Components of orienting in visual space

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ABSTRACT

Components of Orienting in Visual Space

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Experiments were conducted to investigate the alignment of attention with a location in visual space as the result of either an internal search plan or an external stimulus event; namely internally- and externally-controlled orienting. First, if an informative cue is presented to fixation indicating the probable location of a subsequent target to appear in the visual periphery within the next 1000 msec, the detection response is faster to a target appearing in that location than to one appearing elsewhere, even in the absence of eye movements (internally-controlled covert orienting). Second, a brief non-informative cue presented in the visual periphery also speeds the detection response to a target if it appears 100 msec after and in the same location as the cue, compared to a different location (externally-controlled covert orienting). In addition to the facilitation of manual responses, a target from the same location in the periphery as the cue appears to occur earlier than one from a different location, for intervals between the cue and the target of up to 500 msec. Although temporal judgments are unaffected at longer cue-target intervals, both manual and ocular responses are slower to a target appearing between 300 and 1300 msec after a cue in the periphery and in the same location than to one in a different location. This inhibitory effect requires that the cue and the target share environmental, but not necessarily retinal, co-ordinates and occurs regardless of whether or not the first event (the cue) requires a response. Externally-controlled orienting is a necessary but insufficient condition to produce inhibition, as the alignment of either the attention or the eyes with the previously-stimulated location can overcome the effect. However, not every event in the visual periphery results automatically in externally-controlled covert orienting. It can be reduced, delayed or even prevented by additional information present in the visual field, or by the requirements of secondary tasks. The facilitatory and inhibitory components of externally-controlled orienting appear to act together to direct the eye movement system and to maintain selectivity in visual space.

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DECLARATION

I hereby declare that the work in this thesis is entirely my own and that no part has been previously submitted for a degree in this or any other university.

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CHAPTER 1

Introduction

1.1 Historical Background

In 1866 Helmholtz described an experiment where

> 'the attention is entirely independent of the position or the accommodation of the eyes or, indeed, of any known variations in or on the organ of vision. Thus, it is possible, simply by a conscious and voluntary effort, to focus the attention on some definite spot in an absolutely dark and featureless field. In the development of a theory of attention, this is one of the most striking experiments that can be made.' (Reported in Helmholtz, 1925, p455)

Psychologists have long believed that visual attention can be shifted from one object to another without any discernable outward sign such as a change in eye position. The visual system as part of the limited-capacity human organism must be selective in its processing of information. Kinchla (1980) argued that the only consistent feature of attentional research is an interest in this selective aspect of information processing. James (1890) described selective attention as

> 'taking possession of the mind, in clear and vivid form, of one out of what seems several simultaneous possible objects or trains of thought. Focalisation, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others.'(p303-4)

Attentional research conducted since 1950 has largely been concerned with the issue of whether selective attention occurs at the <u>perceptual</u> (early) or <u>response</u> (late) stages of information processing. Early work on spatial selectivity includes Cherry's (1953) studies of dichotic listening and Sperling's (1960) partial report technique. In the dichotic listening experiments it was found that subjects were able to attend to information presented to one ear (or 'channel') and to ignore information presented to the other. Such findings led to perceptual selection models such as that of Broadbent (1958) which proposed a large-capacity sensory storage mechanism that maintained stimuli in a relatively unprocessed state for a short period of time. From this temporary storage, a filter (or device for allocating attention) selected certain stimuli for further processing or elaboration on the basis of some physical property, such as arriving at the eye, or coming from a certain location in space. A selection device was assumed to be necessary in order to prevent overloading of the limited-capacity central processing system. However, several later studies provided support for response selection models which propose that stimuli on 'unattended' channels are fully processed at the perceptual level, selection occurring at the response stage (for example, Deutsch and Deutsch, 1963). An experiment by Moray (1959) required subjects to shadow a message presented to one ear and to ignore a message presented to the other. Subjects occasionally noticed the inclusion of their own name in the unattended message which was taken by the late-selection theorists as evidence that all stimuli receive full perceptual analysis even when they are unattended. This interpretation was challenged by Treisman (1964) who argued that subjects who are instructed to attend to one channel are still influenced by a few features arriving on the other. Broadbent (1982) noted that 'getting a few features..is something very different from total analysis of the unattended'.(p259) Information from an unattended channel is therefore not blocked altogether, but is attenuated. A similar argument was proposed by Egeth (1977) who reviewed experiments in which subjects seemed unable to focus visual attention sufficiently to filter out interfering stimuli as far as five degrees from a centrally located target. The results appeared to be consistent with the idea that perceptual processes operate without attentional control but Egeth argued that the mere fact of interference does not indicate that a stimulus receives the same analysis when unattended as when attended. It is therefore not possible to conclude that subjects cannot filter irrelevant information as it may be that the interfering noise was filtered to some extent and that interference effects were less than they would have been if subjects had not been able to attend selectively.

Broadbent (1982) concluded that by 1970 filtering was seen as a strategy that enables subjects to perform well in tasks when interference would otherwise occur. For example, in situations involving large numbers of stimuli a subject who 'selects those events possessing a particular physical feature (such as location in a particular point in space) will be able to cope adequately with those events at the cost of knowing less about the remainder of the things that are happening'.(p259)

In recent years, research has uncovered some of the details of the processes involved in selectively attending to locations in visual space (for example, Grindley and Townsend, 1968; Posner, Nissen and Ogden, 1978). The important question is whether or not perceptual processing becomes more efficient as the subject is given more precise foreknowledge concerning the stimulus. For example, the subject may be asked to detect the presence of a light. In a single-set condition the subject is informed of the location in which the light will occur. In a multiple-set condition the subject is told that the light can occur in any one of a number of possible locations. It is assumed that if there is a performance difference between single- and multiple-set conditions, then this indicates that attention can be allocated selectively to spatial locations. However, these studies have led to a debate about the locus of the selectivity, which reflects the debate concerning the adequacy of general models of selective attention that have been developed since Broadbent (1958). For example, Shiffrin (1975) argued that selection occurs in short-term memory <u>after</u> early perceptual analysis has been completed. Others have demonstrated visual selectivity using tasks which place only trivial memory demands on subjects (for example, Bashinski and Bacharach, 1980), findings which are difficult to reconcile with a memory interpretation. These studies will be discussed in detail in section 1.4.

An important development in the field of attention in the late 1970s was the distinction drawn between automatic and controlled processing, based mainly on studies of visual search (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977). Automatic processing occurs 'without subject control, without stressing the capacity limitations of the system, and without necessarily demanding attention. Controlled processing is a temporary activation of a sequence of elements that can be set up quickly and easily but requires attention, is capacity-limited (usually serial in nature), and is controlled by the subject.'(p1, Schneider and Shiffrin, 1977) Although both the experiments and the conclusions drawn from them have been criticised (Broadbent, 1982; Ryan, 1983), the concept of automaticity has stimulated much recent research, especially on language and reading. The distinction between automatic activation and conscious attention made by Posner (1978) on the basis of the results from priming studies has been particularly influential. The next section includes a summary of his work.

1.2 Current Views of Attention

Posner (1978) proposed that the nervous system consists of functionally independent isolated processing systems or codes. These are the format by which information is represented (for example, physical or phonetic) and are sufficiently separate so that their time courses can be manipulated. They are brought into relation (or co-ordinated) through the use of an active attentional mechanism of limited capacity that might be identified with conscious awareness. Posner demonstrated that different codes of the same stimulus can be selected depending upon factors such as exposure duration, which could not be explained by a serial levels of processing viewpoint.

From priming studies he developed the idea of an automatic connection between a stimulus and various isolable codes activated by that stimulus. Psychological pathways were defined as the set of internal codes and their connections that are activated automatically when a stimulus is presented. For example, a subject was shown a pair of letters and asked to make a speeded decision on whether they were the same or different. They were preceded by a prime letter that was sometimes identical to one or both of the test letters. When the prime was identical to one of the test letters, reaction time was faster than when it was not identical. In addition, the benefit increased when the prime was reliably informative about the following letters. A smaller benefit was obtained when the prime was only rarely followed by a pair containing the same letter. When the prime was reliable there was also a cost for an invalid prime (that is, one that was not identical to either test letter) compared to a neutral condition in which there was no prime. From a study of the costs and benefits from priming a pathway, Posner argued that it is possible to separate the automatic activation of pathways from attentional processing. Automatic processes produce benefits without costs and occur with unreliable primes or with associations derived from experience. Attentional processes, however, take longer to develop, need reliable primes or specific instructions and give rise to both benefits and costs. Thus Posner proposed three formal criteria for assessing automaticity : Automatic processing occurs without intention, without giving rise to conscious awareness and without producing interference with other mental activity. These criteria give a more precise indication of automatic processing than those of Schneider and Shiffrin (1977), and have received much empirical support from single-word priming studies (for example, Neely, 1977) and from studies employing full sentence contexts (for example, Stanovich and West, 1981).

To summarise, automatic activation facilitates the processing of stimuli that share the same pathway. Such activation has no inhibitory consequences since the pathways are activated in parallel. However, when a subject begins to attend to an activated pathway the pattern is very different. Since attentional mechanisms are of limited capacity, both facilitation of the attended pathway and widespread inhibition of any other pathway occur. Posner (1978) presented experiments using a variety of dual-task probe procedures to investigate this second type of processing and to reveal the way subjects bring their expectations to bear upon automatic processes. He argued that stimulus detection and recognition, for example, result from the use of a single limited capacity system. 'Limited capacity in this sense refers to the characteristics of an isolable system that is so richly interacting that its efficient utilisation for the processing of a signal will usually reduce the efficency with which it can process any other signal.'(p123) The isolability of the central attentional system is important in that it implies that its time course can be manipulated experimentally, for example, by the use of warning signals, independently of the time for the activation of psychological pathways.

An important feature of conscious control therefore seems to be that it is primarily inhibitory. Posner considered that this was consistent with the basic nature of the nervous system which seems to provide inhibition from higher levels upon activity occurring at lower levels. The limited capacity central system is seen as serving an important controlling function by giving priority to particular pathways and thus preventing other pathways from having access. It is not tied to any specific mental operation, is independent of stimulus modality, and its time course can be manipulated experimentally by various chronometric techniques. Posner associated the processes of orienting and detecting with this mechanism of limited capacity. Before these are described in detail, a separate mechanism, that of *alerting* must be considered. The effects of alertness (both tonic and phasic) appear to be to reduce the time for the central mechanism to respond to the build-up of information about a stimulus (Posner and Boies, 1971; Posner, Klein, Summers and Buggie, 1973). Alerting effects, for example as produced by a temporal warning signal, are regarded as being independent of pathway activation. In a sense a stimulus has a cortical pathway that activates particular stored codes and a subcortical pathway that produces alerting. Pathway activation improves the build-up of information whereas alertness does not alter the sensitivity of sensory or memory systems. In reaction time tasks, increased alertness results in a reduction in reaction time but has little effect on error rate. However, providing a model of the stimulus to be received improves both speed and accuracy. Thus Posner distinguished alertness and *set* as separate components of attention. Set is considered as an active process that arises from the subject's knowledge regarding the nature of the stimulus to be received. Posner's recent work (1978; 1980; 1981) has been concerned with the study of simple detection tasks in which cognitive control, involving the operation of the limited capacity system, is used to select stimuli of high priority. His experiments investigated the 'most fundamental question one can ask about set', that is, how do we prepare to receive information from a particular location in space? Posner (1978) demonstrated that set for the location of a visual stimulus affects motor responses towards that stimulus and that set can also be achieved by 'orienting the central systems themselves without any overt response'.(p215) Thus the ability to move attention in visual space in the absence of eye movements was illustrated by costs and benefits from location cues.

Posner distinguished between the three internal mechanisms of alerting, detecting and orienting in the following way. Alerting has already been described as the overall activation level of the central processing system. Orienting is the aligning of peripheral or central mechanisms with a source of sensory input or an internal semantic structure stored in memory, whereas detection indicates that a stimulus has reached a level of the nervous system at which it is possible for a subject to report its presence. Posner (1978) provided evidence to suggest that there are differences between the modalities in their activation of the three attentional mechanisms. For example, detection of a visual stimulus occurs as a result of orienting towards the stimulus, whereas an auditory stimulus causes detection prior to orienting. Posner (1980) claimed that early work on the orienting reflex (Sokolov, 1963) failed to distinguish between the orienting and detecting processes. However, section 1.4 reviews work which clearly demonstrates that visual orienting can occur without detection, that is, the central mechanisms can be aligned with a potential stimulus source before a stimulus has occurred. Also experiments showing that subjects can orient with their eyes to stimuli that they are unable to bring to consciousness (Weiskrantz, 1980) provide further support for the dissociation between orienting and detecting.

To conclude, attentional research has been concerned with the mechanisms by which we prepare for and select stimuli from a source of information in the presence of competing stimuli from other sources. The work includes experiments on the concentration upon a particular sensory channel (for example, Broadbent, 1958) and more recently upon one location in visual space (Posner, 1978). Information that might compete with the selected stimulus source appears to be filtered or attenuated.

Posner's most recent work on visual orienting (Posner, Cohen, Choate, Hockey and Maylor, 1982) considered the concept of filtering in the light of the distinction between passive and active mechanisms (Posner and Snyder, 1975; Schneider and Shiffrin, 1977). The experiments were concerned with the ability to maintain concentration upon a source of sensory information for an extended period of time. Posner et al contrasted two possible views of the filtering mechanism involved. The first assumes that the filter is set actively but is maintained passively, that is, without using processing capacity, whereas the second emphasises the active nature of both components, so that effective filtering occurs only when central processing capacity is available. The results seemed to provide tentative support for the second view, that is, sustained concentration depends upon active orienting towards the selected stimulus source.

The experiments presented in this thesis were designed to investigate orienting in visual space following Posner's (1980) suggestion that further study of visual orienting 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.'(p4)

However, before reviewing previous work on visual orienting, several terms to be used throughout the thesis must be defined.

1.3 Definitions

First, a distinction is drawn between overt and covert visual orienting. Overt orienting refers to a change in the alignment of sensory receptors (that is, eye and head movements), whereas covert orienting refers to a change in the alignment of the central processing system. The second distinction is between symbolic and direct cueing and refers to the two experimental methods used in the thesis to indicate possible stimulus locations in the visual field. For example, both an arrow pointing to the left (presented to fixation) and a brief stimulus in the left visual field are used to inform the subject that a target stimulus may occur to the left of fixation. The arrow represents symbolic cueing as the subject must interpret the cue in order to know the cued location. The second type of cue provides a more direct indication of stimulus location without requiring the subject to know the meaning of arbitrary symbols such as arrows. Thirdly, visual orienting can be internally- or externally-controlled (Posner, 1980). For example, eye movements can result from an internal search plan or be driven by an external stimulus event (Kahneman, 1973). (However, in natural viewing conditions it is possible that this dichotomy is an oversimplification and that internally- and externally-controlled orienting form the extreme ends of a continuum.)

1.4 Internally-Controlled Orienting

The observations of Helmholtz described in section 1.1 have been confirmed by a number of recent experiments where subjects have been induced to shift their attention (but not their eyes) to specific locations in the visual field. Various experimental techniques have been used. Several studies have employed a paradigm based on Sperling's (1960) cueing technique and have demonstrated improved target identification following priming by a spatial cue. For example, Eriksen and Hoffman (1973) demonstrated that prior knowledge of spatial location improves the recognition of tachistoscopically-presented letters. They found that performance steadily improves with increasing delay between the location cue and display presentation up to 150 msec. Sperling and Melchner (1978) and Jonides (1980) used a visual search task to demonstrate that even in the absence of eye movements, subjects are able, upon instruction, to attend selectively to parts of visual arrays. The results of Engel (1971) from a task demanding high acuity indicated that selective attention can be decoupled from the line of sight by voluntary control. In an ingenious experiment, DelPezzo and Hoffman (1980) made use of a reflex-modification procedure to demonstrate that attention can indeed be directed away from the fovea. They presented a brief stimulus to various locations in the visual field, which inhibited an eyeblink elicited by a subsequent tap to the glabella (the region between the eyebrows). Subjects were able to move their attention towards and away from the location of the visual stimulus, thereby changing the amount of inhibition.

Bashinski and Bacharach (1980) employed a signal-detection task to examine the effects of selective attention on perceptual sensitivity. Visual signal-detection tasks are especially effective in assessing shifts in attention (Remington, 1978) and the analyses enable changes in sensory processing to be separated from changes in decision processes. Their results indicated that selective attention can enhance perceptual sensitivity without any change in response bias.

Several electrophysiological studies (for example, Eason, Harter and White, 1969; Van Voorhis and Hillyard, 1977; Eason, 1981) have revealed a clear and consistent enhancement of components of the visual evoked potential produced in response to stimuli at attended locations in space. Moreover, the results indicated that information from attended and unattended visual locations is in fact processed differentially as early as 100 msec after the onset of the stimulus. Behavioural and electrophysiological evidence thus converge on the conclusion that the human visual system has a mechanism for selectively processing information from attended spatial locations.

Probably the most extensive work on internally-controlled orienting has been conducted by Posner and his colleagues (Posner, Nissen and Ogden, 1978; Posner, 1980). They measured simple reaction time to the onset of a visual target, which could appear either to the left or to the right of a central fixation point. Before the presentation of the target, the subject was provided with a cue which was either an arrow pointing to the left or to the right, or a cross. The arrows correctly pointed to the target's location on 80% of the trials. The cross indicated that the target was equally likely to occur on the left as on the right. Reaction time was faster when the target appeared in the location indicated by the cue than on 'neutral' trials (when the cue was the cross). Furthermore, reaction time for the 20% of trials in which the arrow pointed in the wrong direction was slower than in the neutral condition. Thus Posner et al (1978) demonstrated both a benefit in processing for a 'valid' cue, and a cost in processing for an 'invalid' cue. They were able to discount two possible explanations for these results. First, the monitoring of eye movements during the task and the subsequent deletion of trials when movements occurred, showed that changes in detection speed were not associated with preparatory eye movements towards the expected target location. Secondly, because a simple reaction time task was used, the results could not be mediated by selective motor preparation.

Posner interpreted his results as being due to selective visual attention of limited capacity. Thus attending to one location requires the commitment of attentional resources to that location, which, since resources are limited, entails a reduction of resources at other locations. This separation of the benefits due to the subject's knowledge of where a stimulus might occur from the costs when it occurs at an unexpected location is an example of the 'cost-benefit analysis' described in section 1.2. The analysis was originally used in letter-matching studies (see Posner, 1978) but has been adapted for use not only in experiments on attentional allocation but also on movements of attention through visual space (Shulman, Remington and McLean, 1979; Remington and Pierce, 1982). For example, Shulman et al found that the shift of attention appears to take place within 500 msec following a cue indicating the most likely location of the target (either 18 degrees to the left or 18 degrees to the right of fixation). These shifts can be 'time-locked' to a central cue and the important result was that a probe stimulus located between the cue and the target received maximal benefit from attention at a time _prior_ to maximal benefit at the target. Such a result provides support for an 'analogue' model which supposes that attention moves in a continuous manner across the visual field. This contrasts with a 'discrete' model which assumes that moving attention involves the same type of suppression found in saccadic eye movements. These results were taken by Posner (1980) to indicate that when subjects are asked to commit attention to a particular location in space other than fixation, the instruction is executed by

> 'orienting a covert (attentional) mechanism that seems sufficiently time-locked to external events that its trajectory can be traced across the visual field in terms of momentary changes in the efficiency of detecting stimuli.'(p3)

Posner, Nissen and Ogden (1978) were also able to demonstrate costs and benefits when the response was an eye movement to a peripheral target. Subjects were given a symbolic cue indicating where in space the target was most likely to appear. Benefits in terms of reduced saccade latency occurred when the target appeared at the expected location and costs were found when the target appeared at an unexpected location.

However, there are two potential problems in interpreting these experiments as demonstrating capacity limitations. First, a decline in performance as stimulus uncertainty increases (for example, from valid to neutral trials) is generally assumed to indicate that several channels cannot be monitored as effectively as one. However, even if attentional capacity were unlimited, performance might still be expected to decline under certain conditions (Egeth, 1977). For example, in studies of visual search a present/absent judgment is made by integrating the information from all the relevant channels. As the number of channels increases, so does the probability of a response being triggered by noise in a channel not containing the target. It is unlikely, however, that this explanation could account for the results presented above, particularly from studies measuring reaction time to suprathreshold stimuli and from electrophysiological studies. Secondly, Duncan (1980a) and Mulligan and Shaw (1981) have pointed out that if a subject is biased towards one stimulus, the benefits enjoyed by this alternative may reflect not a preferential allocation of attentional capacity, but simply a willingness to decide in its favour with relatively little evidence. Thus it may be possible to describe Posner's results as being due to a reduced criterion at the expected target location. This explanation can be discounted for a number of reasons. Posner (1978) noted that knowledge regarding the spatial location of auditory and tactile stimuli is of no benefit, which

> '..helps to provide an answer to the view that visual cues may improve performance only because subjects are somehow reluctant to respond to information arising from an unexpected position in space. If this were so, all modalities should show a similar reluctance or bias. That they do not suggests that costs and benefits found in vision represent genuine advantages from orienting internal attentional mechanisms toward the input signal.'(p205)

The experiment by Bashinski and Bacharach (1980) mentioned above employed a visual signal-detection task within a cost-benefit analysis. Their procedure provides a means of separating changes in sensory and decision processes. A symbolic cue directed the subject's attention either to the left or to the right of fixation. The task was one of detection of near-threshold stimuli and the cue indicated with high, low or neutral validity the location at which the stimulus would occur. Receiver-operating characteristic curves were constructed from the subject's rating scales and target location judgments. Significant costs and benefits were found, supporting the view that selective attention can actually enhance perceptual sensitivity. However, the important result was that there were no overall differences in response bias among the three conditions (valid, neutral and invalid). Posner, Snyder and Davidson (1980) reported four experiments demonstrating ways in which expectancy improves performance at the expected target location. First, costs and benefits were reduced when the expected location remained constant throughout a block of trials, rather than being cued at the start of each trial. Second, information regarding stimulus _location_ affected performance but not information about stimulus _form_. Third, the costs and benefits in terms of reaction times were not associated with changes in accuracy. Fourth, subjects seemed unable to lower their criterion at two spatially-separate locations simultaneously. Posner et al concluded that

> 'a framework involving the employment of a limited-capacity attentional mechanism seems to capture these constraints better than the more general language of criterion setting.'(p160)

The costs and benefits associated with a spatial cue have been clearly demonstrated by Posner and his colleagues. It is therefore surprising that there are several studies in the literature which have failed to find effects on reaction time or threshold detection in apparently similar experiments. For example, Mertens (1956) measured the probability of detection of peripheral test flashes and found that it was

> 'disadvantageous to have special attention for the direction in which the flashes can be seen instead of general attention for the whole field.'(p1069)

Grindley and Townsend (1968) found that instructions to attend to a particular peripheral location had no effect on perception unless there were simultaneously exposed stimuli in other parts of the field. Shiffrin's (1975) view, mentioned in section 1.1, was based on the results of a number of studies involving different sensory modalities - visual (Shiffrin and Gardner, 1972), tactile (Shiffrin, Craig and Cohen, 1973), auditory (Shiffrin, Pisoni and Castaneda-Mendez, 1974), and mixed modality (Shiffrin and Grantham, 1974). He concluded that selective attention does not affect the accuracy of perceptual processing and that attentional effects arise in short-term memory. For example, Shiffrin and Gardner (1972) asked subjects to identify which of two letters was present in a briefly-presented four letter display. There were two conditions : simultaneous and sequential. All the letters were presented together in the simultaneous condition, whereas in the sequential condition the letters were presented one at a time in a fixed spatial pattern known to the subject. They argued that models assuming attentional control and limited capacity would predict an advantage for the sequential condition as processing capacity could be allocated separately to each letter. However, performance in the two conditions was very similar and it was concluded that the initial stages of visual processing occur without capacity limitation and attentional control. There are several possible explanations for these anomalies. Bashinski and Bacharach (1980) suggested that the demonstration of attentional effects is dependent first upon the ability of the particular experimental procedure to produce real changes in attentional allocation, and secondly on the type of measure used to index costs and benefits. They attributed the results of Mertens (1956) to the first factor, that is, to a failure to produce changes in attentional allocation. The second factor relates to experimental procedures in which the stimulus location is known exactly (that is, the cue is 100% valid), so that the results can only demonstrate benefits for an attended location, but offer no information about unattended locations. In addition, the assessment of benefits is accurate only if the neutral condition controls for factors that may affect responses such as the alerting properties and the processing demands of the cue. Sperling and Melchner (1978) pointed out serious methodological flaws in the Grindley and Townsend (1968) study, the major problem being that different (unreported) exposure durations were used in the single and multi-element displays, making a comparison between them difficult. Several investigators have attempted to explain the results of Shiffrin and Gardner (1972) (for example, Beck and Ambler, 1973; Duncan, 1980b). First, the visual angles involved were very small (less than 1 degree). It is possible that attention improves performance primarily outside of the fovea. The visual system processes stimuli in detail at the fovea and so it may not be possible for attention to increase foveal sensitivity. Second, their experimental procedure in the sequential condition probably did not allow selective attention to take place. In the light of recent evidence (Shulman, Remington and McLean, 1979; Sperling and Reeves, 1980) it seems unlikely that 40 msec per stimulus was adequate in order for 'attention switching' to occur. Unfortunately, in an attempt to increase possible switching time Shiffrin and Gardner included a condition which required subjects to divide their attention between two locations either side of fixation, a task which subjects seem unable to carry out (Posner, Snyder and Davidson, 1980).

