental evaluation of the precise nature of noise-induced performance changes could distinguish between these two concepts.

One final point should be made when interpreting the results of a noise experiment. It is possible that data fit with one or several models proposed to account for noise effects. This was the case in a study carried out by Fisher (1984a). Her data were compatible with the view that noise absorbs mental capacity (see Section 7.3.1), but equally consistent with the idea of the operation of attentional strategies. She pointed out that these two explanations were not necessarily mutually exclusive, and that as demand increased, different strategies could be implemented. As Fisher (1984b) points out, there is often a tendency to seek single-factor explanations for performance under stress. This can result in a number of plausible sources of influence being ignored. To avoid this problem, she develops a composite model which assumes that any one stress has a number of influences, all of which can operate simultaneously. She argues that "the modes of influence identified are assumed to be only potential. Situational factors such as the task and the instructions may determine which modes actually operate to influence performance" (p. 132). Such a position would for example allow for the instability of the results of noise on multi-component tasks (see Section 2.2.3) without dismissing them as artifactual.

Despite a lack of clarity in the current state of noise research, and the earlier caution and pessimism noted amongst many in the area, the resolution of all debate in the field is not necessary for one to draw a relatively positive conclusion concerning the effects of noise on task performance. This is provided that, as in the experiments reported here, more detailed attention is paid to the nature of the factors that influence task performance. This is particularly true regarding the selectivity of attention. As demonstrated by the results reported in this thesis, it is likely that noise produces a particular state of responding within an individual, akin to a kind of behavioural homeostasis (Teichner 1968). There is a qualitative pattern of effects which are produced by noise; a pattern which is a reflection of a compensatory response on the part of the subject in an attempt to perform in the most optimal manner given the demands made upon his system.

It is apparent that sensitive research methodologies are necessary in order to measure these changes with any degree of accuracy. The way forward is clear: If we are to arrive at a place of greater clarity in the area of noise research, then greater care must be taken in all aspects of experimental design, and a research programme undertaken which systematically investigates the precise role played by the various factors involved. It is also important to educate researchers to abandon the search for single-factor explanations, and instead be prepared to appeal to more all-encompasing composite models.

Main Conclusions on the Effects of Noise on Orienting

1) Task and subject factors are of central importance in determining the outcome of a noise experiment.

2) Orienting tasks can provide a sensitive and suitable test-bench for the investigation of noise effects, but the "mechanical" effects of noise are absent or weak in the experiments reported here and are swamped by other alerting effects.

3) Noise may result in the adaptation of behaviour so that more attention is paid to situations of high priority and less to those of low priority, but these effects are minimal in this setting.

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APPENDIX 1

Instructions given for Experiments 1-2

"This experiment should last about 3/4 hour.* There will be a line of three boxes on the screen at all times, and your job is to press this space bar with your preferred hand as quickly as possible as soon as you see a small white dot appearing in either of the two outside boxes. Just before this dot appears an arrow will occur in the central box telling you which side it will come on. This arrow will be 80% reliable - that means it tells the truth 80% of the time. The dot will come in the opposite box for the remaining 20% of the time. Sometimes you will not get an arrow, but a plus sign instead. This means that the dot is equally likely to occur either side.** The gap between the warning signal and the dot will vary between 1/10th, 1/4, 1/2 and 1 whole second.* The same time delay will operate for 36 trials in a row and then you'll be offered a rest by the computer. Also, before each run of trials starts, you'll have a few to practise on. Occasionally you will get a warning signal but no dot will appear. This is to make sure you are waiting for the dot to appear. Don't respond on such trials.

One thing is very important, and that is that you keep your eyes on this central spot all the time. I'm measuring attention movements, not eye movements, so you must keep your eyes still. When the experiment is over, the computer will tell you. You can leave the room then. Is there anything you don't understand?"

* = Different for Expt 2   ** = Omitted for Expt 2

Instructions given for Experiment 3

"This experiment should last about an hour. There will be a line of boxes on the screen at all times, and your job is to press the space bar with your preferred hand as fast as possible as soon as you see a small white dot appearing in either of the two outside boxes. Just before this dot appears an arrow will occur in the central box telling you which side it will come on. This arrow is 80% reliable - that means it tells the truth 80% of the time. The dot will come in the opposite box for the other 20% of the time. Sometimes you will get a plus sign instead of an arrow and this means that the dot is equally likely to occur in either box. The gap between the warning sign an the dot will vary randomly between 1/10th of a second and 1 second. Occasionally you will get a warning signal but no dot. This is to make sure you are responding to the dot. Do not press the space bar on such trials. Before you begin you will get a few trials to practise on.