It can be concluded that in the absence of eye movements, attention can be moved around the visual field in accordance with instructions ('internally-controlled covert orienting'). Possible reasons have been given for the failure of a few studies to demonstrate this ability.

1.5 Overt and Covert Orienting

What is the relationship between these shifts of attention (covert orienting) and the saccadic eye movement system (overt orienting)? Saccades provide a fast and accurate means of bringing foveal vision and therefore high acuity to potentially interesting areas of the periphery. However, the previous section has shown that spatial selectivity can occur in the absence of eye movements; that is, changes in the allocation of attention from one location to another can affect the perception of visual stimuli. This suggests that the movement of attention through visual space is not under the complete control of the saccadic eye movement system. An alternative might be that the two systems are entirely separate and independent. A more moderate position is provided by 'efference theory', described by Klein (1980), which proposes that in order to move attention to a particular location in space, the subject prepares to make an eye movement to that location. However, experiments reported by Rayner, McConkie and Ehrlich (1978), Posner (1980 and 1981), Klein (1980) and Remington (1980) provide evidence in favour of a less restrictive view of the relationship; that is, eye movements and attention are both summoned by important peripheral stimuli and so have a _functional_ but not a physiological relationship. The most important work has been that of Remington (1980) using a detection - threshold paradigm. His subjects attempted to detect brief stimuli which occurred at different locations in space and at various times relative to an eye movement. The results showed that attention moves to the target location for an eye movement _prior_ to the eye leaving the fixation point. The attention movement takes place within 50-100 msec following the peripheral target presentation which represents a similar time course to that observed by Wurtz and his colleagues for selective enhancement of collicular units in monkeys. A number of physiological studies (for example, Goldberg and Wurtz, 1972; Wurtz and Albano, 1980; Wurtz, Goldberg and Robinson, 1980; Fischer and Boch, 1981) have suggested that there is a close relationship between the mechanisms responsible for saccades and shifts of attention. Cells in the superior colliculus of the monkey appeared to be involved in both saccadic eye movements and shifts of visual attention. When a peripheral stimulus was the target for a saccade, some cells whose receptive field included the target location responded with increased activity to the stimulus 40-50 msec following its onset. No enhancement was observed to stimuli in the receptive field of a cell when the monkey was making an eye movement to another location. The enhanced response of these collicular cells was time-locked to the onset of the movement cue rather than to the saccade itself. No enhancement occurred during spontaneous saccades. Indeed, Remington (1980) also found that human attentional movements were more closely tied to the onset of relevant peripheral stimuli than to eye movements. When a peripheral stimulus elicited an eye movement, an attention movement also occurred which did not appear to be under the subject's control. However, when eye movements were generated in response to a symbolic cue at the fovea no shifts of attention were found prior to the saccade. These results suggest that there is a closer relationship between peripheral stimuli and attention than between attention and eye movements.

Posner (1980) concluded that the relationship between overt and covert orienting is a functional one and

> 'often depends more upon the presentation of an important peripheral event than on the eye movement toward that event.'(p19)

When eye movements and attention are coupled by the appearance of a peripheral stimulus, the movement of attention occurs before the saccade.

1.6 Externally-Controlled Orienting

Engel (1971) distinguished between internally- and externally-controlled orienting in the following way:

> 'In daily life only a very few visible objects around us are actually noticed. Some objects generally strike the attention and as a consequence are seen, while most others are overlooked unless our attention is directed towards them. Apparently our attention performs an information selection. The factors influencing this selection process can be divided into object factors and subject factors, termed external and internal determiners of attention...'(p563)

Remington (1980) concluded that relevant stimuli in the peripheral visual field trigger both a saccade and a shift of attention, and that 'to some degree' the attentional movement automatically follows the presentation of a significant peripheral stimulus. A similar observation was made by Flowers, Polansky and Kerl (1981) who noted that certain familiar visual stimuli 'automatically' direct attention to particular locations within a display. However, the first experiments on externally-controlled orienting were conducted by Jonides (1976). He demonstrated that a peripheral stimulus can 'involuntarily capture' a subject's attention. Target presentation was preceded by a direct cue (a brief visual stimulus that could occur to the left or right of a central fixation point). Simple reaction time was faster when the target occurred on the same side of the visual field as the cue than when it appeared on the opposite side. Further work by Jonides (1981) attempted to compare internally- and externally-controlled orienting. Subjects were induced to shift their attention (but not their eyes) through the use of two types of visual cue (symbolic and direct) which were described in section 1.3. Direct cueing was shown to produce shifts of attention which were more consistent with a number of criteria for automaticity (to be described in chapter 5) than shifts produced by symbolic cueing. Jonides gave three possible explanations for this difference. First, direct cues can be more precise in their localisation of the cued position. Second, symbolic cues are less effective because they need to be interpreted (which requires time) before the cued location is known to the subject. Third, a peripheral cue 'effectively captures attention because it exploits a predisposition of the visual system to be especially sensitive to salient discontinuities off the fovea.'(p200-1) For example, recent work by Yantis and Jonides (1982) suggested that transient stimuli, that is, those with sharp temporal boundaries, engage selective visual attention 'perhaps automatically' through the activation of transient visual channels (see also Todd and Van Gelder, 1979).

An important issue concerning externally-controlled orienting is the question of automaticity. Jonides and Irwin (1981) commented that a recent focus of research has not been on attention but rather on its absence. It was noted in section 1.1 that several investigators (for example, Posner and Snyder, 1975; Schneider and Shiffrin, 1977) distinguished between processes that are under conscious or strategic control and those that are automatic. Posner and Snyder defined an automatic process as one that is rapidly developing and initiated without the subject's intention or awareness. In contrast, conscious processes are controlled by the central, limited-capacity processor and thus are characterised as slowly developing, intention-requiring processes that interfere with other activities. The evidence from the work of Jonides (1976 ; 1981) seems to indicate that externally-controlled orienting occurs automatically.

A second major issue concerns the consequences of externally-controlled orienting. These have been investigated by Posner and Cohen (1980). They presented subjects with three boxes, one on the left, one at the centre and one on the right of an oscilloscope screen. Subjects were required to fixate on the central box throughout the experiment. A trial began with the brightening of one of the peripheral boxes, chosen randomly, for 150 msec (a direct cue). Targets occurred at 0, 50, 100, 200, 300 or 500 msec following the onset of the cue and were dots appearing well above threshold usually inside the central box (probability = 0.6), but also inside either peripheral box (probability = 0.2). A small number of trials were catch trials when no target occurred. A simple detection response of a single manual key press to the appearance of the target was required. Trials when eye movements occurred were deleted from the analysis. Their results showed that targets occurring inside the cued peripheral box were responded to faster than those inside the opposite box for the cue onset - target onset intervals of 0, 50 and 100 msec. For the intervals of 300 and 500 msec however, this was reversed so that targets were responded to slower when they appeared inside the cued box than inside the opposite box. Responses to targets appearing in the centre were faster throughout which was to be expected because they would benefit from foveal processing and were more likely to occur there. Posner and Cohen argued that the initial advantage to the cued side was due to the summoning of attention by the direct cue. This effect was termed _facilitation_. However, this early advantage to the cued side was replaced by a subsequent _inhibition_ after attention had presumably returned to the centre (because targets were more likely to occur there).

They investigated some possible explanations for these effects. First, they found that facilitation and inhibition occurred regardless of whether the direct cue was the brightening or the dimming of the peripheral box. This demonstrated that facilitation cannot be explained by forward brightness enhancement. Secondly, concerning inhibition, it may be that after failing to find a target at the cued location, the subject switches attention to the alternative. In order to test this, they again used a central box, though it was surrounded by four boxes rather than two. The extra boxes were placed above and below the central box. Targets appeared inside the central box with a probability of 0.6 and in each one of the four peripheral boxes with a probability of 0.1. The cueing procedure was the same as in their original study. They found that there was the usual early advantage for the cued location which was replaced by a disadvantage with respect to the other three peripheral locations at the longer cue-target intervals. However, the location opposite the cued box was no faster than the locations above and below the central box, suggesting that the inhibitory effect is not due to the realignment of attention towards the opposite location. Also, a target occurring in the direction of the assumed attention movement from the cue to the centre is not necessarily at an advantage over targets in other locations.

To investigate further the nature of inhibition, Posner and Cohen returned to the simple three-box display and included trials in which both peripheral boxes were cued simultaneously. (No central targets appeared, so in order to 'summon attention back to the centre', the central box brightened 300 msec following the peripheral cue.) The results of the single-cued trials were as before. However, the double-cued trials showed reduced early facilitation but as much subsequent inhibition, in comparison with the single-cued trials. They suggested that the facilitation result was consistent with their previous work which showed that attention cannot be divided effectively either side of fixation (Posner, Snyder and Davidson, 1980). The finding of the usual amount of inhibition was taken as evidence that the inhibitory effect is directly due to the sensory stimulation rather than the result of attentional orienting produced by the cue. The final experiment reported by Posner and Cohen (1980) provided more support for this view. The subject's attention was directed towards a peripheral location using a symbolic cue presented to fixation. This was an informative arrow which told the subject that a target was more likely to appear at the cued location (probability = 0.8) than in the opposite location (probability = 0.2) if it occurred during the following 600 msec. After this however, the central box brightened to inform the subject that targets were now more likely to appear at the centre (probability = 0.6) than in the periphery (equal probability of 0.2 on the left and on the right). In this way, attention was first directed towards the periphery under internal control then brought back to the centre by its brightening and by the probability manipulation. The symbolically-cued peripheral location was initially facilitated but this disappeared after attention had been redirected towards the centre and was <u>not</u> replaced by inhibition. This supported their view that inhibition is a consequence of the peripheral stimulation and not of the previous directing of attention towards the periphery.

Posner and Cohen concluded that visual stimulation in the periphery both summons attention and inhibits the processing of further information from that location in visual space. Thus there appears to be a reciprocal relationship between attention and sensory processes. They suggested that this balance prevents overcommitment of the subject's resources to a cued location and is in line with the general tendency of the nervous system to use opposed mechanisms to maintain equilibrium. Because facilitation occurs in response to symbolic as well as direct cues, Posner and Cohen regarded it as attentional and the result of orienting to a visual location. The inhibitory effect, however, seems to depend upon the presentation of sensory information in the periphery, since it does not occur when attention is directed by a symbolic cue presented to fixation.

There are a number of possible explanations for the inhibitory effect observed in externally-controlled orienting. First, it may be a 'response inhibition' of the type described by Neill (1977) and Harvey (1980). Harvey investigated possible non-informative effects of cues by using the same stimuli as both cues and targets. Two neon bulbs were mounted, one above and the other below fixation. At the beginning of each trial one of the bulbs (chosen at random) was lit for a short period (the cue), which was followed after an interval by the target. This was the lighting of either the bulb which had acted as the temporal cue or the other (with equal probability). Thus subjects were required to avoid responding to the first light (the cue) but to make a speeded decision regarding the location of the second light (the target). Choice reaction time was slower when the target was the same light as the brief visual cue than when the cue and the target were different lights. This was interpreted as the effect of response inhibition to the cue still being present when the target appeared.

The second possibility is forward masking (for example, Breitmeyer and Ganz, 1976). Metacontrast refers to a particular type where the masking stimulus does not overlap spatially with the target. Averbach and Coriell (1961) demonstrated metacontrast in an experiment using Sperling's (1960) partial report technique. A letter display was presented briefly, followed after various intervals by a cue indicating one letter of the matrix which was to be reported. Performance was surprisingly poor when the cue was an unfilled circle surrounding the location of the target. The effect (termed metacontrast) was maximal for an interval of 100 msec between the letter display and the cue. However, Cohen (1981) provided several reasons why forward masking fails to explain the inhibitory effect observed by Posner and Cohen (1980). For example, inhibition lasts for at least 500 msec following a direct cue, which is well outside the range of forward masking effects and indeed facilitation is found at the time when masking normally occurs (0-100 msec). Also, metacontrast has been shown to have no effect on simple reaction time (Fehrer and Raab, 1962; Proctor, Nunn and Pallos, 1983).

The third possibility is that inhibition may be related to habituation. Singer, Zihl and Pöppel (1977) found that visual detection thresholds increased by up to 1 log unit when targets were repeatedly presented in the visual periphery. They concluded that 'these local changes in detection threshold reflect shifts in visual attention'.(p188) Frome, MacLeod, Buck and Williams (1981) also noted changes in threshold for repeated presentations of peripheral flashes which could not be due simply to retinal light adaptation. They referred to the effect as 'habituation to repetitive stimulation' because the loss of sensory excitability exhibited seven out of the nine characteristics of behavioural habituation listed by Thompson and Spencer (1966). The effects were quantitatively similar to those of Singer et al. However, the habituation observed by Frome et al was found not to transfer binocularly, which differed from the observations of Singer et al who observed complete binocular transfer, that is, presenting a stimulus to one eye influenced the threshold for a stimulus presented to the other eye. This difference led Frome et al to suggest that there may be more than one type of visual habituation in humans. Most of the experiments reported in this thesis were designed to investigate these possible explanations for the inhibitory effect.

1.7 Outline of the Thesis

Methodology common to a number of the experiments is described in chapter 2. Chapter 3 is concerned with replicating and extending the work of Posner, Nissen and Ogden (1978) on internally-controlled orienting. The remaining experimental chapters (4 to 8) investigate externally-controlled orienting, building on the work of Posner and Cohen (1980). Chapter 4 attempts to replicate their main findings and extends their technique to investigate the effects of peripheral stimulation on eye movements. The attentional nature of the facilitatory component and the question of automaticity are considered in chapter 5. Chapters 6, 7 and 8 investigate the nature of the inhibitory component and its relationship to facilitation. Finally, the significance of the effects observed and suggestions for future investigation are discussed in chapter 9.

CHAPTER 2

General Methods

2.1 Introduction

Many of the experiments to be reported in this thesis share similar apparatus and stimuli and so to avoid unnecessary repetition this chapter provides a description of the basic methods used. The appropriate section of this chapter will be referred to when an experiment is described and only procedural details specific to the particular study will be given in chapters 3-8.

2.2 Subjects

The subjects were undergraduates, postgraduates and staff at the University of Durham (including the author). All reported normal or corrected-to-normal vision. They were volunteers and were not paid for their participation.

2.3 Symbolic-Cueing Experiments

The experiments to be described in chapter 3 used a 'cue-target' technique for measuring voluntary movements of spatial attention. They involved the presentation of a symbolic visual cue which gave information about the probable location of a target. Simple reaction time to the target was then taken as a measure of the effectiveness of the use of the cue as a spatial and a temporal warning signal.

2.3.1 Apparatus

Timing, presentation of stimuli and the recording of responses were controlled by an IBM 1130 computer with a WDV interface. The computer generated the visual display through two Digital-Analogue-Converters (DACs) applying voltages to the X and Y amplifiers of a Tektronix 602 display oscilloscope (P-31 phosphor). A morse key connected to the digital input was used to measure reaction time to the nearest millisecond (msec). A chin rest was placed in front of the oscilloscope so that the subject's eyes were level with and 30 cms from the centre of the screen (see Figure 2.1). An angle-poise lamp placed at the back of the laboratory provided dim background illumination.

2.3.2 Stimuli

A permanent central fixation point was provided by a small black 'Letraset' spot (1 mm diameter) on the oscilloscope. The cues all appeared well above threshold in the centre of the screen immediately behind the fixation point. These were arrows and crosses occupying 1 degree of visual angle. Targets were slightly smaller (0.6 degrees of visual angle across) and were squares of 25 dots of the same intensity as the cues. (The stimuli

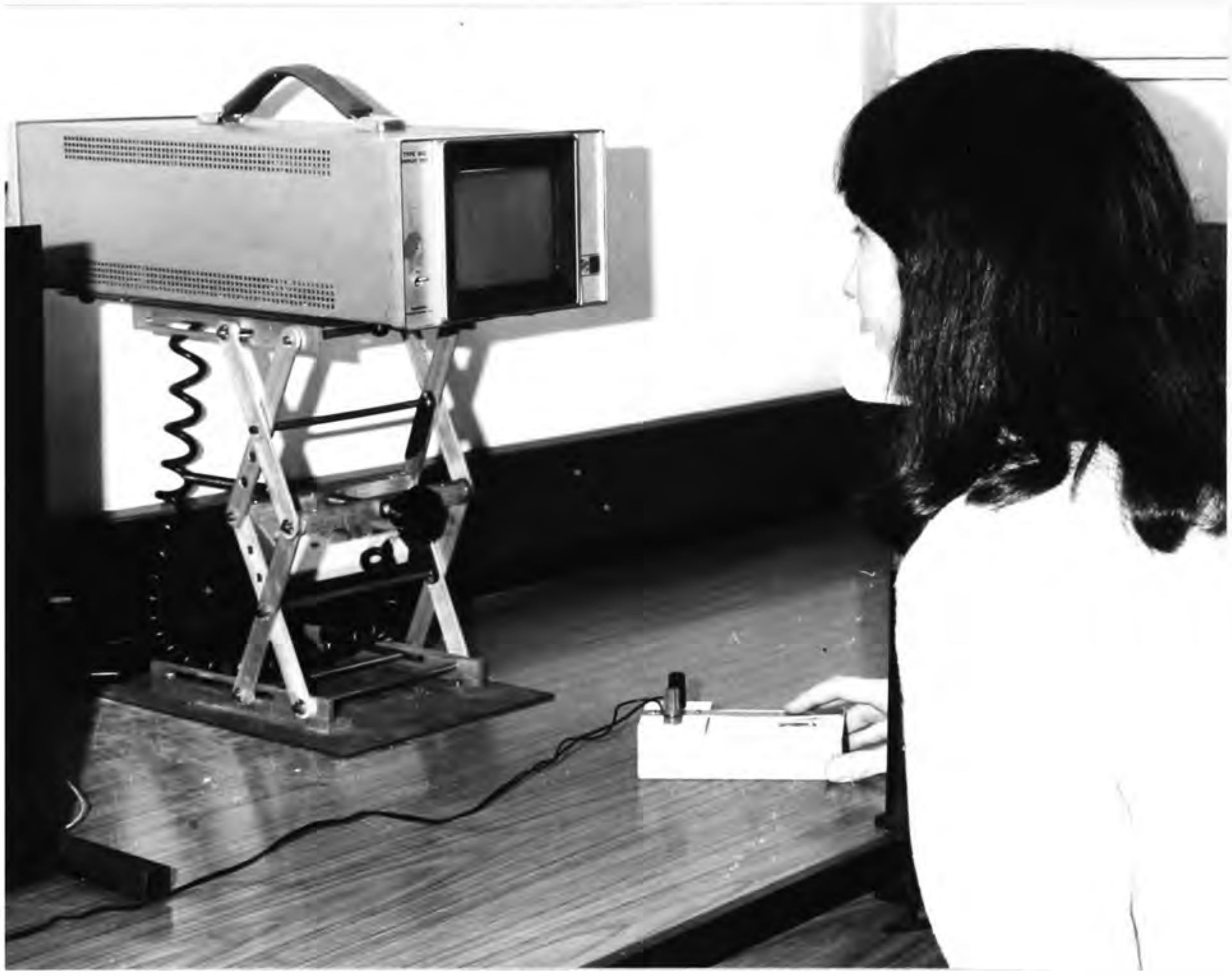


Figure 2.1 Set-up for experiments where stimuli were displayed on an oscilloscope.

are illustrated in Figure 2.2.) Some procedural details and reminders to the subject were also presented on the oscilloscope (see below).

2.3.3 Procedure

The subject was seated in front of the oscilloscope and the heights of the chin rest and the oscilloscope were adjusted so that the subject was comfortable with eyes level with the fixation point. The morse key was placed in a position to be operated comfortably by the forefinger of the dominant hand. Instructions were given informally by the experimenter and any queries regarding the subject's task were answered.

Experimental sessions were run in blocks of trials, each block being preceded by the presentation on the oscilloscope of information regarding the time in milliseconds between the cue and the target (for example, 'DELAY=1000'). Also there was a reminder that the eyes were to remain on the fixation point during the experiment, that is, 'N.B. Keep eyes on fixation point throughout block'. A key press by the subject started a block of trials. The instructions disappeared, to be replaced by a number of practice trials. The experimental trials did not begin until a further key press was made. At the end of a block the results were printed out in the adjoining room by the computer. These were in the form of medians, semi-interquartile ranges, means and standard

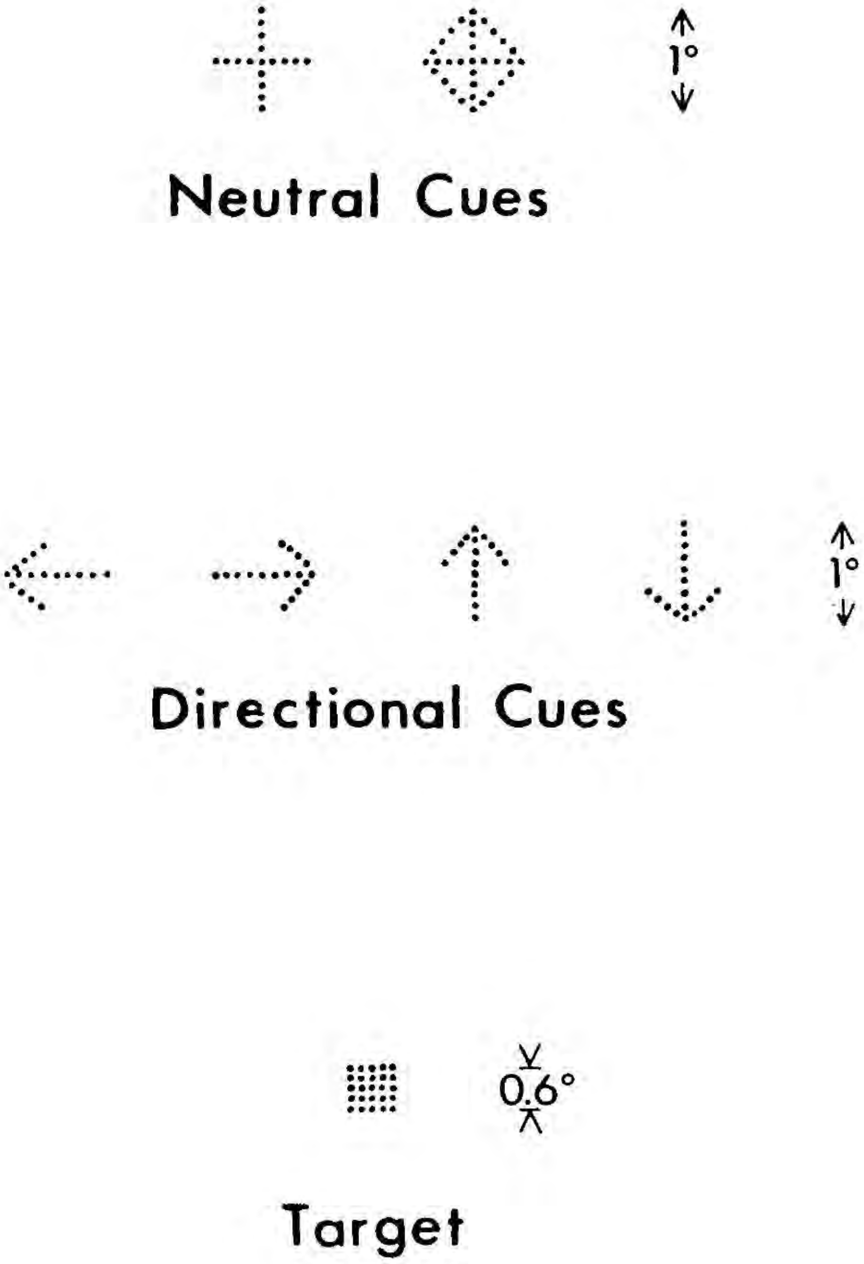


Figure 2.2 Stimuli used in symbolic-cueing experiments.

deviations of the simple reaction times for each combination of cue type and target position, in addition to error data.

Following an experimental session the aims of the experiment were explained to the subject and any questions were answered. In addition an indication of the subject's own performance was given.

2.4 Direct-Cueing Experiments

Chapters 4,5,6 and 8 include experiments which used a technique adapted from one originally devised by Posner and Cohen (1980) to produce externally-controlled orienting. Again a cue-target procedure was used.

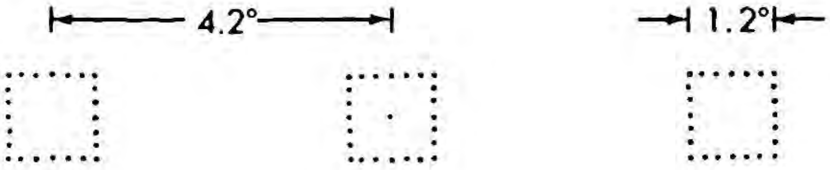
2.4.1 Apparatus

Some of the direct-cueing studies were conducted using the IBM 1130 computer as described earlier (section 2.3.1). Others, however, were run by a Computer Automation ALPHA LSI 2/20 minicomputer with a Cambridge Electronic Design (CED) interface. The only significant differences between the studies conducted on these two machines were (1) the reaction times were measured to the nearest millisecond in the IBM-run experiments but to the nearest centisecond in the ALPHA-run experiments; (2) subjects were seated 50 cms away from the oscilloscope in the experiments using the ALPHA, rather than 30 cms. The display parameters were altered to ensure that the visual angles involved remained the same. In addition, one direct-cueing experiment was conducted using a PDP 11/34 computer; this is described in detail in section 2.5.1. In all important respects there was no difference between the experiment run on the PDP computer and those run on the IBM computer.

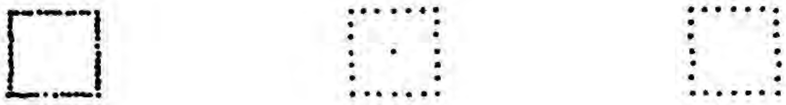
Again, analogue output to a Tektronix 602 display oscilloscope was used to present the stimuli. In the simple reaction time experiments a single key-operated microswitch connected to the digital input was used as the response key. In the choice reaction time studies button-operated microswitches mounted in a small box were used. The subject's head was again held in position by a chin rest. The laboratory was dimly illuminated either by an angle-poise lamp or by one of the room lights (though not the one directly above the subject).

2.4.2 Stimuli

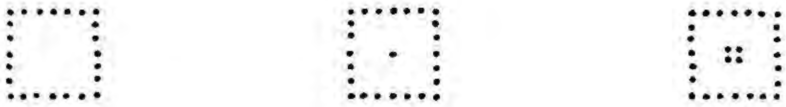
In most direct-cueing experiments to be reported, three square boxes and a central fixation point inside the middle box were generated by the computer and displayed on the oscilloscope throughout a block of trials. The positions and visual angles of the boxes are shown in Figure 2.3. 'Cueing' was achieved by displaying the intermediate points of a box in addition to those already displayed. Each point was displayed at the same



Initial Display



Left box cued



Target in right box

Figure 2.3 Example of stimuli used in direct-cueing experiments.

suprathreshold intensity level so that the effect of doubling the number of points in a cued box was one of brightening. Targets appeared as small squares of four dots at the centre of either the left or the right box.

2.4.3 Procedure

The experimental procedure was similar to that given in section 2.3.3. However, the information displayed before the start of a block was changed and there were no practice trials as such because of the use of an entire block as practice.

2.5 'LED' Experiments

The electrical and optical properties of Light Emitting Diodes (LEDs) have been described by Nygaard and Frumkes (1982) who recommended them as being convenient and inexpensive sources for visual experimentation. In chapters 6,7 and 8 experiments are reported which used LEDs as stimuli and in some cases as both the cue and the target.

2.5.1 Apparatus

Some of these experiments were controlled by the IBM 1130 computer, the LEDs being driven by the transistor register. Here the stimuli were mounted in a peg-board that was placed in front of the oscilloscope (see Figure 2.4). In this way the exact positions of the stimuli could be altered easily. The screen of the oscilloscope was covered by a piece of black card with a small hole (1 mm diameter) punched in the centre. The background illumination of the oscilloscope was set at maximum thus providing a bright yellow spot as the central fixation point. A key-operated microswitch was connected to the digital input.

Most of the LED experiments, however, were controlled by a PDP 11/34 computer using a CED laboratory interface. Timing of the experiments was controlled by interrupts from the interface clock running in milliseconds, and a key-operated microswitch generated interrupts using the external event function of the interface. The LEDs were driven by digital output and mounted in a black stand (see Figure 2.5). A chin rest was placed so that the eyes were directly in line and level with the central fixation point at a viewing distance of 30 cms. The LED experiments were all conducted in a very dimly-illuminated room, the only light source being a shaded angle-poise lamp at the back of the laboratory. In this way the rather crude method of mounting the stimuli (shown in Figure 2.4) was not obvious to the subject. In all important respects, the LED experiments controlled by the IBM and PDP computers were identical.

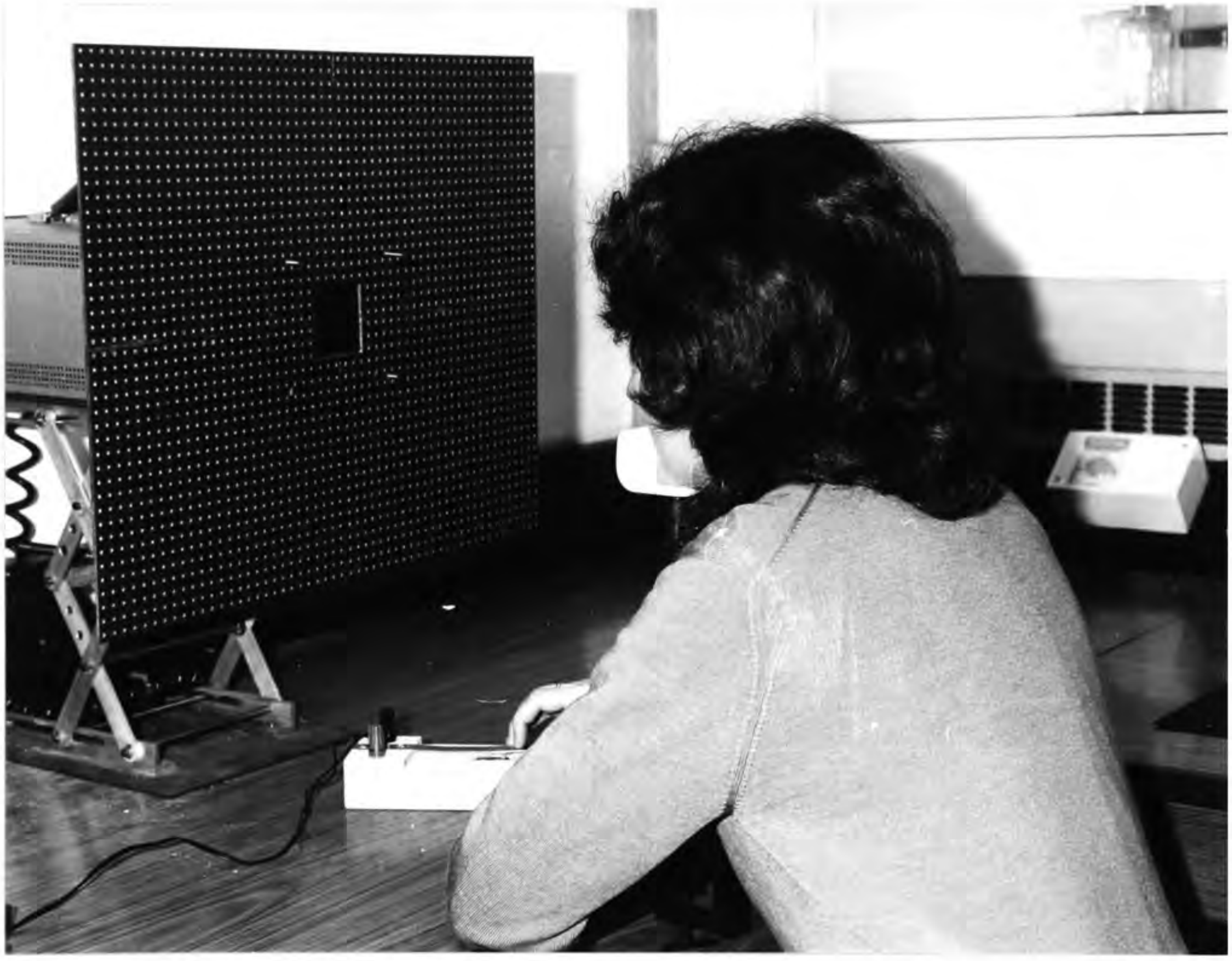


Figure 2.4 Method of displaying LEDs for experiments controlled by the IBM computer.

Figure 2.5 Method of displaying LEDs for experiments controlled by the PDP computer.

2.5.2 Stimuli

The LEDs were 3 mm diameter, thus subtending approximately 0.6 degrees of visual angle depending upon eccentricity. Red and occasionally green LEDs were used as cues and targets while a yellow one driven by a 9 volt battery acted as a central fixation point in the experiments using the set-up shown in Figure 2.5. The fixation point for the experiments controlled by the IBM computer (see Figure 2.4) has already been described in section 2.5.1.

2.5.3 Procedure

The LED experiments differed from those described previously in that all the instructions had to be delivered by the experimenter. This was because the oscilloscope was either almost completely masked (Figure 2.4) or not used at all (Figure 2.5).

2.6 Medians

In most of the experiments to be reported the measure of central tendency of reaction times is given by the median. Because of the positively-skewed nature of reaction time distributions (Ashby, 1982; Grice, Nullmeyer and Spiker, 1982), the median is a more appropriate description of the data than the mean. (Chapter 8 includes examples and a discussion of reaction time distributions.)

2.7 Speed-Accuracy Trade-Off

Both speed and accuracy were stressed in the instructions given to the subject. Following a practice session the subject was provided with feedback on performance so that an appropriate adjustment to the speed-accuracy trade-off could be made in order to keep the error rate low. (The actual rates for each experiment are given in the text.)

2.8 Eye Movements

Most of the experiments required the subject to fixate on a central point throughout a block of trials. Reminders were given frequently and the initial instructions stressed the importance of maintaining steady fixation. Because of the technical difficulties involved and the inconvenience to the subject, eye movements were not monitored. All the subjects reported that they had no difficulty in avoiding moving their eyes and the following two comments from Posner's work provide further justification for not directly monitoring eye movements:--

> 'After having found that movements of the eyes of more than one degree occurred on less than 4% of the trials (Posner, Nissen and Ogden, 1978) and that these trials did not in any way change the cost-benefit results of the study, we did not maintain careful monitoring of eye position in all subsequent studies, although we used the same instructions and training to suppress movements. When monitoring was instituted in some of the later studies, results were not

substantially altered by the eye movements that were detected.' Posner, Snyder and Davidson (1980), p162.

'In a luminance detection experiment, 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. They quickly recognise that it is an effort to move their eyes and that it does not help performance.' Posner (1980), p9.

CHAPTER 3

Internally-Controlled Orienting

3.1 Introduction

This chapter is concerned with some experiments which were designed to replicate and extend the work of Posner, Nissen and Ogden (1978), and Posner (1980) on voluntary movements of spatial attention. It was shown in chapter 1 that the importance of Posner's work was the introduction of a cost-benefit analysis and it is this approach that provides the basis for the present experiments.

Posner et al (1978) used differences in reaction time to targets at expected and unexpected locations in the visual field as a measure of the effect on simple detection of the alignment of attention towards an expected target location. The subject was presented with a cue at the beginning of a trial, which was a plus sign or an arrow pointing to the left or to the right. The plus sign indicated that a target was equally likely to occur to the left or to the right of a central fixation point (neutral condition). If an arrow was presented, the target would appear in the indicated direction with a probability of 0.8 (valid condition) but it could appear on the other side with a probability of 0.2 (invalid condition). The subject's task was to respond to the onset of the target by pressing a single key. The comparison of neutral trials with valid and invalid ones means that both the benefits from knowing where in the visual field a target will appear and the costs when it appears at a location other than the expected one can be measured. Their results were interpreted as being the direct result of selective visual attention of limited capacity. Thus attending to one location requires the commitment of attentional resources to that location and a corresponding reduction of resources to other locations.

The following experiments used this powerful cost-benefit analysis to separate the benefits of knowing the likely target location from the costs when the target appears at an unexpected location. Experiment 3.1 was designed to compare internally-controlled orienting in the vertical and horizontal dimensions, Posner's studies being confined to the horizontal only. Experiment 3.2 considered the consequences of non-informative symbolic cueing and the possible implications for further experiments on internally-controlled orienting. Finally, experiment 3.3 investigated the effects of the cueing (symbolically) of a single peripheral location on the detection of nearby targets in an attempt to define the spatial specificity of attentional allocation.

3.2 Experiment 3.1

The main aim of experiment 3.1 was to compare internally-controlled covert orienting in the horizontal and vertical dimensions. Heywood and Churcher (1980) demonstrated that eye movement latencies to peripheral targets (that is, externally-controlled overt orienting) are equivalent in the two dimensions. However, reading is an important and extensive human activity and a study by Chang (1981) indicated that it involves horizontal covert attentional movements. Therefore it might be expected that internally-controlled covert orienting would be more efficient in the horizontal than in the vertical dimension. Experiment 3.1 was also conducted in order to provide a partial replication of Posner, Nissen and Ogden (1978) and to establish quantitatively the effect of attending to a location in visual space for subjects and stimulus conditions typical of those used throughout the thesis.

3.2.1 Method

3.2.1.1 Subjects

Five subjects participated in three experimental sessions on separate days although only the data from the last two days were used in the analysis. Each session lasted approximately 40 minutes.

3.2.1.2 Apparatus and Stimuli

Most of the details are described in sections 2.3.1 and 2.3.2. The targets appeared 3.5 degrees to the left and right (horizontal condition) or above and below (vertical condition) the central fixation point. The neutral cue for three of the five subjects was the simple cross (see Figure 2.2). The cross within the diamond formed the neutral cue for the remaining two subjects. (The neutral cue was changed from the latter to the former type because of computer-programming difficulties. There was no reason to expect this to affect the results in any significant way.)

3.2.1.3 Design and Procedure

The general procedure is described in section 2.3.3. The first experimental session, which was regarded as practice, was divided into five blocks of trials of the horizontal condition followed by five of the vertical condition. The order of conditions in the two experimental sessions was approximately counterbalanced, three of the five subjects starting with the horizontal condition, and the remaining two with the vertical condition.

A block consisted of three practice trials, followed by 52 experimental trials. The blocks were presented in a random order and differed only in the interval between the cue and the target, or 'Stimulus Onset Asynchrony' (SOA), which could be 0, 100, 250, 500, or 1000 msec. This information was presented to the subject at the beginning of each block (e.g. 'DELAY=1000').

The timing of an individual trial is summarised in Figure 3.1. At the start of a trial one of the three cues for the particular condition under test appeared (for example, left arrow, right arrow or cross for the horizontal condition). This was followed after the SOA on 40 out of the 52 trials by the target, which disappeared along with the cue when a simple detection response of a single key press had been made by the subject. On a 'catch' trial, no target was presented and the cue remained on the screen for 3000 msec. An intertrial interval (ITI), randomly chosen from the range 1500 to 3000 msec occurred before the onset of the next trial.

The distribution of trials in a block for the two conditions is shown in Table 3.1. In each block there were 20 neutral trials when the target occurred on one side of the fixation point on 10 occasions, and 10 times on the opposite side. There were 20 directionally-cued trials, 10 pointing to one side and 10 to the other, the direction of the cue being valid on 8 trials and invalid on 2 for each direction. In addition there were 12 catch trials when no target occurred, merely the cue, that is, 6 neutral cues and 3 of each directional cue. The subject was required to withhold a response on these trials. The

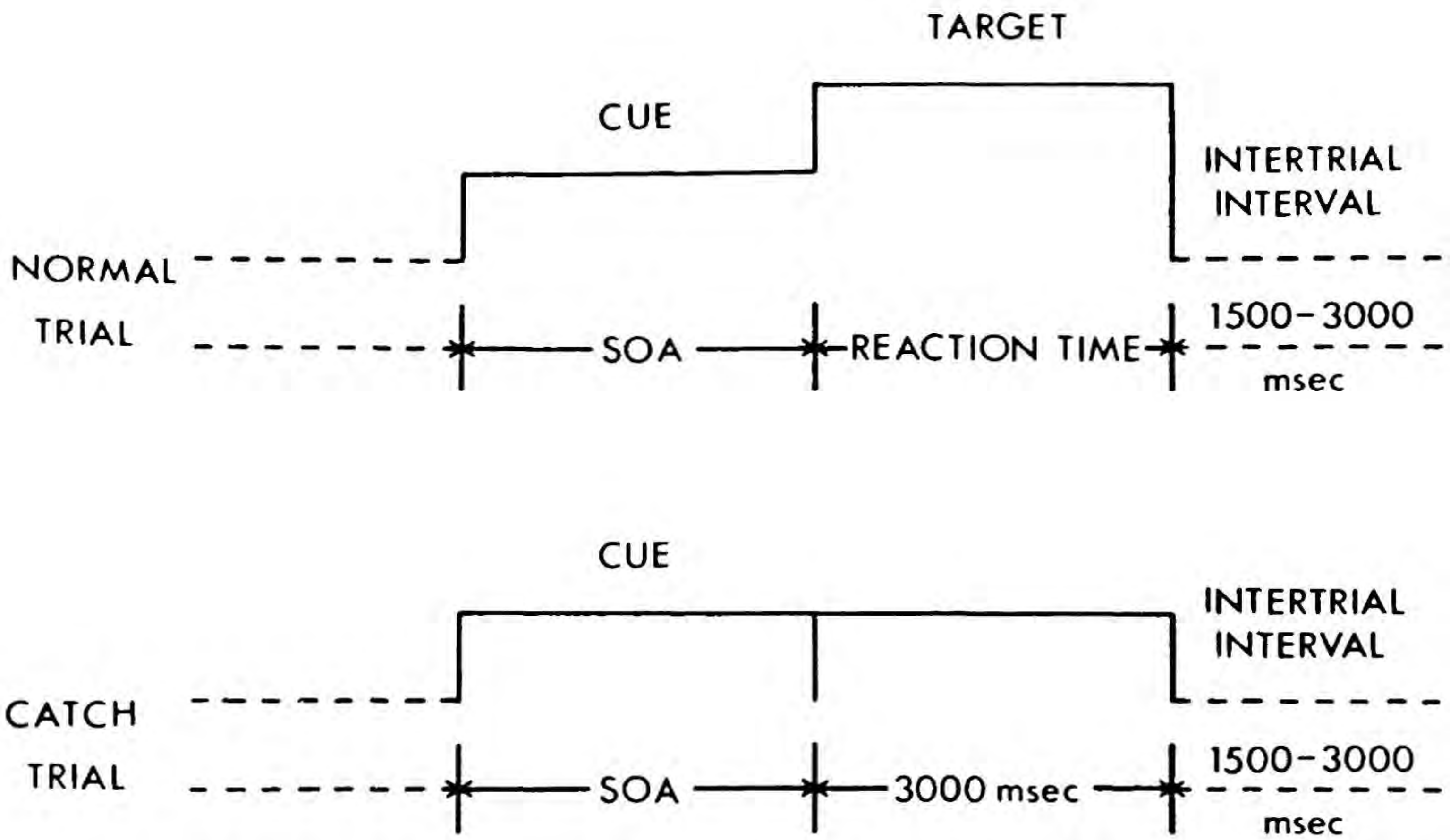


Figure 3.1 Timing of trials in experiment 3.1. ('SOA' = Stimulus Onset Asynchrony.)

		TARGET POSITION		
		LEFT	RIGHT	(no target)
CUE	+	10	10	6
	←	8	2	3
	→	2	8	3

HORIZONTAL CONDITION

		TARGET POSITION		
		ABOVE	BELOW	(no target)
CUE	+	10	10	6
	↑	8	2	3
	↓	2	8	3

VERTICAL CONDITION

Table 3.1 Distribution of trials in a block for the two conditions in experiment 3.1.

aim of including such trials was to prevent anticipatory responses. The three practice trials at the beginning of each block consisted of one of each of the cues for that condition followed by the appropriate targets.

The coding of the trials is illustrated (for the horizontal condition only) in Table 3.2 and the instructions given to the subject are reproduced in Appendix A. In addition the subject was informally encouraged to make use of the cue to prepare to receive a target from the expected location.

The error data that was printed out by the computer consisted of the number of anticipations made for each cue-type for each block. An anticipation was recorded when the subject responded during the SOA, those trials being deleted from the analysis. Also the number of false positives, that is, responses to catch trials, was recorded for each block.

3.2.2 Results and Discussion

For each subject the median reaction times were taken for each type of trial for the five SOAs in both the horizontal and vertical conditions. Figure 3.2 shows the means of the median reaction times from the five subjects. The anticipation rate was less than 1% and the false positive rate less than 8% for every subject. Table 3.3 shows the overall distribution of false positives as a

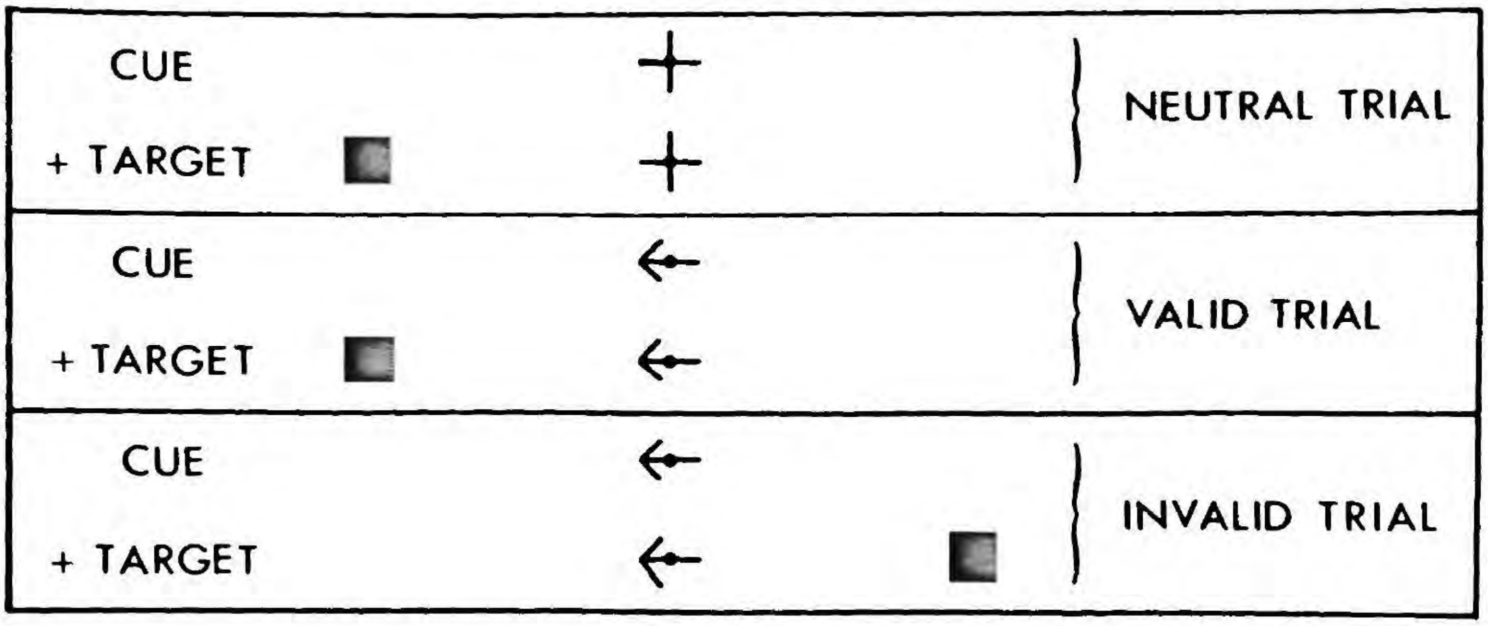
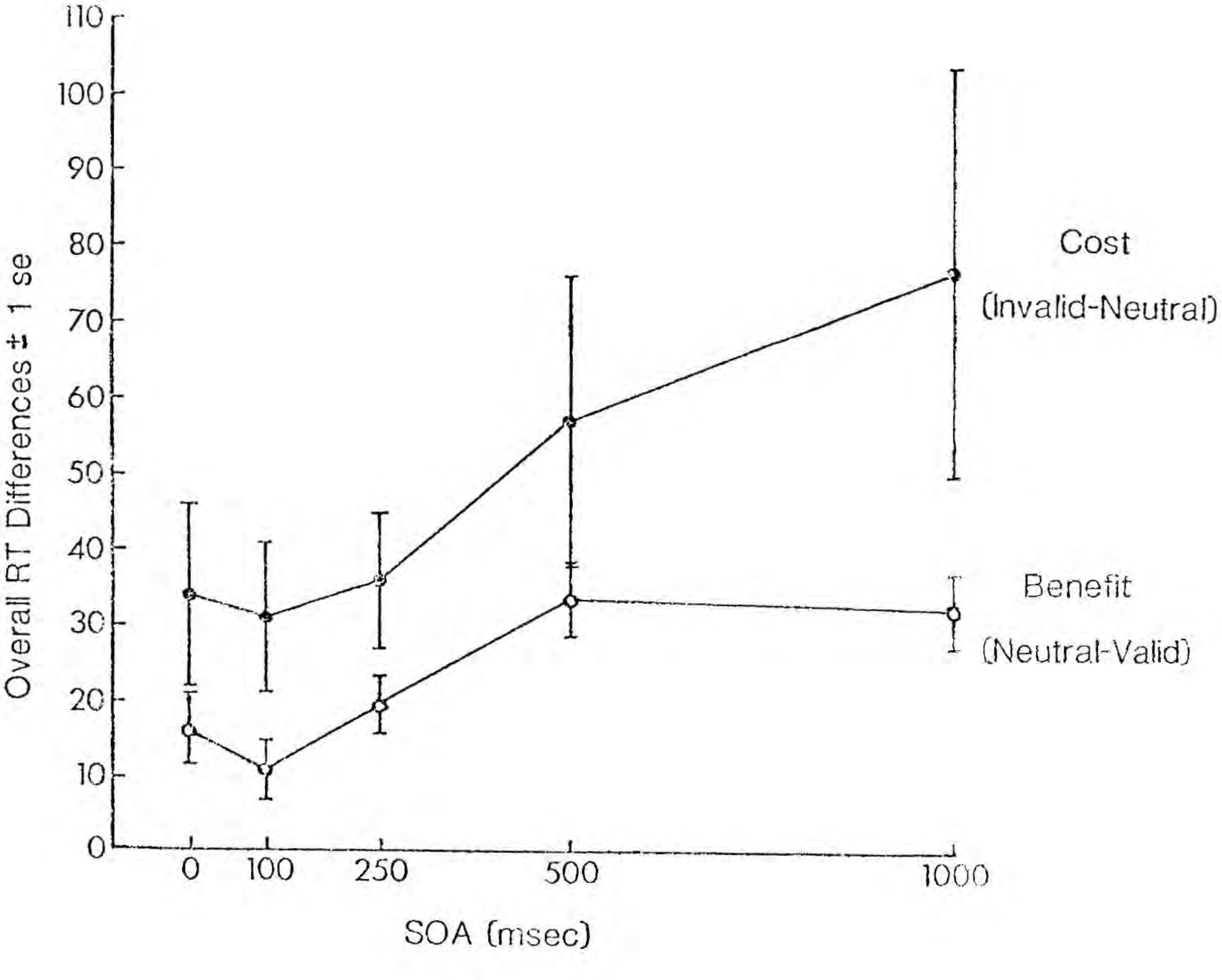


Table 3.2 Coding of trials in experiment 3.1 (horizontal condition only).