One thing is very important and that is that you keep your eyes on this central spot all the time. I am measuring how you move your attention, not your eyes. When the experiment is over the computer will tell you. Then you can leave the room. Is there anything you don't understand?"

Instructions given for Experiments 4-7

"This experiment will last about 20 minutes. There will be three boxes on the screen at all times in this experiment. Your job is to press the space bar with your preferred hand as soon as you see a small white dot appear in either of the outside boxes. These dots will come in groups of 10. Just before the run of trials begins, you will be shown an arrow pointing to the left or the right or a plus sign. The arrow means that 8/10 of the next set of dots will come on the side indicated. The plus sign means that 5 will come on each side. After each run of 10 dots you will be offered a rest. Please do not try and count your way through a sequence of dots.

One thing is very important, and that is that you keep your eyes on this central spot all the time. I'm measuring attention movements not eye movements, so you must keep your eyes still. When the experiment is over you will be told by the computer. You can leave the room then. Is there anything you don't understand?"

Instructions given for Experiment 8

These were identical to the above except that at the end of the first paragraph subjects were additionally told: "You will also be reminded about the most likely target position for the sequence of trials immediately before the dot appears."

Instructions given for Experiments 9-11

"In this experiment you will have to respond to a series of 5* dots occurring in one these two outside boxes. As soon as the dot appears on the screen you must press the space bar with your preferred hand as quickly as possible. You must keep your eyes on this central spot while these dots are appearing. This is very important. Now, before each group of 5* dots appears you will receive some information which will tell you where they are likely to occur. This will be in the form of 5* warning signals, one for each dot in a sequence. If they are arrows they mean that the dot is probably going to appear on the side indicated. 80% of the time these arrows tell the truth. A plus sign means that the dot is equally likely to occur either side. I want you to remember these symbols as they will help you when the dots appear. You will have 8 seconds* to memorise the sequence and you can do this any way you wish. Then the sequence will disappear and the three boxes will appear with the run of dots. Just before the dots appear you will receive a brief flash in the central box.** You will be offered rest periods every now and then and the computer will tell you when the experiment is over. You may leave the room then. The whole thing should last about 3/4* hour. Is there anything you don't understand?"

* = Not for Expt 10

** = Not for Expt 11

APPENDIX 2

REACTION TIMES AND STANDARD DEVIATIONS

Experiment 1:

		Valid	Neutral	Invalid
QUIET	SOA 100	313	344	338
		35.2	32.8	37.3
	SOA 250	291	317	337
		29.4	35.9	34.1
	SOA 500	284	314	333
		22.9	20.1	32.8
	SOA 1000	301	324	351
		22.5	29.5	32.8
NOISE	SOA 100	312	348	359
		36.3	39.0	45.5
	SOA 250	295	318	341
		29.1	33.9	41.1
	SOA 500	293	325	342
		25.1	27.2	30.4
	SOA 1000	307	334	358
		29.1	28.9	30.8

Experiment 2:

		Valid	Invalid
QUIET	SOA 80	332	363
		73.9	105.8
	SOA 120	333	380
		55.8	90.5
	SOA 160	318	361
		63.3	80.8
	SOA 200	322	372
		57.4	94.9
NOISE	SOA 80	331	364
		78.6	98.3
	SOA 120	315	364
		66.7	85.1
	SOA 160	325	371
		60.3	93.9
	SOA 200	363	378
		75.3	98.9

Experiment 3:

		Valid	Neutral	Invalid
QUIET	SOA 100	382	396	395
		59.8	52.2	64.8
	SOA 250	331	344	360
		38.5	42.4	48.3
	SOA 500	324	347	365
		48.5	44.1	56.1
	SOA 1000	349	365	396
		59.8	55.5	52.4

		Valid	Neutral	Invalid
NOISE	SOA 100	376	394	391
		40.2	47.7	37.8
	SOA 250	329	343	352
		36.7	36.5	41.2
	SOA 500	321	343	361
		36.9	47.5	42.5
	SOA 1000	338	361	389
		36.8	41.9	49.3

Experiment 4:

	Valid	Neutral	Invalid
POS 1-2	326	354	397
	46.0	42.8	77.5
POS 3-4	288	301	349
	36.8	50.4	41.25
POS 5-6	287	289	321
	30.7	38.1	44.3
POS 7-8	291	289	322
	30.4	37.2	32.9

Experiment 5:

		Valid	Neutral	Invalid
QUIET	POS 1-2	313	329	371
		65.9	66.6	85.7
	POS 3-4	278	287	306
		52.9	46.1	46.5
	POS 5-6	277	279	287
		44.6	39.4	38.4
	POS 7-8	275	275	285
		37.5	41.6	35.1
NOISE	POS 1-2	303	329	366
		52.8	55.1	44.2
	POS 3-4	279	285	312
		37.6	33.4	34.2
	POS 5-6	268	280	307
		32.2	26.1	31.5
	POS 7-8	277	284	296
		26.6	33.8	30.6

Experiment 6:

		Valid	Neutral	Invalid
QUIET	POS 1-2	315	330	366
		37.9	31.9	47.9
	POS 3-4	301	306	318
		31.6	34.3	39.9
	POS 5-6	303	309	330
		28.9	25.8	41.9
	POS 7-8	313	317	332
		44.6	36.7	34.6

		Valid	Neutral	Invalid
NOISE	POS 1-2	319	319	351
		32.8	23.7	40.2
	POS 3-4	301	302	325
		23.3	32.1	36.3
	POS 5-6	301	306	323
		20.4	29.6	44.5
	POS 7-8	303	311	316
		32.7	30.8	35.7

Experiment 7:

		Valid	Neutral	Invalid
QUIET	POS 1-2	289	308	368
		30.3	40.1	64.5
	POS 3-4	274	286	293
		22.1	25.7	35.7
	POS 5-6	272	283	291
		23.8	25.4	29.7
	POS 7-8	276	281	296
		22.9	22.1	31.7
NOISE	POS 1-2	292	317	344
		33.5	36.5	54.5
	POS 3-4	278	285	310
		29.3	30.6	46.7
	POS 5-6	276	295	307
		32.1	27.6	34.4
	POS 7-8	278	286	297
		30.9	32.1	45.3

Experiment 8:

		Valid	Neutral	Invalid
QUIET	POS 1-2	259	271	311
		22.5	31.1	46.2
	POS 3-4	266	273	293
		31.6	27.6	39.5
	POS 5-6	263	274	295
		29.3	33.2	41.5
	POS 7-8	263	268	297
		30.2	26.6	50.8
NOISE	POS 1-2	265	278	303
		29.6	34.9	41.9
	POS 3-4	262	275	303
		30.1	35.5	45.4
	POS 5-6	265	280	290
		34.7	34.3	45.7
	POS 7-8	274	282	306
		31.9	35.9	52.6

Experiment 9:

		Valid	Neutral	Invalid
QUIET	SOA 100	291	317	343
		44.2	46.4	52.5
	SOA 250	282	307	344
		30.3	31.5	42.2
	SOA 500	296	316	358
		42.6	42.9	41.8
	SOA 1000	319	347	387
		57.1	62.5	52.8
NOISE	SOA 100	285	306	344
		33.7	38.8	38.9
	SOA 250	283	309	345
		37.7	37.5	49.8
	SOA 500	284	310	363
		36.3	45.1	50.5
	SOA 1000	306	336	379
		38.1	37.0	40.1

Experiment 10:

		Valid	Neutral	Invalid
QUIET	POS 1	281	301	368
		42.0	58.7	110.2
	POS 2	284	301	362
		43.0	51.6	92.5
	POS 3	278	297	337
		46.6	50.1	72.6
	POS 4	281	283	323
		32.5	98.6	95.3
	POS 5	281	302	339
		41.2	51.3	76.7
	POS 6	283	296	314
		42.0	46.9	75.5
NOISE	POS 1	279	295	360
		31.1	42.9	53.8
	POS 2	271	284	353
		30.2	35.6	75.3
	POS 3	265	282	311
		27.5	36.7	57.3
	POS 4	268	280	309
		28.4	37.2	48.9
	POS 5	269	281	297
		30.4	51.2	50.2
	POS 6	275	295	304
		27.2	43.0	58.3

Experiment 11:

		Valid	Neutral	Invalid
QUIET	POS 1	363	374	414
		62.1	54.1	54.3
	POS 2	279	296	324
		32.7	27.1	52.4
	POS 3	278	303	326
		23.7	32.7	38.8
	POS 4	276	291	316
		22.8	34.3	68.0
	POS 5	269	304	302
		26.8	37.2	47.8
NOISE	POS 1	359	385	407
		60.9	51.8	51.9
	POS 2	283	308	339
		32.3	38.9	55.4
	POS 3	279	308	333
		29.7	42.5	62.4
	POS 4	280	305	319
		31.8	32.4	64.2
	POS 5	276	296	322
		25.9	33.5	70.9