110
100
90
80
70
60
50
40
30
20
10
0
Overall RT Differences ± 1 se
0
100
250
500
1000
SOA (msec)
Cost
(Invalid-Neutral)
Benefit
(Neutral-Valid)

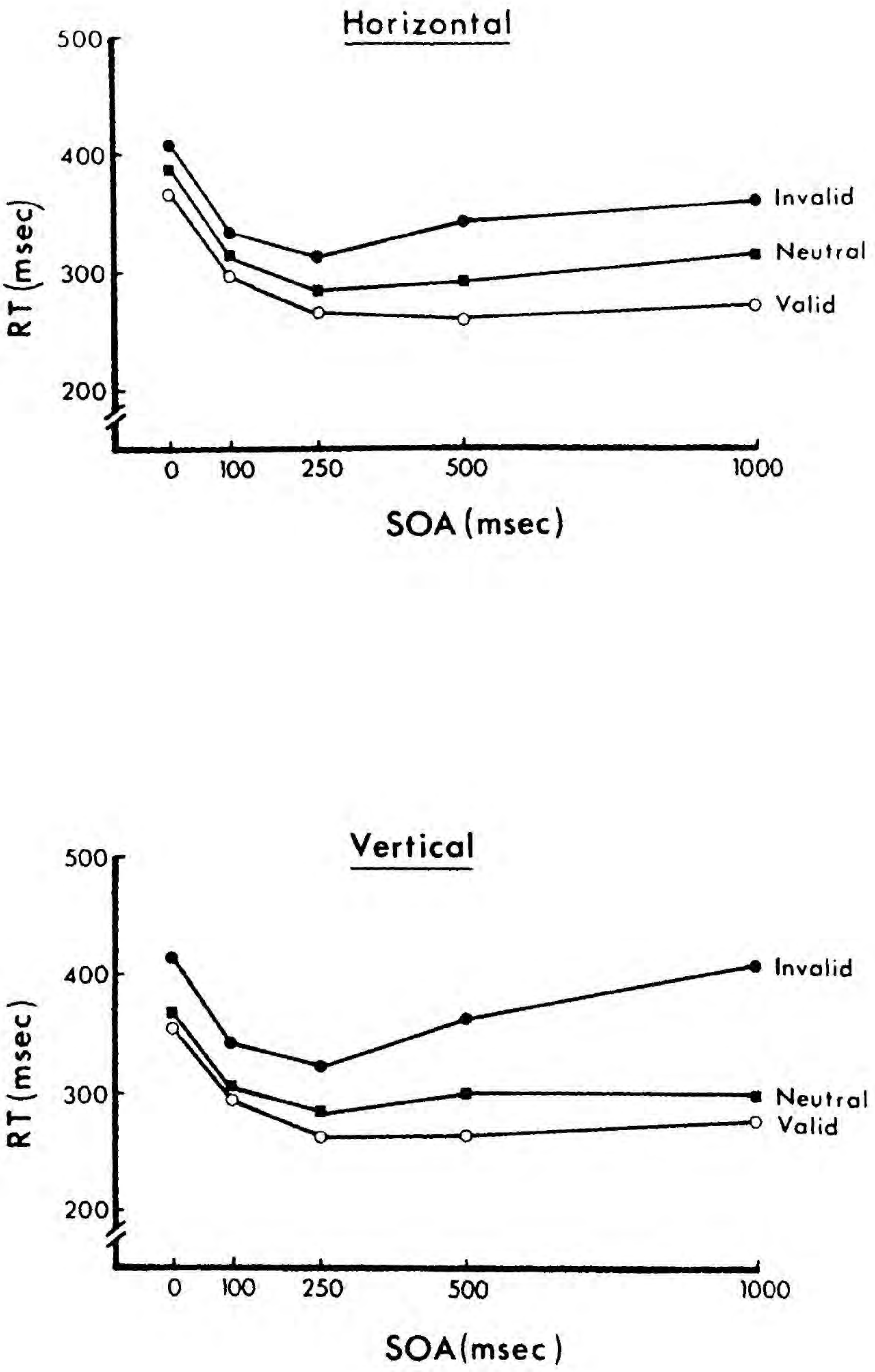


Figure 3.2 Results of experiment 3.1.

SOA(msec)	0	100	250	500	1000
% RATE	15.9	8.6	1.4	0.9	1.4

<u>Table 3.3</u> False positive rate in experiment 3.1.

percentage of the number of catch trials for each SOA separately.

The most striking feature of the data in general is the sharp decrease followed by the slight increase in reaction time as SOA increases from 0 to 1000 msec for all types of trial. This is the usual alerting effect which has been described in the literature (for example, Posner and Boies, 1971; Brebner and Welford, 1980; Niemi and Näätänen, 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. When cues are used in simple reaction time tasks, the subject seems to require a fixed minimum time (SOA) to prepare adequately for the onset of the target. As the SOA increases further, the subject becomes less accurate at estimating SOA duration and so predicting the moment of target onset (Rabbitt, 1981). The optimum SOA in this particular experiment is 250 msec.

Costs and benefits (as compared to the neutral condition) are found for all SOAs but tend to increase from 0 to 500 msec. This is consistent with Posner's data and he suggests that this result, combined with the false positive data, shows that the process of preparing to detect a target from a specified location is an active one. Up to an SOA of 500 msec, the subject is developing an expectancy and it is during this time that errors (in the form of false positives) are likely to be made.

However, the high rates at SOAs of 0 and 100 msec are probably also due to a combination of the use of a blocked-SOA procedure, and the presentation of the cue on every trial. Posner, Nissen and Ogden's (1978) error rate was much smaller for the zero SOA, the only procedural difference being that in their studies no cue was presented. In the present experiment the task at the short SOAs becomes one of the discrimination between responding if there are two stimuli on the screen (the cue and the target), and withholding a response if there is only one (that is, the cue). It is therefore surprising that costs and benefits are found at all at these SOAs. This will be returned to later.

The active nature of the attentional preparation is also reflected in the observation that the costs and benefits are nearly symmetrical. When a subject begins to attend to a possible target location by the use of a limited capacity conscious mechanism, there is both facilitation of that pathway (reflected in the benefits) but also inhibitory consequences (costs) for the processing of other targets.

There does not appear to be any difference between internally-controlled orienting in the vertical and horizontal dimensions. Indeed, this and the previous observations were confirmed by an analysis of variance with subjects as a random effects factor and condition (horizontal and vertical), SOA (0, 100, 250, 500 and 1000 msec) and trial-type (invalid, neutral and valid) as fixed effects factors. First, there was no overall difference between reaction time in the horizontal and vertical conditions [F(1,4)=0.09, p>0.1]. Secondly, there were highly significant effects of SOA [F(4,16)=18.00, p<0.001] and trial-type [F(2,8)=21.47, p<0.001]. The only significant interaction was that between SOA and trial-type [F(8,32)=3.64, p<0.01].

A surprising feature of the results is that costs and benefits are found for a zero SOA. Posner et al (1978) presented no cue at all for this SOA and so were unable to look at the effect of the simultaneous presentation of a cue and a target. The use of a delayed target to trace the time course of attentional processes is one of the most important features of Posner's paradigm, and Shulman (personal communication) has suggested that the zero SOA data indicate that the SOA manipulation does not completely time-lock movements of visual attention. Remington (1978) explained a similar observation in his own data as stemming from a lack of temporal resolution with the reaction time measure. Thus, if attentional movements and response processes overlap, reaction time may be speeded so long as attention is at the target location prior to the completion of the response. A more simple explanation, however, is that the overall configuration of the display affects the speed of response. For example, a target appearing in the opposite direction to the cue could produce a slow reaction time at least partly as a result of the incongruity of the display. This possible consequence of the cueing procedure was investigated in experiment 3.2.

To conclude, in addition to replicating the findings of Posner et al (1978), experiment 3.1 has demonstrated that internally-controlled covert orienting is as efficient in the vertical as in the horizontal dimension. Attending to a peripheral location in visual space (3.5 degrees from fixation) produces combined costs and benefits of approximately 100 msec for SOAs of greater than 500 msec. [From the work of Shulman, Remington and McLean (1979) it can be assumed that the required attentional movements are completed within 500 msec following the onset of the cue.] The problem of the combined costs and benefits of 50 msec for the zero SOA was addressed by experiment 3.2.

3.3 Experiment 3.2

From the results of experiment 3.1 it was suggested that the informative effect of the cue may have been overestimated because of possible overall configurational effects. In experiment 3.2 this was investigated by using cues which had no spatial predictive value but were merely temporal warning signals. In this way the effects of the overall configuration of the display could be assessed.

Logan and Zbrodoff (1979) demonstrated effects of visual configuration in an experiment using a paradigm first introduced by Stroop (1935). Their subjects responded to a word (ABOVE or BELOW) that appeared above or below a central fixation point. Response time was longer for conflicting trials (for example, ABOVE/below) than for compatible trials (BELOW/below). Logan (1980a) noted that in order to respond appropriately, the subject need attend only to one source of information, yet he is clearly influenced by other sources. The conflicting sources of information in the Stroop paradigm are the different dimensions of the one stimulus. Experiment 3.2 used a cue-target paradigm to investigate whether or not response time to a target could be influenced by visually-conflicting information from a spatially-separate cue used only as a temporal warning signal.

Experiment 3.2 was divided into three conditions (A, B and C). Condition A considered the effect of a non-informative symbolic cue (in the sense of providing temporal but not spatial information regarding the target) which was present in the visual display when the target appeared. It was predicted from the results of the zero SOA in experiment 3.1 that 'valid' trials (when the cue and target were visually congruent) would be speeded relative to 'invalid' ones as a result of the compatibility of the overall visual configuration. If, however, the cue was presented for a brief duration, which was the case in condition B of experiment 3.2 so that the target appeared in an empty field, there should be no effect on reaction time of the relationship between the symbolic cue and the target location. The third condition (C) also investigated the effect on target detection of a cue which contained irrelevant spatial information and was based on the experiment by Harvey (1980) (described in section 1.6). Harvey's cues and targets were physically identical so that the subject had to attend to the temporal sequence of events in order to respond appropriately. Choice reaction time was longer when the target was the same as the brief visual cue than when the cue and the target were different, indicating that the subject was influenced by the non-informative spatial aspect of the cue. Experiment 3.2C differed from that of Harvey in three important respects. First, a simple detection task was used. As Harvey employed a choice reaction time procedure his effect could be attributed to differential priming of response muscles, that is, response inhibition at a peripheral level. The second change was the introduction of a variable intertrial interval (ITI). By using a constant ITI of 2000 msec Harvey may have underestimated the non-informative effects because the salience of the cue as a temporal warning signal may have been reduced if the subject was able to predict the onset of the target without attending to the cue. Thirdly, in order to control the retinal position of the target, experiment 3.2C required the subject to fixate on a central point throughout the experiment.

3.3.1 Method

3.3.1.1 Subjects

Six subjects participated in three experimental sessions, each lasting 30 minutes. The three sessions were run on separate days.

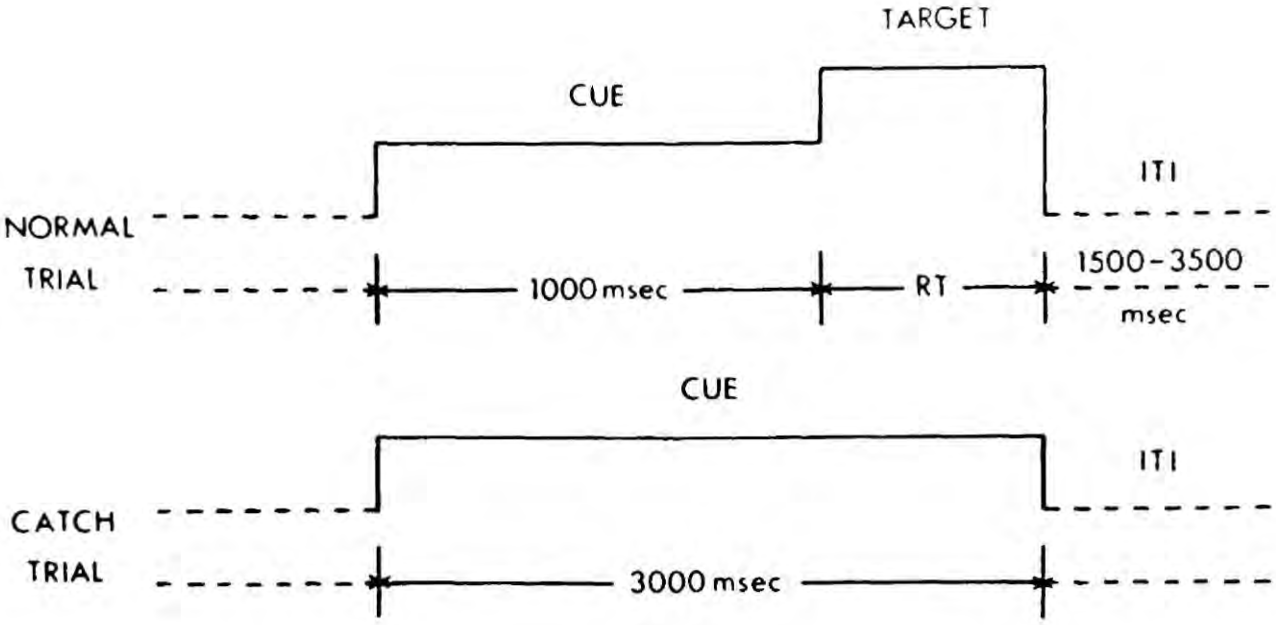
3.3.1.2 Apparatus and Stimuli

These are described in sections 2.3.1 and 2.3.2. Two target locations were used, 3.5 degrees above and below the central fixation point. In two of the experimental conditions (A and B) the four arrows were used as cues. In condition C the cue was a 'target' stimulus in one of four target locations, 3.5 degrees above, below, to the left and to the right of fixation.

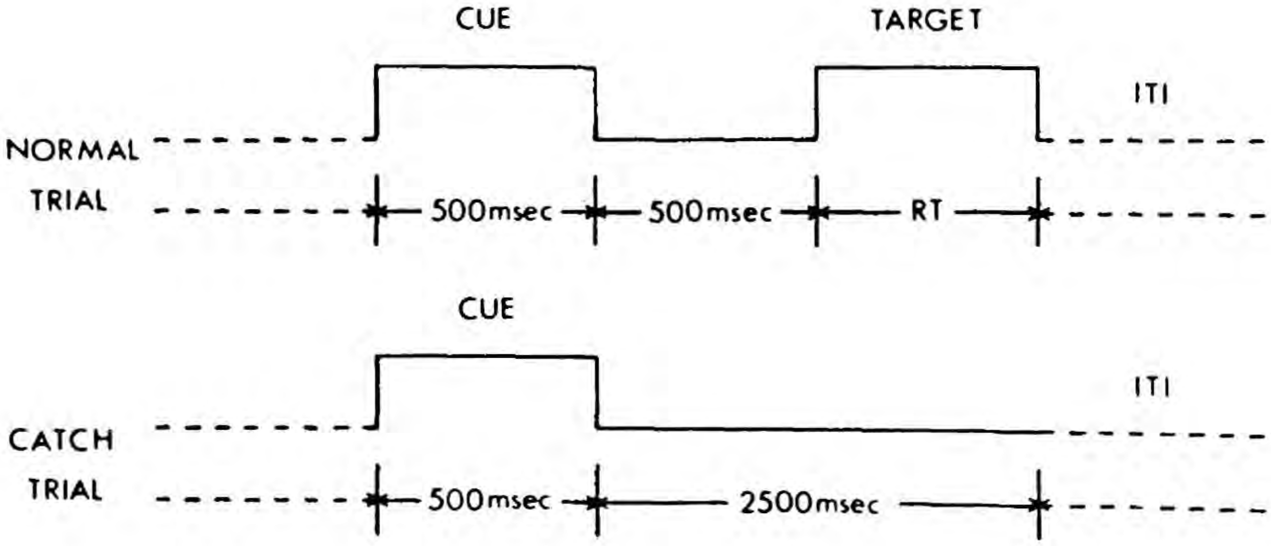
3.3.1.3 Design and Procedure

Section 2.3.3 outlines the basic procedure. Conditions B and C were run in the first two experimental sessions, the order being counterbalanced across the six subjects. The third session was condition A for all subjects.

The timing of the trials is shown in Figure 3.3. In condition A the cue remained on the screen until the detection response to the target had been made (as in experiment 3.1), whereas in conditions B and C the cue was



CONDITION A



CONDITIONS B & C

Figure 3.3 Timing of trials in experiment 3.2.

on the screen for just 500 msec. In all cases the SOA was 1000 msec.

Each session was divided into six blocks of trials although only the data from the last five were used in the analysis. A block consisted of 52 trials, plus four additional practice trials at the start of a block (one of each of the cues). The trials comprised 12 catch trials (when no target occurred) and 40 normal trials.

The distribution of trials within a block is shown for all three conditions in Table 3.4. In conditions A and B the cue was a central arrow whereas in condition C the cue was a 'target' presented for 500 msec in the locations shown. The relationship between the nature of the cue and the target location was non-informative since, for example, an arrow pointing to the left (conditions A and B) or a 'target' on the left (condition C) was equally likely to be followed by a target above or below the fixation point. The instructions given to the subjects were based on those in Appendix A though the non-informative spatial nature of the cue was stressed. Subjects were told to use the central arrow in conditions A and B, or the first brief 'target' in condition C merely as a temporal warning signal, and that the target only ever appeared above or below fixation, with equal probability.

			TARGET		
	A&B	C	ABOVE	BELOW	(no target)
CUE	←	LEFT	5	5	3
	→	RIGHT	5	5	3
	↑	ABOVE	5	5	3
	↓	BELOW	5	5	3

Table 3.4 Distribution of trials in a block in experiment 3.2.

The information presented on the screen was the same at the beginning of each block, that is, 'DELAY=1000', which was equivalent to an SOA of 1000 msec. Also there was the usual reminder to the subject to 'Keep eyes on fixation point throughout block'. Anticipations and false positives were defined as in section 3.2.1.3.

The trials were coded according to the spatial relationship between the cue and the target as shown in Table 3.5. Condition C was coded in a similar way so that a cue of a brief 'target' above fixation followed by a target below fixation was labelled 'invalid' and so on. As targets could only occur above or below fixation, the left and right cues provide a neutral condition of a kind. However it should be noted that the 'neutral' trials were actually invalid in the sense that the target position was 'inconsistent' with the cue.

3.3.2 Results and Discussion

The overall means are shown in Figure 3.4. The total error rate (that is anticipations and false positives) was less than 2% for all six subjects and therefore was not analysed further. Two separate analyses of variance were carried out on the mean reaction times from the six subjects. First, because condition A was run after conditions B and C (see section 3.3.1.3 above), the data from condition A were considered separately. The analysis of variance with trial-type (invalid, neutral and valid)

	CUE	TARGET
INVALID	↑	BELOW
	↓	ABOVE
NEUTRAL	←	BELOW, ABOVE
	→	BELOW, ABOVE
VALID	↑	ABOVE
	↓	BELOW

Table 3.5 Coding of trials in experiment 3.2.

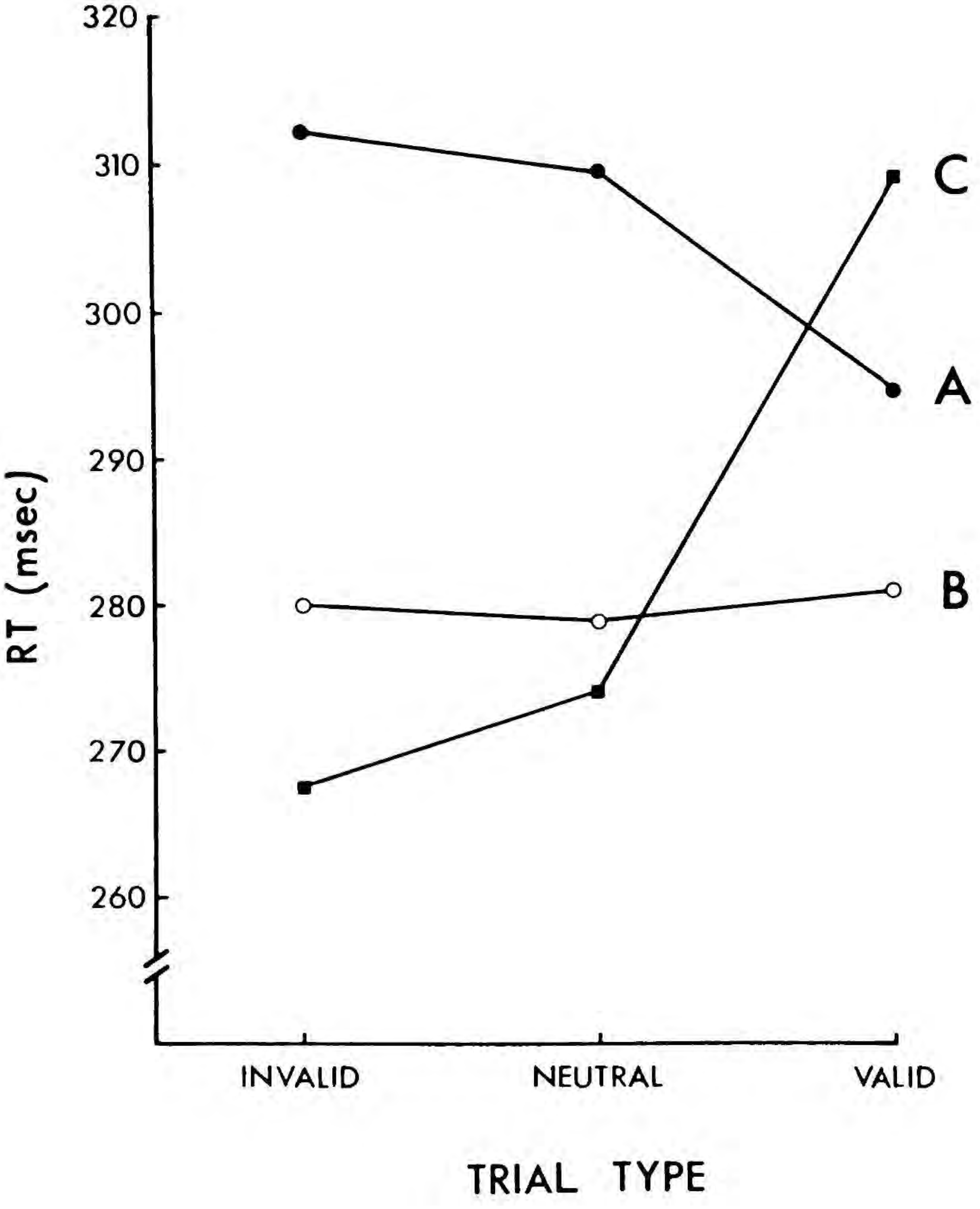


Figure 3.4 Results of experiment 3.2. [A = symbolic cue displayed until response. B = symbolic cue displayed for 500 msec only. C = target stimulus acting as cue, displayed for 500 msec.]

as the fixed effects factor revealed a significant effect of trial-type [F(2,10)=5.07, p<0.05]. The second analysis of variance was carried out with condition (B and C) and trial-type (invalid, neutral and valid) as fixed effects factors. There was no effect of condition [F(1,5)=0.47, p>0.1] but a highly significant effect of trial-type [F(2,10)=17.23, p<0.001] with an interaction between them [F(2,10)=8.47, p<0.01].

The results from condition A, where the cue remained present until the response to the target had been made indicate that responses are speeded to congruent displays (valid trials) relative to incongruent ones (invalid and neutral trials). For four of the six subjects valid trials were considerably faster than invalid and neutral trials. The remaining two subjects showed no difference between the three types of trial. Although there are individual differences (probably reflecting the degree to which the subject is able to ignore the spatial aspect of the cue), the overall effect (of about 16 msec) is quite large and suggests that at least part of the result demonstrated in experiment 3.1 may be attributed to the congruity of the overall configuration on the screen. If an effect of visual congruity can be obtained when the subject is encouraged to ignore the spatial content of the cue, the effect may be larger (and the combined costs and benefits of 50 msec for the zero SOA in experiment 3.1 suggest that it is) when the subject is required to attend to the cue's spatial property. The result of condition A is similar to that of Goolkasian (1981) who found that subjects process foveally-presented information while attending to targets presented in the periphery. Incompatible distractor information is suppressed while compatible information is used to facilitate target processing.

It can be seen from Figure 3.4 that when the symbolic cue is presented briefly (condition B) and is therefore not on the screen when the target appears, there is no effect of the spatial relationship between the cue and the target. The results of conditions A and B have obvious implications for experiments on internally-controlled orienting. If any reaction time differences in such studies are to be attributed entirely to the informative effects of the cue (that is, as a spatial and temporal warning signal), then the cue presentation must be brief so that the target appears in a blank field. Experiment 3.3 used this procedure in order to ensure that the results are due entirely to the effect of the allocation of attention to a particular location in visual space.

The analysis of variance on conditions B and C revealed a significant effect of trial-type and an interaction between condition and trial-type. These effects can be attributed to the results of condition C which demonstrate that when the cue and the target occur in the same location (valid trials), reaction time to the target is substantially longer (for all six subjects) than if the cue and the target occur in different locations (invalid and neutral trials). This replicates the findings of Harvey (1980) despite the use of simple rather than choice reaction time. Response inhibition at a peripheral level was proposed in section 3.3 as a possible explanation for Harvey's results, that is, the choice response associated with the location of the cue must be inhibited in order to prevent an error, which results in a longer reaction time to a target sharing that motor response. However, the results of experiment 3.2C using simple reaction time suggest that motor response inhibition can be discounted as an explanation. It will be argued from the experiments presented in chapters 4 to 8 that the inhibition observed is a consequence of externally-controlled covert orienting produced by a non-informative direct cue.

3.4 Experiment 3.3

Experiment 3.1 demonstrated that if a subject is asked to attend to a location in visual space other than the point of fixation (internally-controlled covert orienting), targets from that location are responded to more quickly than those from unattended locations. A searchlight metaphor has been used to describe such movements of attention (for example, Cohen, 1981; Broadbent, 1982) and the work of Shulman, Remington and McLean (1979) suggests that the searchlight moves in a continuous way over space and time. The question of the width and focus of the searchlight's beam then arises. From a series of studies Eriksen and his colleagues (Eriksen and Eriksen, 1974; Eriksen and Hoffman, 1972 and 1973) concluded that it is impossible to tune visual attention so that performance is affected only by information presented to a precise spatial location. They measured reaction time to respond to a target letter which was flanked by noise items and proposed that attention can be focused on an area of the visual field with a radius of 1 degree such that performance is affected by information falling inside but not outside this focus. However, their conclusions were challenged by Merikle and Gorewich (1979) who suggested that estimates of the width of the searchlight depend upon the size of the noise material used. The processing of peripheral noise items may be more limited by visual acuity than by the ability to focus attention upon a small area of the visual field. Experiment 3.3 therefore used an adaptation of the simple detection task of experiment 3.1 in order to plot out the spatial extent of the attentional field following instructions to attend to a specific peripheral location. The method was also based on that used by Shulman et al (1979) to trace attentional movements over time and space. A cue was presented which indicated the most likely location of the target. On most trials the target did indeed appear at the expected location. However, on the rare occasions when it appeared elsewhere, the movements and consequences of the attentional allocation could be measured by comparing reaction times to expected and unexpected targets as a function of SOA. Measuring the attentional field across space and time ideally requires a large number of both target locations and SOAs. However, in order to avoid lengthy experimentation while ensuring a reasonable number of trials of each experimental type, experiment 3.3 was divided into two conditions (A and B). Experiment 3.3A presented targets at four possible locations (all in the horizontal dimension) and at three different SOAs, while experiment 3.3B used only one SOA but eight target locations.

3.4.1 Method

3.4.1.1 Subjects

Three subjects from experiment3.1 participated in four sessions on separate days. Each session lasted 30 minutes.

3.4.1.2 Apparatus and Stimuli

The apparatus is described in section 2.3.1. The left and right arrows from section 2.3.2 were used as the cues, and the target locations are shown in the lower part of Figure 3.5.

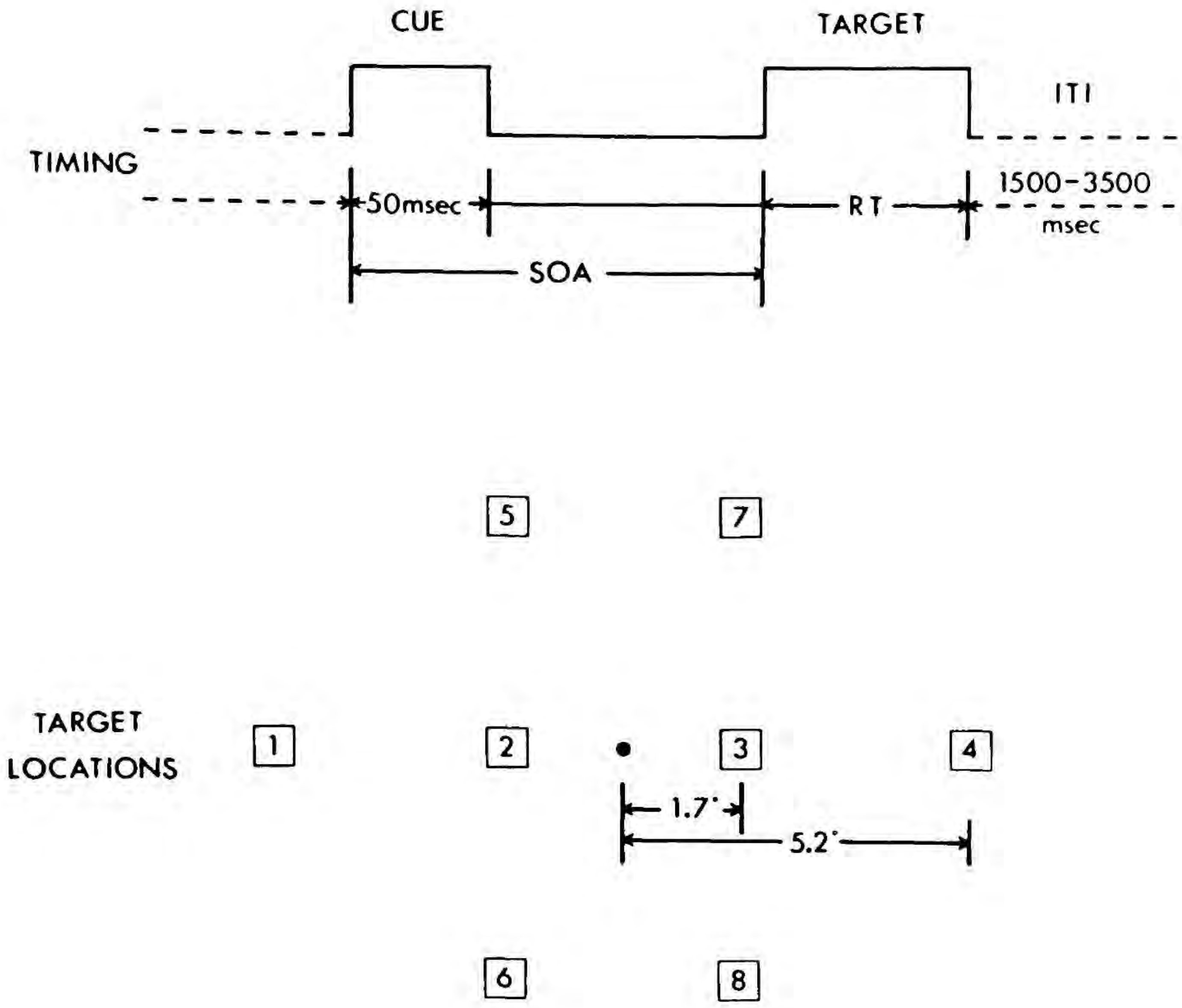


Figure 3.5 Summary of trials in experiments 3.3A and 3.3B.

3.4.1.3 Design and Procedure

Because all three subjects had participated in experiment 3.1 they were not given any practice sessions, although they had the usual practice trials at the beginning of each block of trials. Experiment 3.3A was conducted during the first three sessions, and experiment 3.3B on the fourth session. The three sessions for experiment 3.3A differed in the SOA (200, 500 or 1000 msec), the order of presentation being randomised. Experiment 3.3B used only an SOA of 500 msec. The timing of the normal trials is shown in Figure 3.5. Because of the results of experiment 3.2 the cue was presented for only 50 msec so that the target always appeared in a blank field.

Each session consisted of five blocks of 52 trials, each block including 12 catch trials, divided equally between the two cues. At the beginning of a block there were two practice trials, one of each cue. The distribution of cues and targets for a block for the two versions of the experiment is shown in Table 3.6. The instructions given to the subject for experiment 3.3A are reproduced in Appendix B. These were adapted slightly for experiment 3.3B to include the extra possible target locations. In summary, the subject was asked to use the informative symbolic cue to prepare to receive a target from the expected location. In both versions of experiment 3.3 this was either location 2 or 3 of Figure

EXPERIMENT3.3A

		CUE	
		←	→
TARGET	1	2	0
	2	16	2
	3	2	16
	4	0	2
	0	6	6

EXPERIMENT3.3B

		CUE	
		←	→
TARGET	1	1	0
	2	16	1
	3	1	16
	4	0	1
	5	1	0
	6	1	0
	7	0	1
	8	0	1
	0	6	6

Table 3.6 Distribution of trials in a block in experiments 3.3A and 3.3B. (See Figure 3.5 for coding of target locations.)

3.5 for the left and right arrow as the cue respectively. The subject was warned of the other possible target locations but informed of the probabilities involved (see Table 3.6).

3.4.2 Results and Discussion

Experiment 3.3A. The number of errors made was very small, false positives and anticipations occurring at rates of less than 8% and 1% respectively. For each subject the overall median reaction times for each SOA and trial-type were taken; the means of the three subjects are presented in Figure 3.6. 'Invalid' refers to trials where the target occurred in the opposite direction to the cue (for example, a target in location 3 following a left arrow). The trials where targets occurred in the same direction as the cue were divided into 'near' and 'far' trials. For example, following a left arrow, these would include trials when a target appeared in locations 2 and 1 respectively. Near trials correspond to valid trials in experiment 3.1 because the target appeared in the cued location. Far trials are invalid in the sense that the target occurred in an unexpected location although the target location was consistent with the direction of the cue.

Figure 3.6 indicates that there is no difference between far and near trials but both types are considerably faster than invalid trials. This was the

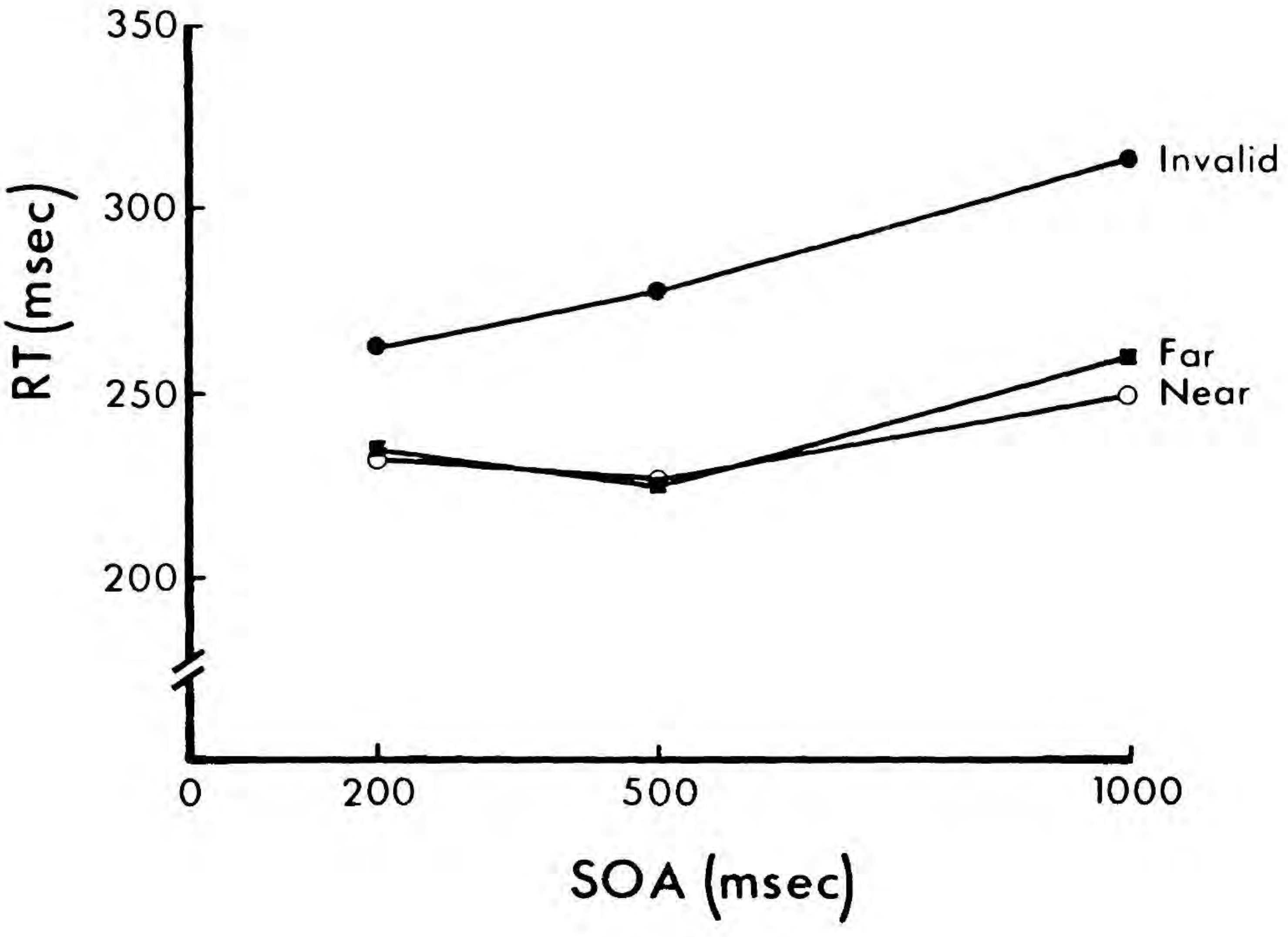


Figure 3.6 Results of experiment 3.3A.

pattern for all three subjects. The medians from each subject were analysed by an analysis of variance with SOA (200, 500 and 1000 msec) and trial-type (far, near and invalid) as fixed effects factors. This revealed significant effects of SOA [$F(2,4)=17.44$, $p<0.02$] and trial-type [$F(2,4)=49.59$, $p<0.005$] but no interaction between the two [$F(4,8)=1.29$, $p>0.1$]. The effect of SOA has been discussed (see section 3.2.2). The trial-type effect is of more interest here. Although the display parameters were calculated so that far and invalid targets were equidistant from near ones, the main reaction time difference is between targets on the side of the visual field consistent with the direction of the cue and those on the opposite side. Shulman et al (1979) concluded that reaction time tends to be a direct function of the distance of the target from the present focus of attention. For these visual angles this is clearly not the case. An arrow pointing to the left seems to facilitate responses to near and far targets on the left equally with respect to those on the right despite the fact that the subject was expecting the target to be in the near location.

For these small visual angles, attentional allocation does not therefore seem to be very specific, yet the effect of visual hemifield is strong. The cueing of one peripheral location may result in the allocation of attention to all locations in the same hemifield. Alternatively, the attentional field may only include locations along the direction indicated by the cue.

Experiment 3.3B. The additional unexpected target locations used in experiment 3.3B enable the two possibilities outlined above to be tested. The means of the medians from the three subjects for an SOA of 500 msec are shown in Table 3.7. The first three types of trial are coded as in experiment 3.3A. The additional trials (that is, when targets occurred above or below the near location) are coded as 'above/below' trials. An analysis of variance revealed a significant effect of trial-type [F(3,6)=10.48, p<0.01]. Post-hoc comparisons using the Scheffé method showed that the invalid trials were significantly slower than near trials [F(3,8)=24.88, p<0.01], far trials [F(3,8)=17.44, p<0.05] and above/below trials [F(3,8)=19.54, p<0.05]. The three other pair-wise comparisons were not significant so that the main reaction time difference is between trials where the target occurs in the same hemifield as the cued location and those where the target occurs in the opposite hemifield.

Experiments 3.3A and 3.3B together show that at least for small visual angles (that is, less than six degrees) attending to a specific location facilitates detection responses to targets from locations within 3.5 degrees in the same hemifield. Comparison of reaction times to targets from locations at equal distances from the focus of attention shows that the most important factor influencing the speed of detection is whether or not the

TRIAL TYPE	NEAR	FAR	INVALID	ABOVE /BELOW
RT (msec)	232	239	274	237

Table 3.7 Results of experiment 3.3B.

target is in the same visual hemifield as that indicated by the cue. Posner, Snyder and Davidson (1980) concluded that attention can be regarded as an internal eye or spotlight. The results of experiment 3.3 suggest that the spotlight can have a wide spatial range and is not necessarily symmetrical about the most likely target location. Broadbent (1982) suggested that while it is useful to consider visual selectivity as the 'beam of a searchlight, with the option of altering the focus', its motion and width are 'dependent on the events already detected'.(p271) In experiment 3.3 it is possible that the subject may have been able to focus visual attention sharply on the near expected target location as instructed, but instead may have adopted a strategy of allocating attention to a wider area of visual space to include all possible target locations in the same hemifield. In doing so, the probability of the target occurring within the attentional field rather than outside it would increase from 16/20 to 18/20 (experiment 3.3A) and from 16/20 to 19/20 (experiment 3.3B). The subject may have decided upon the second attentional strategy following an analysis of the target probabilities involved (given by the instructions - see Appendix B) and before the experiment began. Alternatively, the attentional allocation may have been developed during the course of the experiment as a consequence of the 'events already detected'. However, a block-by-block analysis of the data was not conducted because of the small numbers of non-valid trials involved.

It must be concluded that any estimate of the size of the visual attentional field is dependent upon the nature of the task. Estimates based upon modified Stroop tasks are influenced by the size of the noise material (for example, Merikle and Gorewich, 1979) and by the attentional strategy 'actively chosen to suit the prevailing conditions' (Lowe and Mitterer, 1982). The actual target locations used in simple detection tasks such as experiment 3.3 may lead to alterations of the searchlight's beam possibly as a result of either a subjective analysis of the target probabilities involved or through experience of the task. Unlike the modified Stroop tasks, there is no obvious incentive for the subject to focus the beam on the single expected location as instructed, if by simply widening the beam extra target locations can be included.

3.5 General Conclusions

The experiments on internally-controlled covert orienting presented in this chapter demonstrate that the allocation of attention to a cued location speeds the detection of targets from that region of visual space with respect to other regions. Visual orienting is similar in the horizontal and vertical dimensions (experiment 3.1), the overall costs + benefits increasing from 50 to 100 msec for intervals between cue and target onsets of 0 to 1000 msec. However, the results of experiment 3.2 suggest that the effects of symbolic cueing may be attributed partly to the procedure used whereby the cue is visible when the target is presented, resulting in visual congruity effects. These are small when the subject is encouraged to ignore the non-informative spatial aspect of the cue but may be larger when the subject is required to attend to the spatially-informative symbolic cue. When the cue is briefly presented so that the target appears in an empty field, the costs + benefits are reduced to 50 msec for SOAs of 500 and 1000 msec (experiment 3.3) suggesting that visual congruity may be a large component in experiment 3.1, possibly accounting for the costs + benefits of 50 msec for a zero SOA. [The different visual angles used in experiments 3.1 and 3.3 are not considered important following the results of Posner (1978) which demonstrated that costs and benefits are independent of visual angle.] To conclude, internally-controlled covert orienting can be considered as the movement and focusing of the beam of an internal attentional searchlight such that simple detection responses to targets falling inside the beam are approximately 50 msec faster than those to targets outside the beam.

CHAPTER 4

Externally-Controlled Orienting

4.1 Introduction

Chapter 3 demonstrated the effect of internally-controlled covert orienting on simple reaction time to a peripheral target. However, visual attention can not only be directed internally but it can also be 'captured' by an external stimulus event in the visual periphery (Jonides, 1981). The present chapter is concerned with some experiments on externally-controlled orienting which were designed to replicate and extend the findings of Posner and Cohen (1980). Their procedure was described in section 1.6 and involved presenting a brief visual stimulus in the periphery (- a direct cue) then measuring its effect on the response to a subsequent target. In experiment 3.2C, simple reaction time to a target appearing in the same location as a brief non-informative direct cue was longer than to a target in a different location. However, the interval between the cue and the target had to be long (SOA = 1000 msec) because of the procedure used whereby the cue and the target could be physically identical. The advantage of Posner and Cohen's technique is that much shorter SOAs can be investigated. Experiments 4.1 and 4.2 were based on their study, the subject's task being the simple detection of targets following brief non-informative direct cueing.

The effects on saccade latency and manual choice reaction time were investigated by experiments 4.3 and 4.4.

4.2 Experiment 4.1

Experiment 4.1 was conducted for two main reasons. First, it was considered necessary to attempt to replicate Posner and Cohen's recent (and so far unpublished) study in order to demonstrate the reliability of the effects. The second aim of experiment 4.1 was to provide baseline data particularly for comparison with the experiments on externally-controlled orienting reported in this chapter and in chapters 5, 6 and 8.

4.2.1 Method

4.2.1.1 Subjects

Fourteen subjects each took part in a single experimental session lasting 10 minutes.

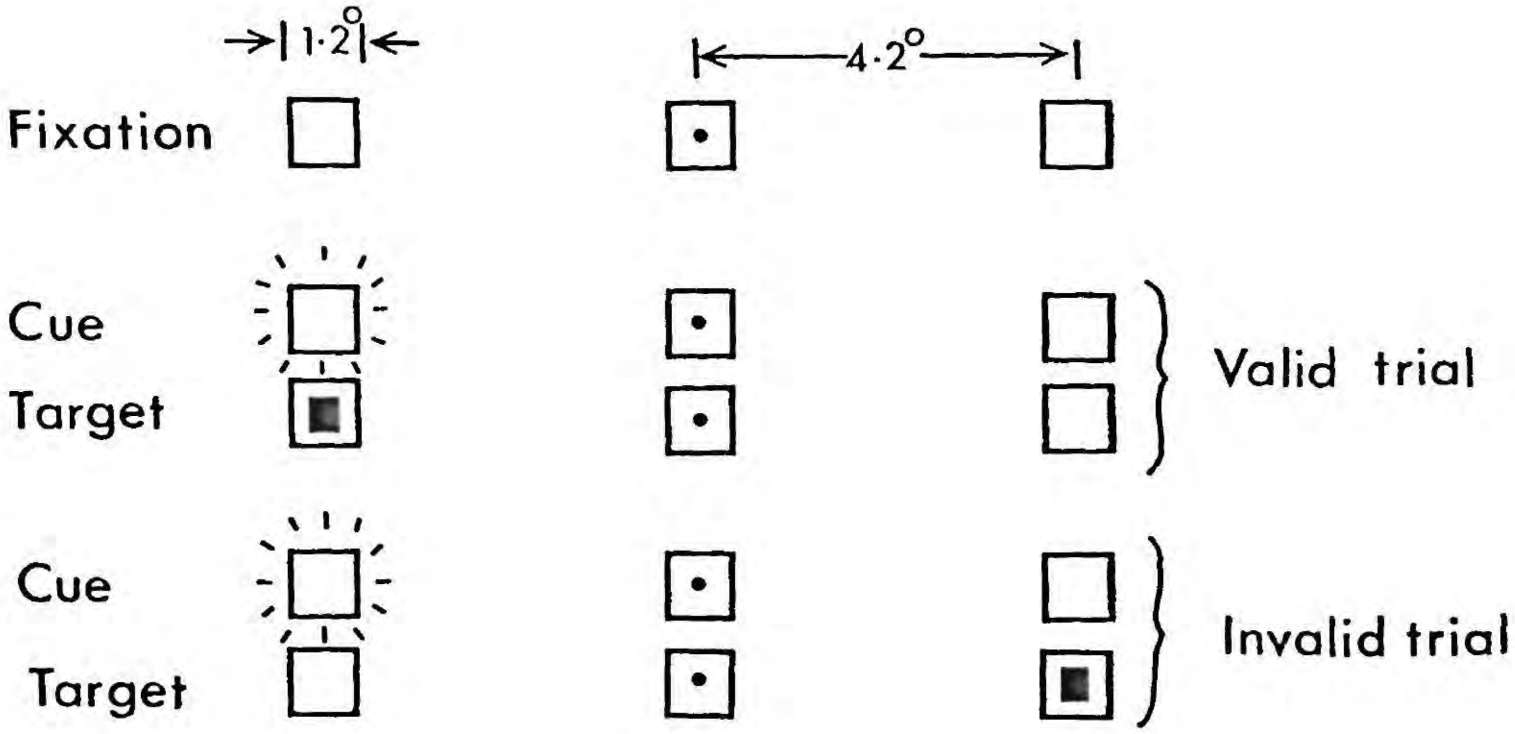
4.2.1.2 Apparatus and Stimuli

The apparatus and stimuli are described in sections 2.4.1 and 2.4.2. For this particular experiment the IBM computer was used.

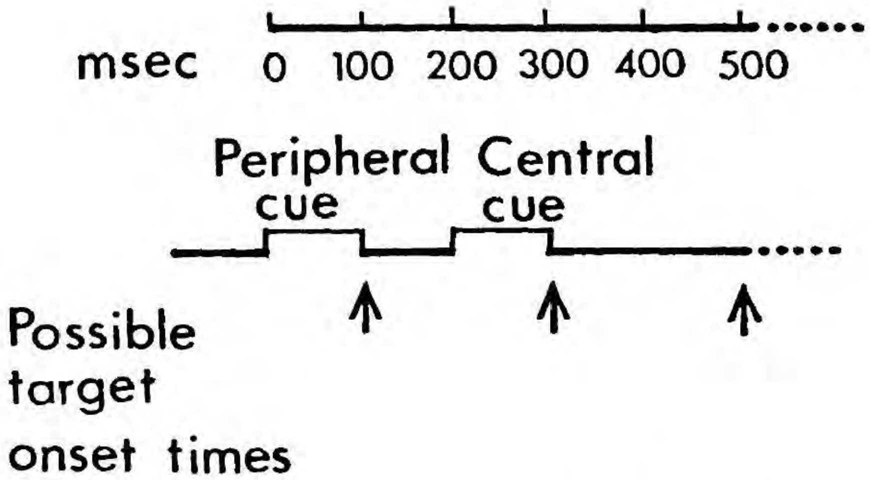
4.2.1.3 Design and Procedure

Section 2.4.3 outlines the procedure. Each subject was given approximately two minutes of practice (depending on his familiarity with simple reaction time experiments), followed by two blocks of experimental trials. After receiving instructions from the experimenter (reproduced in Appendix C), the subject started a block by pressing the single key. The first block then proceeded without a break (approximately two minutes). At the end the screen went blank, to be replaced by a reminder to 'Keep eyes on fixation point throughout block'. A single key press by the subject started the second block of trials.

Each block began with the presentation of the display shown at the top of Figure 2.3 for five seconds. This enabled the subject to locate the three boxes and fixate on the spot inside the central box. 120 trials then followed of the type shown in Figure 4.1. A trial began with the cueing (that is, the brightening as described in section 2.4.2) of one of the peripheral boxes for 100 msec (labelled the 'cue'). This was followed after another 100 msec by a similar brightening of the central box. (This was included by Posner and Cohen in order to 'summon attention back to the center'.) Targets could occur at three different times following the onset of the cue: 100, 300 or 500 msec. The target disappeared when a detection response of a single key press had been made. The interval between the offset of the target and the



Simplified sequence of events for each type of trial



Time course of a trial

Figure 4.1 Summary of trials in experiment 4.1.

onset of the next trial was randomly chosen from the range 200 to 700 msec. There were no catch trials equivalent to those used in experiments 3.1-3.3. However, trials when a response was made before or during the first 100 msec of the target presentation were recorded as anticipation errors.

The 120 trials in a block were divided so that there were 40 trials of each SOA (100, 300 and 500 msec). These were further divided into 10 of each left-right/cue-target combination. The order of presentation of trials within a block was randomised. In this way, the cue was in fact non-informative since a cue on the left was as likely to be followed by a target on the left as by one on the right. The label 'valid' thus refers to a target following a cue in the same location, while 'invalid' refers to a target appearing in the opposite location to the cue.

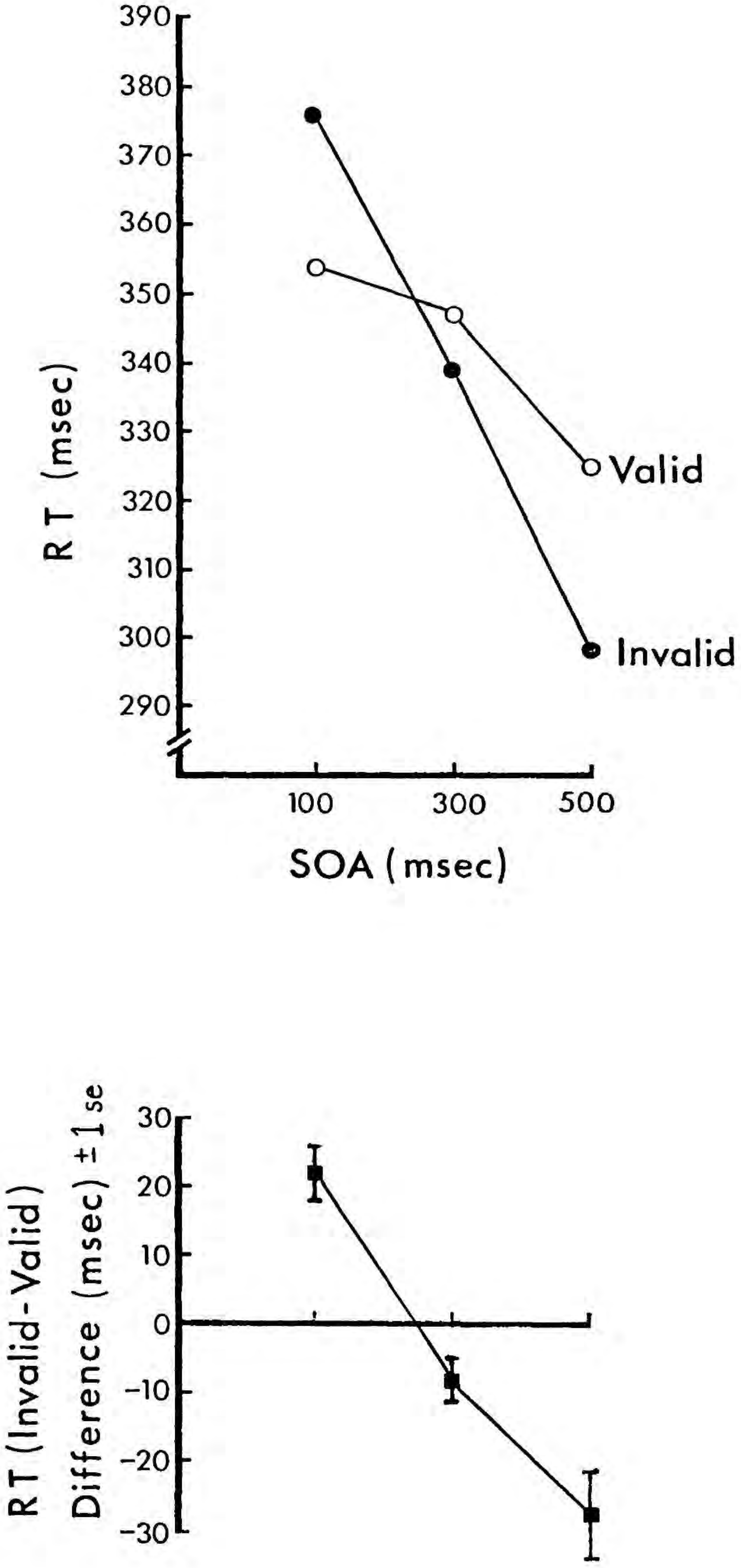
4.2.2 Results and Discussion

Subjects reported that they were unaware of the cueing procedure although they did notice that the three boxes, particularly the central one, tended to flicker throughout the experiment. They also found that the requirement to keep the eyes on the central fixation point was a reasonable one. A pilot study had been carried out using the author as the subject and eye movement recording equipment that will be described in detail in sections

4.4.1.2 and 4.4.1.3. This revealed that the eyes remained fixated within the central box throughout the block of trials.

Median reaction times from each subject were analysed by an analysis of variance with block (first and second), SOA (100, 300 and 500), and trial-type (invalid and valid) as fixed effects factors. There was no overall difference between the first and second block [$F(1,13)=2.94$, $p>0.1$] and block did not interact with any other factor. The means of the medians from the two blocks are presented in Figure 4.2. The lower graph shows the reaction time differences between invalid and valid trials, again as a function of SOA. The overall anticipation rate was 3.9%.

There was the usual highly significant effect of SOA [$F(2,26)=23.01$, $p<0.0001$], but not of trial-type [$F(1,13)=1.40$, $p>0.1$]. The interaction between SOA and trial-type was highly significant [$F(2,26)=63.70$, $p<0.00001$] and replicates the findings of Posner and Cohen (1980). So at an SOA of 100 msec there is what Posner has referred to as *facilitation* such that valid trials are responded to more rapidly than invalid trials. (This effect was observed for 13 of the 14 subjects.) However, at the longer SOAs valid trials are actually slower (again true for 13 of the 14 subjects) demonstrating the second effect, that of *inhibition*.



<u>Figure 4.2</u> Results of experiment 4.1.

Posner, Cohen and Rafal (1981) concluded that a direct cue in the periphery produces two opposed effects. The first is the summoning of attention, which enhances the efficiency of processing information from the cued location. The second effect is that of a temporary inhibition and occurs only when sensory information is used to summon attention. They suggested that in order to observe inhibition, attention must be summoned away from the cued location at some time following the initial cue. Posner and Cohen (1980) described two ways of ensuring that attention returns to the centre. The first uses the paradigm employed here, that is, the cueing of the central box 100 msec after the offset of the cue in the periphery. The second method involves altering the probabilities so that targets are more likely to occur inside the central box (p=0.6) than inside either of the peripheral boxes (p=0.4). It might be supposed, however, that the only necessary condition required to summon attention back to the centre is that of equal probabilities of target occurrences in the left and right boxes. Experiment 4.2 investigated this possibility.

4.3 Experiment 4.2

In order to increase the ecological validity of the inhibitory effect, it is important to demonstrate inhibition without using a central cue or the possibility of central targets to summon attention back to the centre, following brief stimulation in the periphery.

4.3.1 Method

4.3.1.1 Subjects

Five subjects participated in one experimental session lasting 10 minutes.

4.3.1.2 Apparatus and Stimuli

The PDP computer was used to control the experiment. All other details are as described in sections 2.4.1 and 2.4.2.

4.3.1.3 Design and Procedure

Each subject participated in three blocks of trials, the first being a practice block. The timing of the trials was as shown in Figure 4.1 except that the central cue was omitted. Each block consisted of 96 trials. These were divided equally between the three SOAs and further divided into eight of each left-right/cue-target combination. All other experimental details are described in section 4.2.1.3.

4.3.2 Results and Discussion

The results from the two experimental blocks were combined and overall median reaction times taken for each subject. These were put into an analysis of variance with SOA and trial-type as fixed effects factors. The means of the five subjects are shown in Figure 4.3. The overall anticipation rate was 2.3%.

Again there was a significant effect of SOA [$F(2,8)=19.85$, $p<0.01$], no effect of trial-type [$F(1,4)=0.83$, $p>0.1$], but a highly significant interaction between the two [$F(2,8)=19.18$, $p<0.01$]. The results are almost identical to those obtained from experiment 4.1. It can therefore be concluded that central brightening is not necessary in order to produce inhibition. This may mean that if inhibition only occurs when attention has been withdrawn from the cued location, then the presentation of targets with equal probability either side of fixation is sufficient to summon attention back to the centre. Another possibility is that attention is then directed towards the uncued side. This will be returned to in later chapters.

From experiment 4.2 it can be concluded that, in the absence of eye movements, inhibition occurs 300 msec after a brief visual event in the periphery when the target is equally likely to appear either side of fixation. Inhibition is therefore not dependent upon the summoning of attention away from the cued location by any means other than by ensuring that the target has an equal probability of appearing at the cued and uncued locations. The procedure used in experiment 4.2 is probably closer to normal viewing than that of experiment 4.1. The inhibitory effect is therefore seen as a significant

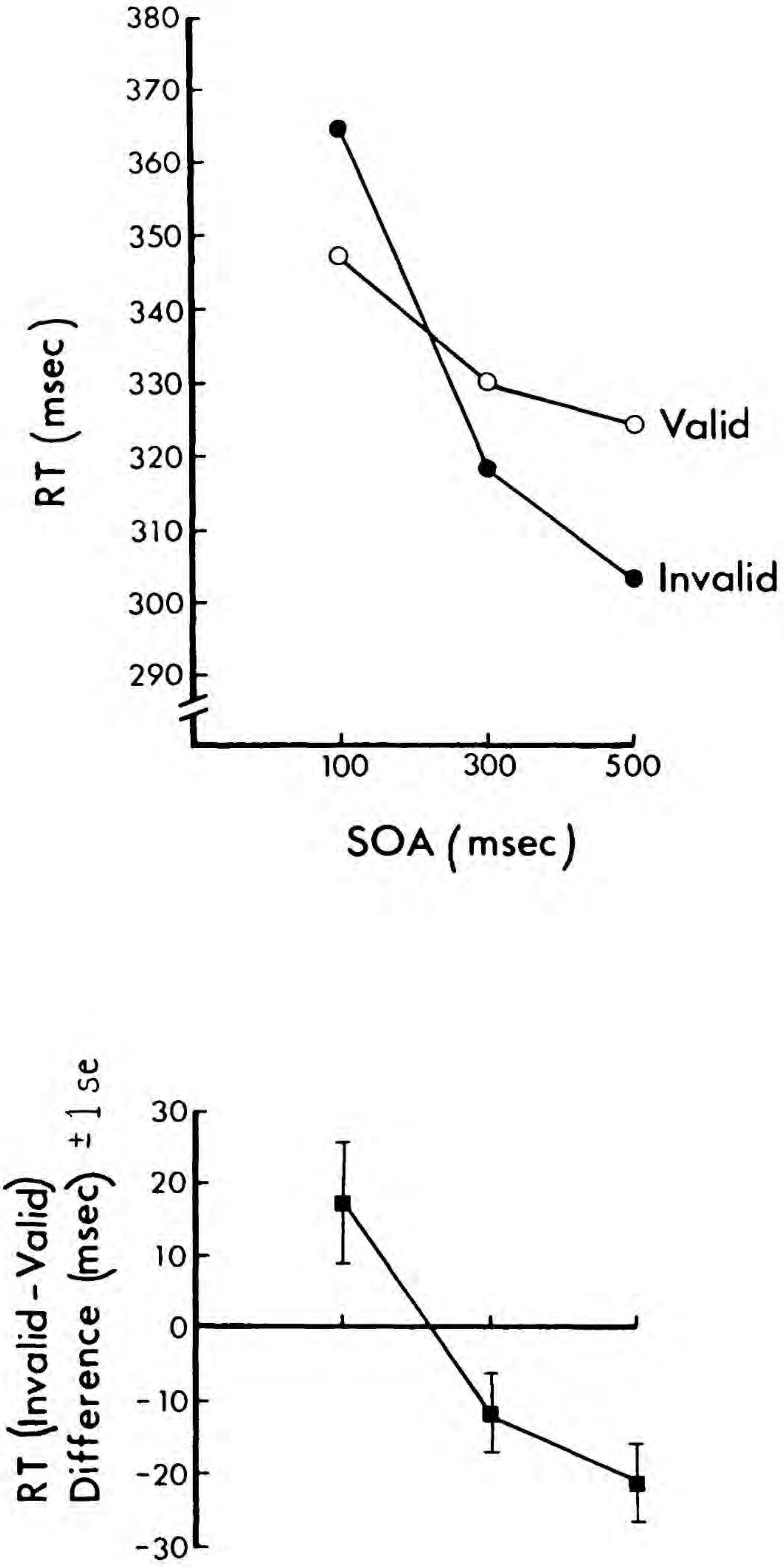


Figure 4.3 Results of experiment 4.2.

phenomenon requiring further investigation.

4.4 Experiment 4.3

The effects on simple reaction time to targets following brief non-informative direct cueing are clear. Initially, the cue speeds the detection of targets that appear in the cued location within the next 100 msec. However, responses to targets occurring more than 300 msec after the brief cue are considerably slower than to those in previously uncued locations. In an attempt to increase further the generality of the effects observed, experiment 4.3 was concerned with a different type of response, namely saccade latency rather than manual reaction time. Instead of the requirement to fixate on the central point, the subject was asked to look at the target as quickly as possible following its presentation. Section 1.5 provided a review of recent research relating overt and covert orienting and it was concluded that the two are most closely coupled in response to an important visual event in the periphery. Therefore similar results to those of experiments 4.1 and 4.2 were expected from experiment 4.3.

4.4.1 Method

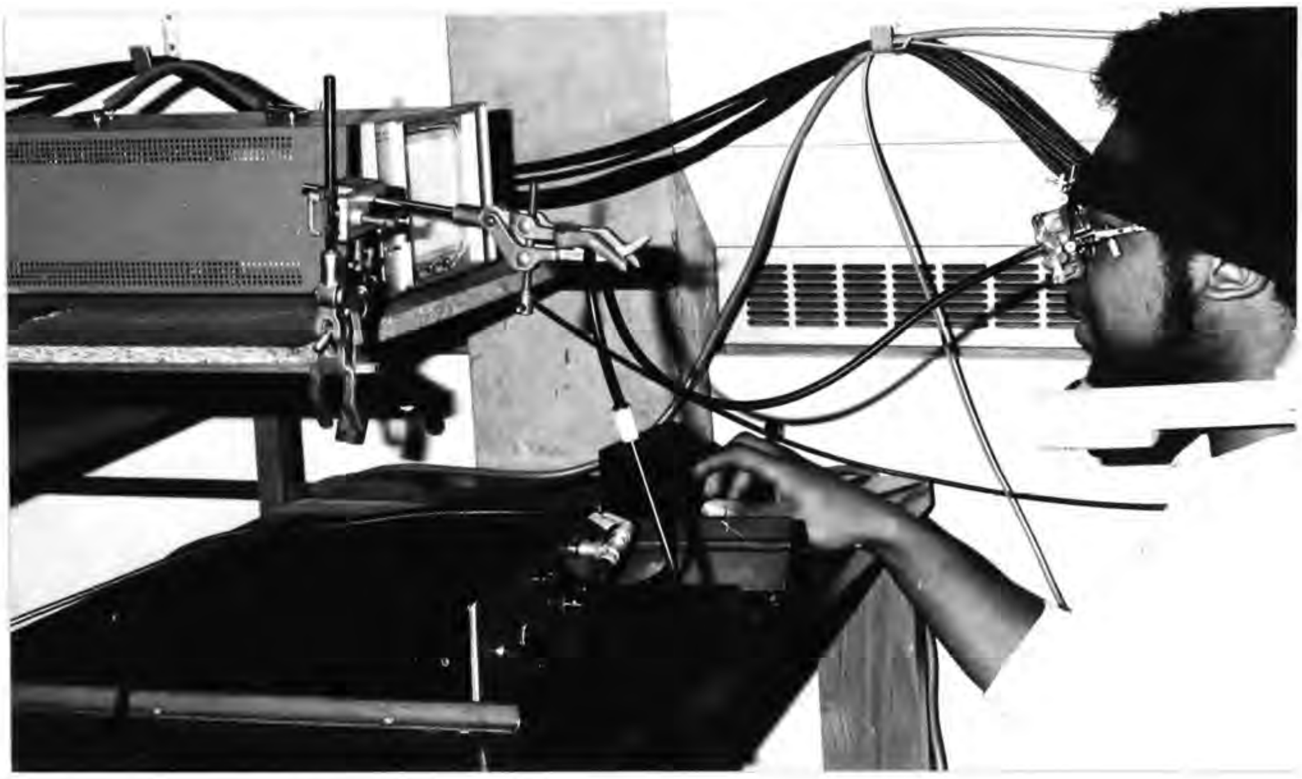
4.4.1.1 Subjects

Six subjects each participated in one experimental session of approximately 30 minutes.

4.4.1.2 Apparatus and Stimuli

The experiment was controlled by the ALPHA minicomputer as described in section 2.4.1. Subjects were seated 50 cms from the oscilloscope screen, with their eyes level with the centre of the screen. The head position for four of the subjects was held by head and chin rests. The remaining two subjects used a securely-clamped bite-bar to prevent head movements. [The latter two subjects had taken part in other eye movement studies and so had personal bite-bars which they preferred to use. The head and chin rest system was however considered adequate for an experiment where saccade latency was the dependent measure rather than amplitude.]

Horizontal eye movements were recorded by a bifurcated fibre optic device (Findlay, 1974). The system is shown in Figure 4.4. Light from an infra-red source was directed by means of a fibre optic probe mounted in a spectacle frame and placed in an appropriate position relative to the limbus. A representation of eye position was obtained by the registration of the change in the property of the reflected infra-red light as the eye rotated. The system was linear over the central region of six degrees and was accurate to within one degree. The output was processed by the ALPHA minicomputer and a digitalised record of the eye movement data was stored on a magnetic floppy disc for subsequent analysis.



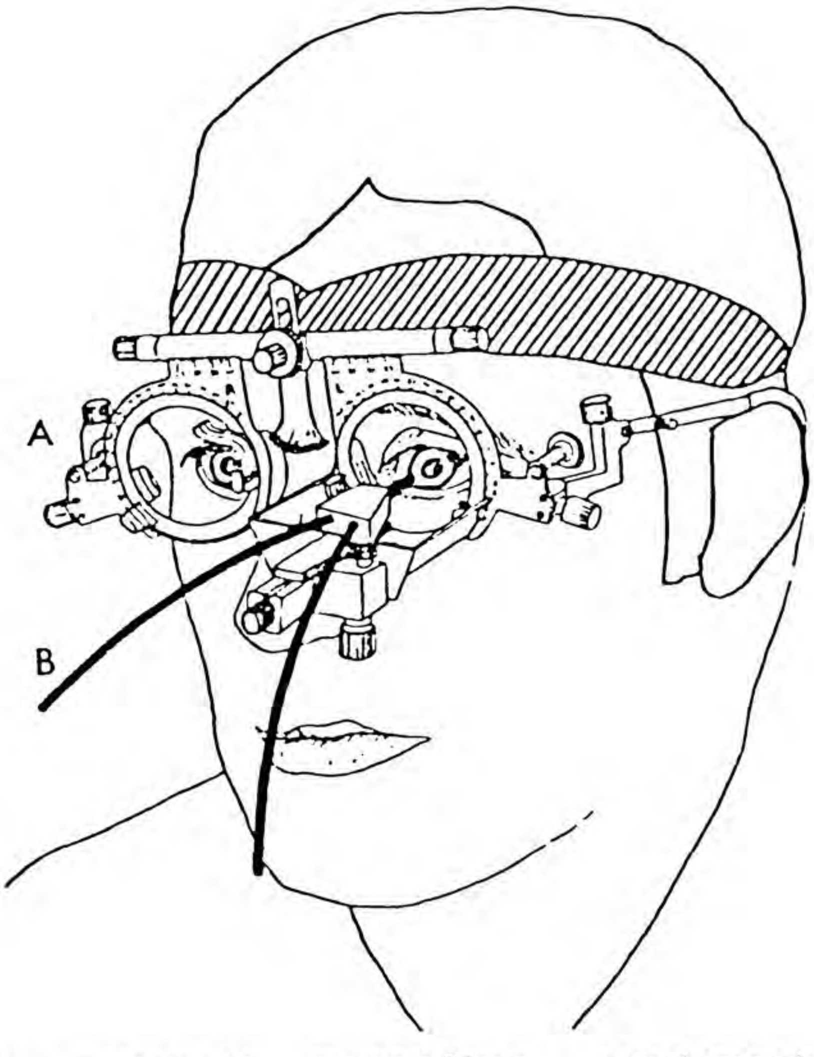


Figure 4.4 Eye movement recording equipment, showing spectacle frame (A) and bifurcated fibre optic probe (B). (Diagram reproduced with permission from Findlay, 1974.)

The subject's right index finger was placed on a button mounted in a response box which was connected to the digital input. This was used to initiate each trial. The stimuli were as described in section 2.4.2.

4.4.1.3 Design and Procedure

The eye movement recording equipment was set up and adjusted to produce strong signals for the visual angles involved in the experiment. When the subject was comfortable and ready to proceed, the button was pressed. On its release, three calibration spots appeared one at a time, at positions corresponding to the centre of the three boxes of the display. Each spot remained on the screen for one second and the subject was asked to look at each one without blinking. This provided baseline data for analysing the saccades. The three boxes then appeared and when ready to begin, the subject pressed the button. When it was released, a fixation point appeared inside the central box to signal the beginning of a trial. At the end of a block of trials, the three calibration spots returned. A complete block lasted only three minutes. Subjects participated in four blocks of experimental trials. However, two of the subjects were given an additional block at the beginning of the session as they were not so familiar with the eye movement equipment.

The instructions to the subject were given informally. The eye movement system was briefly explained and it was emphasised that the subject was required to keep his head as still as possible. He was told that each block started after a button-release with the appearance of calibration spots, which had to be followed with the eyes. The subject was encouraged not to blink during the calibration or during an experimental trial. The box positions were described. The subject was informed that each trial had to be initiated by a button-release. This would produce a fixation point inside the central box, which had to be fixated. This was followed by a target which appeared inside either the left or the right box. A saccade had to be made to this as quickly and as accurately as possible. The subject was told that the target would occur at different time intervals following the start of a trial, but that he was not to anticipate the target or to saccade to the cue. He was informed of the fact that on each trial one of the peripheral boxes would flash very briefly, followed by a similar flashing of the central box. These events would not be informative in terms of either target position or timing and so the subject was encouraged to ignore them and concentrate on saccading to the target. At the end of a trial, the target and the fixation point disappeared and the subject had to initiate the next trial by releasing the button. It was explained that the calibration spots would be presented again at the end of a block. The self-paced nature of the experiment was stressed and so if the subject required a rest or wished to blink, this could be done before the initiation of the next trial. The experimenter was present throughout the session in order to set up each block and monitor errors, which appeared on a visual display unit. If more than three were made in a block, the subject was informed and asked to reduce the number of errors.

The timing of the trials was changed from that of experiment 4.1. Following the button-release which initiated the trial, the fixation point was presented. After 1000 msec the trial proceeded as shown in Figure 4.1 except that the target and fixation point disappeared 1000 msec after the onset of the peripheral cue. This gave the subject a minimum of 500 msec in which to make the appropriate saccade.

Each block consisted of 56 trials. The first eight were practice trials and were taken at random from approximately the middle of the 48 experimental trials. The 48 trials were divided equally between the three SOAs and further divided into four of each left-right/cue-target combination. The order of presentation was randomised for each block. The computer clock was interrupted every 10 msec so that the saccade latencies were measured to the nearest 10 msec.

A computer program was used to examine the saccade records so that, for example, trials when a blink occurred could be deleted from the analysis. In addition, errors were recorded when a saccade occurred before or 100 msec after the target appeared, or to the wrong location.

4.4.2 Results and Discussion

Only four trials had to be deleted because of blinking or technical problems. 36 errors were made out of a total of 1152 trials, which is a rate of just over 3%.

The medians across the four experimental blocks for the twelve conditions for each subject were put into an analysis of variance with target location (left and right), SOA (100, 300 and 500 msec), and trial-type (invalid and valid) as fixed effects factors. This revealed that there was no significant effect of target location [F(1,5)=1.39, p>0.1] and that it did not interact with any other factors. Because of this, the means of left and right targets for the six subjects are presented in Figure 4.5. Again there was a highly significant effect of SOA [F(2,10)=37.27, p<0.001] but also of trial-type [F(1,5)=13.15, p<0.05]. The interaction between SOA and trial-type was significant [F(2,10)=4.81, p<0.05]. Thus the pattern for saccade latency is rather different to that for simple reaction time. No facilitatory component is present at an SOA of 100 msec and there is increased inhibition at 300 msec. [More inhibition was observed at 300 msec than at 500 msec for four of the six subjects.]

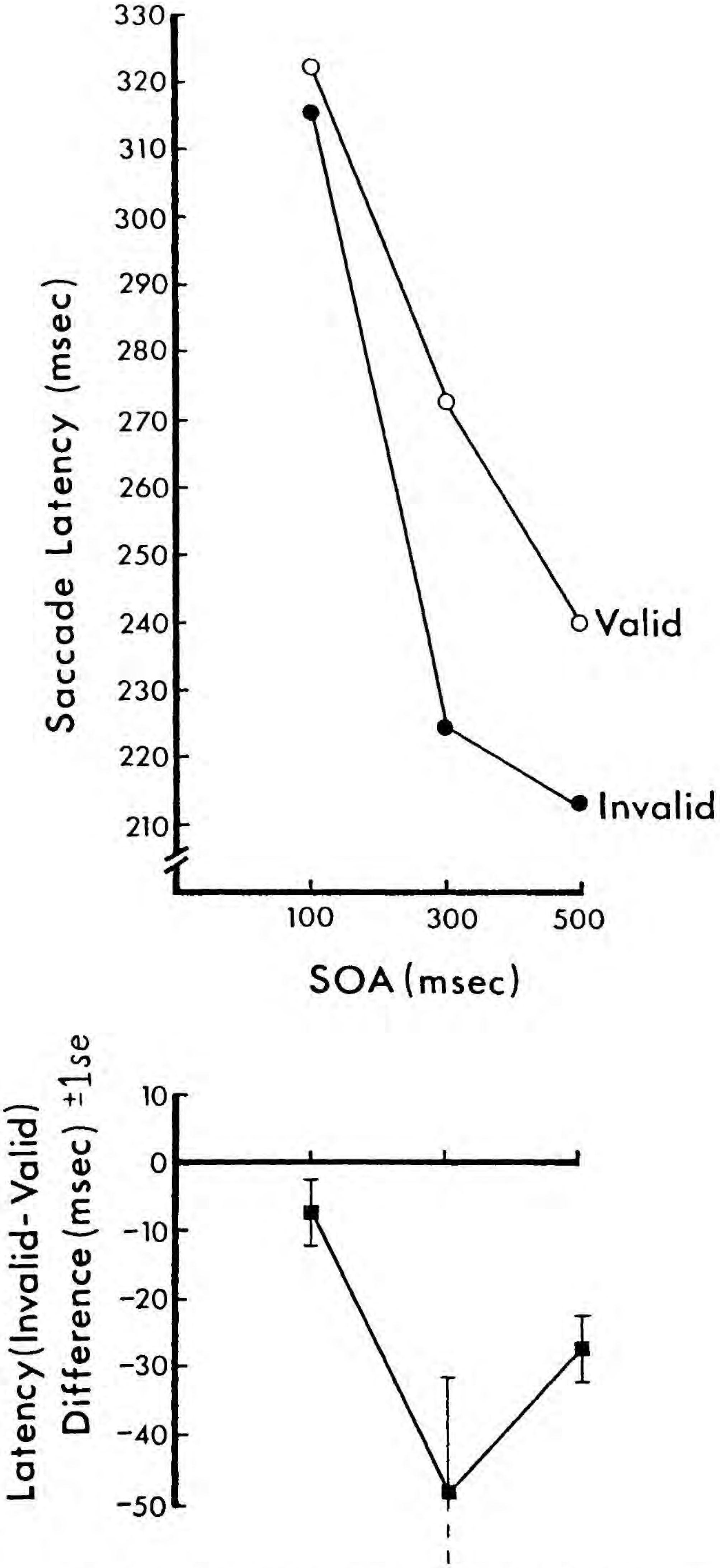


Figure 4.5 Results of experiment 4.3.

Experiments 4.1 and 4.3 differ in three fundamental ways and it is possible that the different results could be due to any one or all of these changes. The first is the use of saccade latency rather than manual reaction time, the second is the use of a choice rather than a simple response, and the third is the altering of the instructions given to the subject to include a description of the cueing procedure. Experiment 4.4 was designed to decide between these three by employing a choice manual reaction time technique.

34 of the 36 errors were easily divided into saccades to the cue and anticipations to the target. Thus 18 saccades were made to the cued box with latencies consistent with a response to the cue (between 160 and 280 msec following the cue onset). 16 errors occurred between 410 and 530 msec after the onset of the peripheral cue and were clearly anticipations of the occurrence of a target at 500 msec. These were equally divided between saccades in the direction of the cue and those in the opposite direction. This suggests that although subjects are quicker to saccade to an invalid target than to a valid target at an SOA of 500 msec, they are not more likely to anticipate in the invalid direction. Although the absolute number of errors was small, this implies that the inhibitory effect observed in this experiment is not due to a change in the evidence required at the cued and uncued locations before a response is made. The remaining two errors had latencies of 350 msec and were possibly

anticipations to a target at 300 msec.

In general the saccades were surprisingly slow (see, for example, Heywood and Churcher, 1980). Both the long delays between trial initiation and target occurrence (1100, 1300 and 1500 msec) and the unblocked SOA procedure probably contributed to this. To assess the effect of the blocking of SOA, one of the slower subjects participated in two further blocks of trials with an SOA of 100 msec only. This reduced saccade latencies from 330 and 320 msec to 240 and 230 msec for valid and invalid trials respectively.

A possible explanation for the abnormally slow saccades at the SOA of 100 msec, compared to the SOAs of 300 and 500 msec, is provided by the work of Ross and Ross (1980; 1981). They found that a nonspecific visual event occurring at the fovea 50-150 msec after the onset of a peripheral target delayed the initiation of a saccade (but not the manual response) to that target. In the present experiment, targets occurring at an SOA of 100 msec were in fact followed after 100 msec by such an event, that is, the brightening of the central box.

From this experiment it can be concluded that the effect of brief non-informative direct cueing on saccade latency is generally one of inhibition. Possible explanations for this will be discussed after experiment 4.4 has been described.

4.5 Experiment 4.4

The different results produced by experiments 4.1 (simple manual reaction time) and 4.3 (saccade latency) could be attributed to one, two or all three changes in methodology made between them, as outlined in the previous section. These were in the *mode* of response (from manual to ocular), in the *type* of response (from simple to choice), and in the information given to the subject regarding the cueing procedure (from no information to a brief description of the cue). Experiment 4.4 was similar to experiment 4.1 except that it used choice rather than simple manual reaction time, and included details of the cueing procedure in the instructions. If the results resembled those from experiment 4.1 rather than those from experiment 4.3, then the different pattern for saccade latency could be attributed unequivocally to the different *mode* of response.

4.5.1 Method

4.5.1.1 Subjects

Six subjects participated in a single experimental session lasting 20 minutes. Five of the subjects had taken part in experiment 4.3.

4.5.1.2 Apparatus and Stimuli

These were as described for experiment 4.3 except that the eye movement recording equipment was not used. Four buttons on the response box were used to initiate trials and to record responses.

4.5.1.3 Design and Procedure

The subject was seated in front of the oscilloscope screen so that the two thumbs rested on the centre two buttons and the forefingers on the outer two buttons of the response box.

The experiment proceeded as described for experiment 4.3 in section 4.4.1.3 except that a manual choice response was required to the target instead of a saccade. The subject initiated a trial by pressing and releasing the two buttons operated by the thumbs. (In fact only one of these buttons actually started the trial, but the subject was asked to press both in order to balance the activity of the two hands before the choice response was made.)

The fixation point appeared inside the central box and the subject was required to look at this throughout each trial. The timing of the individual trials was as given in section 4.4.1.3 except that because choice reaction times are longer than saccade latencies, the target remained on for 1400, 1200 and 1000 msec for SOAs of 100, 300 and 500 msec respectively in order to allow time for a response to be made. The subject was instructed to press the button under the left forefinger when a target occurred inside the left box, and the corresponding right button for targets inside the right box. The cueing procedure was described to the subject in the same way as for experiment 4.3 (see section 4.4.1.3). Each subject participated in two blocks of trials and there were eight practice and 96 experimental trials in a block. In this way there were half as many blocks but twice as many trials in a block as for experiment 4.3. The session was essentially paced by the subject so this change was not important. Choice reaction time was measured to the nearest 10 msec.

4.5.2 Results and Discussion

Only 12 errors (that is, incorrect responses and responses made either before or less than 100 msec after target occurrence) were made out of a total of 1152 trials, and so will not be discussed further. The medians for each experimental condition for each subject were analysed by an analysis of variance, with target location (left and right), SOA (100, 300 and 500) and trial-type (invalid and valid) as fixed effects factors. There was no overall effect of target location [$F(1,5)=1.43$, $p>0.1$], nor was it involved in any significant interaction. Therefore the means of left and right responses across the six subjects are shown in Figure 4.6. There was a significant effect of SOA [F(2,10)=17.39, p<0.001], though not of trial-type [F(1,5)=0.00, p>0.1], and the interaction between the two was significant [F(2,10)=7.26, p<0.02].

First, it should be noted that the effect of SOA is more dramatic in this experiment than in experiment 4.1. The reason for this is not clear although the change in procedure from a continuous task with intertrial intervals from the range 200-700 msec (experiment 4.1) to one where the subject initiated each trial (experiment 4.4) probably contributed to the difference. A second feature of the results is that overall choice reaction time is approximately 200 msec longer than simple reaction time. The increase can be mainly attributed to the additional requirements to discriminate between a left and a right target, make a choice decision and prepare an appropriate motor response. [Because these elements are all involved in the saccade task, it might be expected that the latencies in experiment 4.3 should be similarly increased. Moving the eyes to a peripheral visual event is, however, a highly-practiced and a more compatible response than pressing a key with the left or right hand corresponding to a target to the left or right of fixation.] It is of more interest here that the <u>pattern</u> of results (early facilitation and late inhibition) is very similar between the two manual reaction time tasks. It must be concluded that the results from experiment 4.3 are due to the

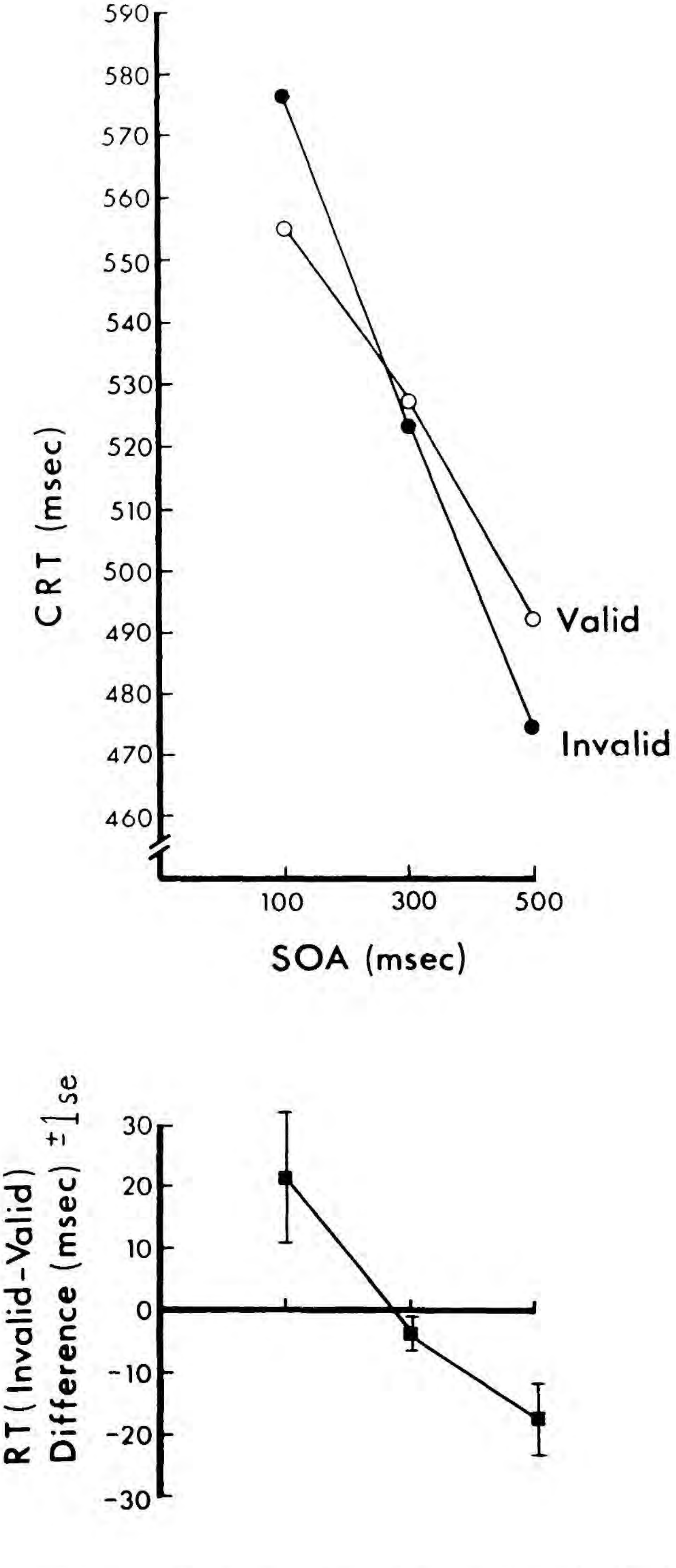


Figure 4.6 Results of experiment 4.4.

requirement to saccade to the target rather than to the introduction of the choice decision, or to the change in the instructions.

4.6 General Conclusions

The experiments reported in this chapter have demonstrated the effects of brief non-informative direct cueing on simple and choice manual reaction time and saccade latency to subsequent targets. For manual responses, detection of targets from a cued location is faster than from an uncued location 100 msec following the onset of the cue. This facilitation is interpreted as being due to externally-controlled covert orienting, that is, the aligning of attention (but not the eyes) with the cued location. [The results of the experiments described in chapter 3 are important here in that they demonstrated that the allocation of attention (although under internal control) to a peripheral location actually speeds the detection of targets from that location with respect to other locations in visual space.] When attention has returned to the centre (drawn either by a central cue, target probability manipulations, or both), facilitation is replaced by inhibition such that detection of targets from the cued location is now slower than from the uncued location. The pattern for saccade latency is different in that the facilitatory component is absent (or at least not present at the three SOAs used), and inhibition is increased at 300 msec. Because the early anticipations made were saccades in the direction of the cue, the lack of facilitation possibly reflects the need to suppress the relatively automatic eye movement response to the peripheral cue which then delays saccades to subsequent targets at the same location. The similarity between the choice and simple manual reaction time results and the fact that anticipations were rarely made in the choice reaction time experiment support the view that the saccade latency result is due to the similarity at some level in the eye movement system between the effect of the cue and the response required, rather than to the introduction of the element of choice.

CHAPTER 5

Divided Attention Studies

5.1 Introduction

Jonides (1981) suggested that a direct cue (a 'high contrast, salient discontinuity in a non-foveal area of the visual field') may automatically capture attention much as it might automatically elicit an eye movement outside the laboratory. Three experiments were reported by Jonides to show that such stimuli have *reflexive* control over attentional allocation. First, he demonstrated that the attention-capturing properties of a direct cue were unaffected by increased alternative demands on processing capacity (an added memory load). Secondly, the effects were resistant to suppression, that is, they occurred even when the subject was instructed to ignore the direct cue. Thirdly, peripheral cues maintained their attention-capturing properties even when the subject did not expect them to occur. The effects of direct cues were contrasted with those of symbolic cues similar to those described in chapter 3. Symbolic cues drew heavily on cognitive resources, they had little effect when the subject ignored them, and their effectiveness in causing attention shifts was directly related to the subject's expectations about their occurrence. These observations led Jonides to conclude that externally-controlled covert orienting is *automatic*.

The results of the experiments reported in chapter 4 seem to support this view. For example, in experiment 4.1 the subject was not informed of the cueing procedure and in fact was told to *ignore* the flickering of the boxes as it would not provide any information about either the timing or the location of the next target (see Appendix C). In Jonides' terms this indicates that the effects of the cue are resistant to suppression and therefore automatic. Facilitation was observed in experiment 4.1 even though the target was equally likely to occur in the cued box as in the uncued box. [Posner (personal communication) found evidence of facilitation even when the target occurred at the cued location on only one tenth of the trials.] In addition, a pilot study was conducted in which the proportion of trials with direct cues in the periphery was reduced (from 100% to 75%), yet the amount of facilitation at the SOA of 100 msec did not decrease. Hence the attention-capturing property of a direct cue in the periphery does not depend upon its validity as a predictor of target location (unlike a symbolic cue - compare experiments 3.1 and 3.2B), nor upon its probability of occurrence. Both these observations suggest that externally-controlled orienting is automatic.

Posner (1978) concluded that automatic processing occurs without intention, without giving rise to conscious awareness and *without producing interference with other mental activity* (see section 1.2). The cost-benefit analysis discussed in chapter 3 provides a means of assessing automaticity in relation to the third criterion. For example, the symmetrical costs and benefits observed in experiment 3.1 were taken as evidence that internally-controlled covert orienting involves the use of the limited capacity attentional system. The evidence presented so far suggests that externally-controlled covert orienting meets the first two criteria for automaticity. In order to investigate the third, a neutral cue is required as the experiments presented in chapter 4 involved comparisons between invalid and valid trials only (equivalent to costs + benefits). There are, however, problems involved in the selection of an appropriate neutral or baseline condition (see, for example, Posner and Snyder, 1975; Simon and Acosta, 1982). First, a neutral cue should have the same general alerting property as a direct cue in the periphery. In addition it should not itself result in orienting to a peripheral location. The inclusion of such a cue would enable a comparison to be made between reaction time to targets following orienting to the periphery (produced by a direct cue) and following no orienting, that is, attention remains at fixation until the appearance of the target. However, an analysis of possible neutral cues reveals that it is difficult to satisfy <u>both</u> the requirements outlined above. For example, the brightening of the central box would not produce orienting away from fixation but may be more alerting than the brightening of a peripheral box by virtue of its foveal location. The simultaneous cueing of both peripheral locations may similarly increase general alertness with respect to a single peripheral cue. Also Posner and Cohen (1980) argued that such a double cue results in reduced externally-controlled orienting to both locations and indeed double-cued trials were faster than invalid but slower than valid trials for the SOA of 100 msec (see section 1.6). The difficulty in equating the alerting properties of events in different modalities rules out the possibility of, for example, an auditory stimulus as a neutral cue. It is therefore concluded that until a suitable neutral cue can be found, the cost-benefit analysis cannot be used to investigate whether or not externally-controlled orienting is automatic.

The successful study of automaticity requires a well-specified, theoretically-motivated set of criteria that can be used to identify an automatic process (Jonides and Irwin, 1981). A number of investigators have tried to establish tests of the adequacy of these criteria (for example, Logan, 1978; Jonides, 1981; LaBerge, 1981; Regan, 1981; Shiffrin, Dumais and Schneider, 1981; Hirst, 1982). In an attempt to clarify recent issues concerning automaticity, LaBerge (1981) examined two properties of automatic processes; absence of capacity limitation and unavoidability.

The first property has been stressed by Posner (1978) who noted that there

> 'is a long history of examining limited capacity mechanisms through interference between tasks. Two signals that occupy the same limited capacity mechanism must be expected to interfere with one another.'(p154)

Although there have been objections to the use of dual task methodology to assess attentional demands (for example, subjects may set up deliberate expectancies that might affect the interference obtained), the experiments in this chapter make use of the technique. Thus they are related to the first of Jonides' (1981) criteria for assessing automaticity, that of the minimal use of mental capacity. The presence of mutual interference between concurrent tasks is usually explained in terms of limitations of either structure or capacity. Structural interference occurs when the interacting tasks require the use of the same specific perceptual or motor mechanisms. A capacity model explains interference in terms of competition for limited capacity and is nonspecific, depending only on the general attentional demands of both tasks. Kahneman (1973) concluded that concepts of capacity and of structure are both needed to account for the patterns of interference from dual task studies. The effects on externally-controlled orienting of three very different secondary tasks were investigated by experiments 5.1, 5.2 and 5.3. This follows Kahneman's recommendation that 'capacity interference is best measured by means of a battery of subsidiary tasks, rather than by a single task'(p182) as 'the results of any single method must be interpreted with caution, because of the ever-present possibility that the observed interference is due to structural factors rather than to limitations of capacity'(p188).

5.2 Experiment 5.1

The secondary task used in experiment 5.1 was dichotic monitoring and was similar to many of the secondary tasks described in Table 4.2 (p132) of Welford (1968). In addition to the primary task (which was identical to experiment 4.1) the subject was required to listen to streams of digits presented to each ear and to count the number of occurrences of a specific target. This extra task did not involve overt responding and had no obvious specific structural requirements in common with the main visual detection task. If the effect of a direct cue in the periphery is entirely automatic, the facilitatory component described in chapter 4 should not be disrupted by this additional cognitive demand.

5.2.1 Method

5.2.1.1 Subjects

Ten subjects each participated in a single experimental session lasting approximately 30 minutes.

5.2.1.2 Dichotic Monitoring Task

The digits 1-9 were spoken and recorded onto a magnetic disc. The IBM computer was then used to digitise the signals so that the digits lasted for the same length of time and were approximately the same volume and frequency. Sequences of these digits were generated by a computer program and then recorded onto cassette tape. They were presented to the subject via headphones. A different digit was played to each ear at a rate of 1.4 per second. All the digits occurred equally often except '6' which had a probability of 0.04 and was used as the target. Following a '6', there was a minimum interval of 10 pairs of digits and a maximum interval of 70 before the next target occurrence. The instructions to the subject were to count silently the number of occurrences of the digit '6', separately for each ear. The subject was told that targets were distributed in such as way that there would be time to update the current total without the risk of missing the next target.

5.2.1.3 Design and Procedure

The headphones were worn throughout the experimental session. The experimenter was present during the entire session in order to switch the cassette player on and off as required. Each subject was given a practice block of trials of the visual task only (described in section 4.2.1.3), followed by two minutes of practice of the dichotic monitoring task.

When the subject was ready to begin the experimental trials, he pressed the single response key. This produced the instructions for the block on the screen. For two of the blocks these were 'COUNT=0' and a reminder to 'Keep eyes on fixation point throughout block'. The subject was informed that this rather curious instruction indicated that only the visual task was required. The instructions for the remaining two blocks were 'COUNT=999' and the fixation reminder, which meant that the dichotic monitoring task was to be carried out in addition to the visual task. The order of the four blocks was randomised for each subject.

The control blocks (visual task only) proceeded as described for experiment 4.1 in section 4.2.1.3. For the dual task blocks, the subject was instructed to treat the visual task as the primary one. Before a dual task block, the experimenter gave a warning signal and then switched on the tape so that the subject began the dichotic monitoring task before starting the visual task. At the end of the block, the experimenter switched off the tape and asked the subject to report the total number of occurrences of the digit '6', separately for each ear. Approximately five targets occurred to each ear during a block. Immediate feedback on performance in the dichotic monitoring task was given.

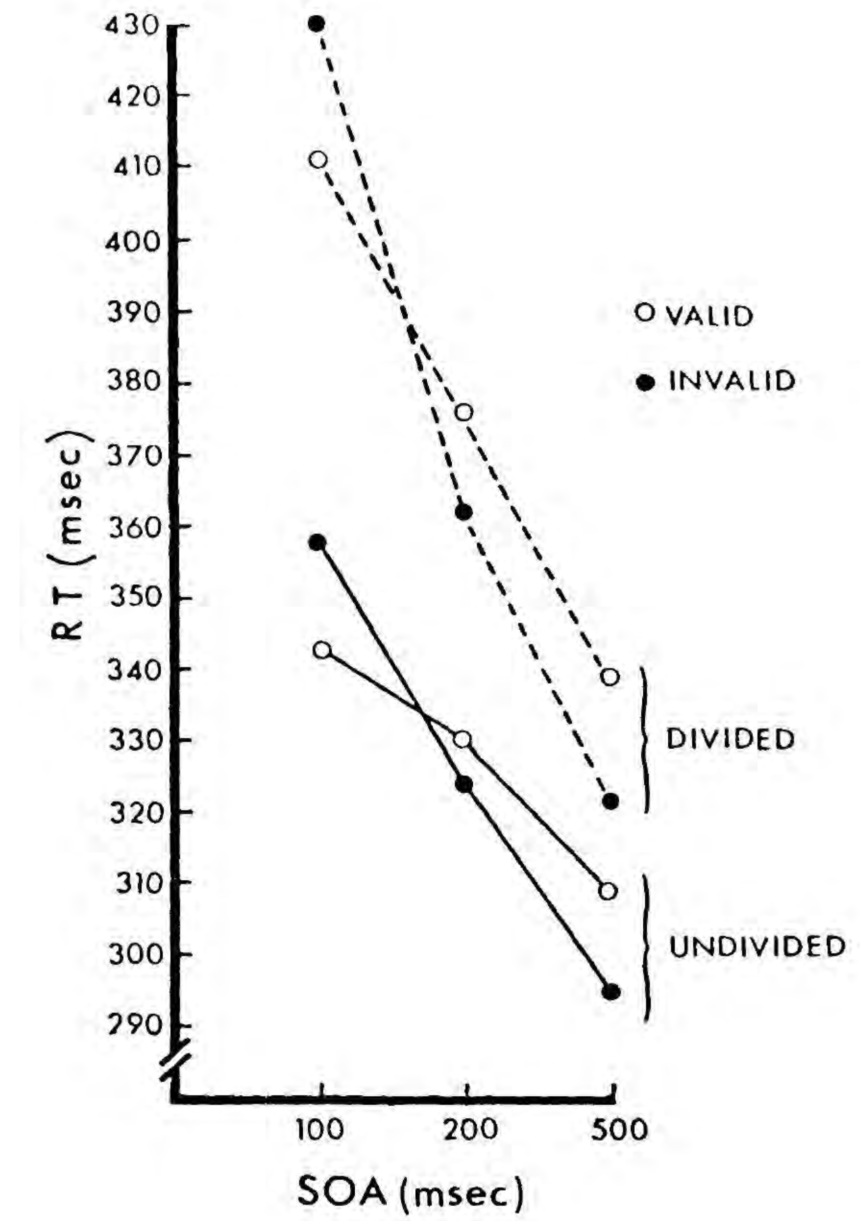
5.2.2 Results and Discussion

The dichotic monitoring task was performed almost perfectly by all subjects. The anticipation rates for the visual task were 3.8% when performed alone ('undivided attention') and 2.8% when performed with the additional task ('divided attention').

The means of the medians from the two blocks of the visual task for each condition were analysed by an analysis of variance with attention (divided and undivided), SOA (100, 300 and 500 msec) and trial-type (invalid and valid) as fixed effects factors. These means from the 10 subjects are presented in Figure 5.1.

There were overall effects of attention [$F(1,9)=13.62$, $p<0.01$], and SOA [$F(2,18)=27.59$, $p<0.0001$], but not of trial-type [$F(1,9)=1.79$, $p>0.1$]. The only significant interactions were those between attention and SOA [$F(2,18)=4.89$, $p<0.05$], and SOA and trial-type [$F(2,18)=10.33$, $p<0.01$]. These are all clearly seen in Figure 5.1. The absence of a significant three-way interaction is illustrated by the similarity of the two reaction time difference functions in the derived graph.

The addition of the extra task significantly increased overall reaction time by about 50 msec, the effect decreasing with longer SOAs. At least part of the increase could be attributed to a change in the



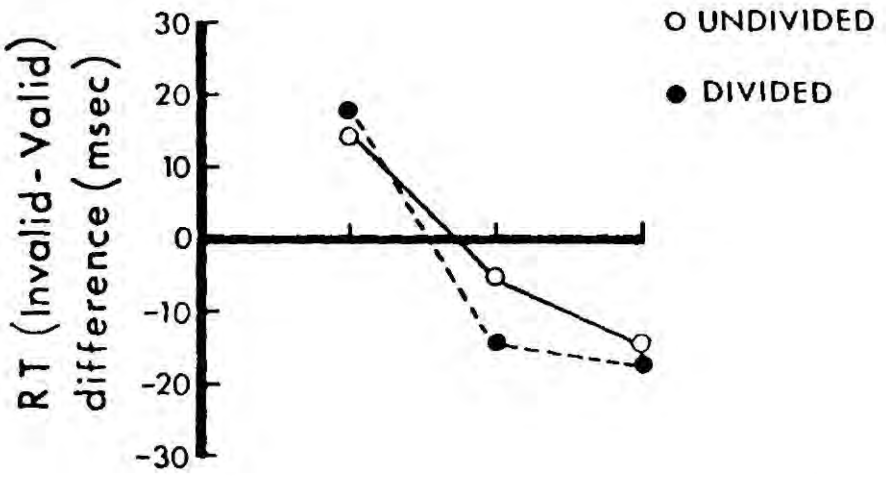


Figure 5.1 Results of experiment 5.1 (Dichotic Monitoring).

speed-accuracy trade-off. The difference between the error rates of 3.8% and 2.8% approached significance using a two-tailed t-test [t=1.84, df=9, p<0.1], so subjects were perhaps performing the visual task more cautiously under divided attention conditions. However, it is unlikely that such a small difference in error rate could account for the substantial reaction time difference. Although the addition of the dichotic monitoring task interfered with the primary visual task to the extent that overall reaction time was increased, the pattern of facilitation and inhibition produced by direct cueing remained unchanged. This result provides further evidence that externally-controlled orienting occurs automatically in response to a peripheral event. However, subjects reported that the dichotic monitoring task was very easy (confirmed by their almost error-free performance) and required only 'passive' listening.

5.3 <u>Experiment 5.2</u>

The failure to disrupt the effects of a direct cue in the periphery by the addition of a reasonably easy secondary task led to the search for a more cognitively-demanding one. Many dual task studies have used counting backwards as a secondary task. For example, Keele (1967) varied the counting decrement and noted that 'as predicted by a capacity model, the quality of performance on each task decreased regularly with the difficulty of the other'. Hockey and Posner (1980) asked subjects to count backwards in threes (aloud) while carrying out a visual detection task very similar to that of Posner and Cohen (1980). They argued that the addition of such a secondary task would provide a 'sensitive test of the degree of automaticity' of externally-controlled orienting. Their prediction was that divided attention would interfere more with facilitation (being due to orienting) than it would with inhibition (being due to sensory information - see Posner and Cohen, 1980). Overall, their results showed little evidence of either facilitation or inhibition in the divided attention condition. However, it is difficult to draw any firm conclusions from their data as the pattern from the first experimental session was different to that from the second (- the two sessions being separated by a day). On the second day there was some evidence of facilitation at 300 msec suggesting that the extra cognitive requirement delayed orienting by 200 msec. As mentioned above, their visual task was based on that of Posner and Cohen (1980) and was therefore similar to experiment 4.1. However, each trial began with the brightening of one of the peripheral boxes for 150 rather than 100 msec so that the early target (at the SOA of 100 msec) occurred while the cue was still present. Because of this, the overall results of Hockey and Posner are difficult to interpret as their valid trials at the SOA of 100 msec may have received an additional benefit from the extra sensory stimulation at the target location. Experiment 5.2 was designed to investigate further the effect on externally-controlled orienting of the secondary task of counting backwards in threes. Like experiment 5.1 the primary task was identical to experiment 4.1 so that the target never occurred while a cue was present.

5.3.1 Method

5.3.1.1 Subjects

Seven subjects participated in a single session of 30 minutes.

5.3.1.2 Apparatus and Stimuli

Details of the apparatus and stimuli are as given for experiment 4.1 in section 4.2.1.2.

5.3.1.3 Design and Procedure

Section 5.2.1.3 provides most of the procedural details. An undivided attention block was again signalled to the subject by the instructions 'COUNT=0'. However, when the number was not zero the subject was required to count backwards in threes (aloud) as fast as possible for the duration of the next block, starting at the three-digit number supplied by the instructions (for example, 'COUNT=512'). Each subject participated in a practice block, followed by two undivided attention blocks (visual task only) and two divided attention blocks (visual and counting tasks). The order of the four experimental blocks was randomised for each subject. Again the visual task was regarded as the primary task and subjects were asked to try to avoid synchronising their manual and vocal responses. The experimenter was in an adjoining room throughout the session in order to monitor the subject's performance on the counting task.

5.3.2 Results and Discussion

All seven subjects were able to carry out the counting task with reasonable accuracy and fluency. The error rates for the visual task were 2.0% and 2.3% for the undivided and divided attention conditions respectively.

The means of the medians from the two blocks for each condition are shown in Figure 5.2. They were also put into an analysis of variance with attention (undivided and divided), SOA (100, 300 and 500 msec), and trial-type (invalid and valid) as fixed effects factors. Again there were overall effects of attention [F(1,6)=49.68, p<0.001], and SOA [F(2,12)=144.87, p<0.0001], but not of trial-type [F(1,6)=0.11, p>0.1]. There were significant interactions between attention and SOA [F(2,12)=9.27, p<0.01], and between attention, SOA and trial-type [F(2,12)=7.11, p<0.01]. The three-way interaction can be seen in the lower graph.

First it should be noted that the results of the undivided attention condition are different to those of

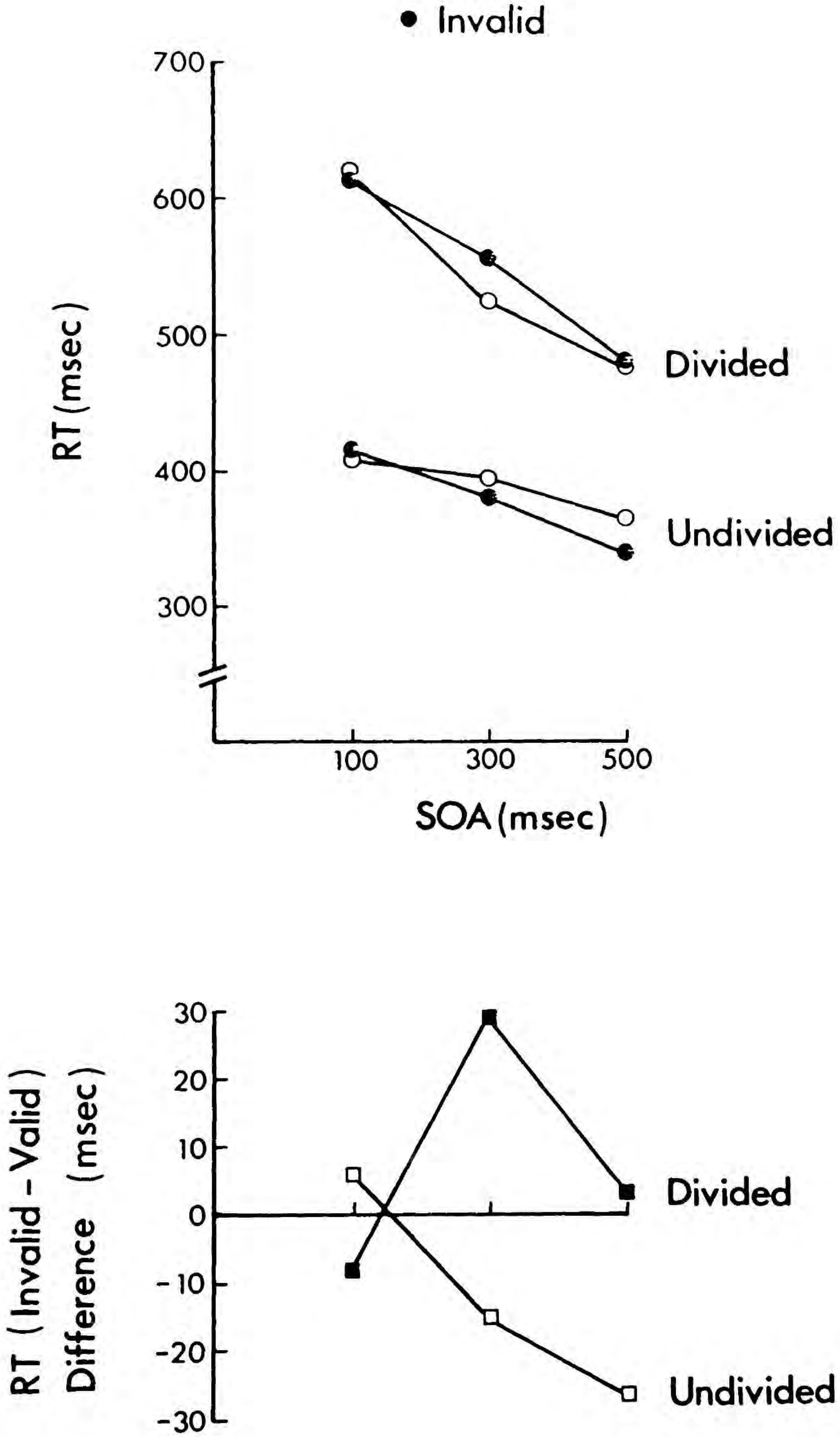


Figure 5.2 Results of experiment 5.2 (Counting Backwards in Threes).

experiments 4.1 and 5.1. Reaction time is increased by approximately 50 msec and the lower graph of Figure 5.2 reveals less facilitation and more inhibition than in the previous experiments. It is unclear why the inclusion of the counting backwards task in half of the experimental blocks should increase reaction time in the remaining visual-task-only blocks. It must be concluded that the seven subjects who took part in the present experiment were generally slower than normal. This is supported by further analysis of the data from experiment 4.1. The following three correlations approached significance : first, between the amount of facilitation and overall reaction time at the SOA of 100 msec [$r=-0.49$, $df=12$, $0.05<p<0.1$], secondly, between the amount of inhibition and overall reaction time at the SOA of 500 msec [$r=0.49$, $df=12$, $0.05<p<0.1$] and finally, between the overall invalid-valid difference and reaction time [$r=-0.47$, $df=12$, $0.05<p<0.1$]. To summarise these findings, the general pattern for slow subjects tends to be one of inhibition, while facilitation characterises the results of fast subjects. As can be seen from the lower graph of Figure 5.2, the results for the undivided attention condition are in agreement with this conclusion. (The correlations presented above will be discussed further in chapter 8.)

In agreement with the results of Hockey and Posner (1980), the secondary task of counting backwards in threes increased overall reaction time on the primary visual task by 160 msec. It can also be seen from Figure 5.2 that the pattern of facilitation and inhibition is similar to that found in the second session of their study, that is, facilitation at the SOA of 300 rather than 100 msec. (Of the seven subjects, six showed most facilitation at 300 msec.) A further study was carried out by a group of undergraduate students, also using counting backwards in threes as the secondary task, the primary task again being similar to experiment 4.1. However, many more subjects took part (18 rather than 7) and twice as many trials were given to each subject in both the divided and undivided attention conditions. The results are shown in Figure 5.3. The overall difference between the divided and undivided attention conditions was 150 msec which is very similar to the difference of 160 msec observed in experiment 5.2 and in Hockey and Posner's study. If the results of the undivided attention condition alone are considered, it can be seen that they are very similar to those of experiments 4.1 and 5.1, again suggesting that the seven subjects who participated in the original version of experiment 5.2 (see Figure 5.2) were unusually slow. A comparison of the results from the divided and undivided attention conditions reveals that doubling the number of trials did not affect the overall reaction time difference but did alter the pattern of facilitation and inhibition as seen in the lower graph of Figure 5.3. Facilitation at the SOA of 100 msec was increased and inhibition at 500 msec reduced in the divided attention condition with respect to the undivided attention

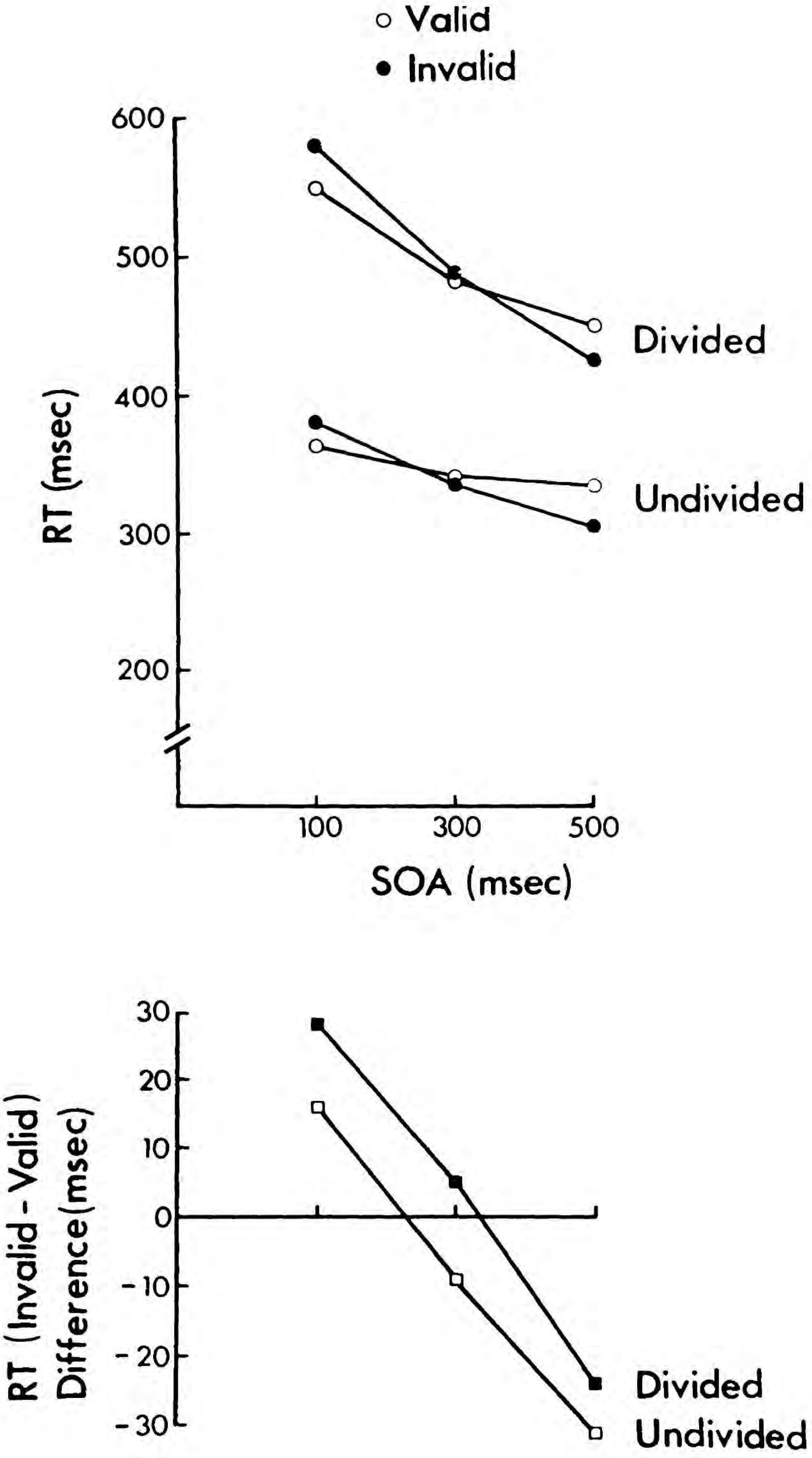


Figure 5.3 Results of an extended version of experiment 5.2 (Counting Backwards in Threes).

condition.

It is important to consider these results in relation to Posner and Cohen's (1980) model (- see also Cohen, 1981). As described in section 1.6 they concluded from their experiments on externally-controlled covert orienting that the facilitatory component is attentional. A direct cue in the periphery initially summons attention so that targets appearing in that location have an advantage (in terms of reaction time) over those in uncued locations. However, after attention returns to fixation, the early facilitation is replaced by inhibition such that reaction time to targets appearing at the cued location is slower than to those at uncued locations. Posner and Cohen noted that the inhibitory effect occurs 'without the need for any deliberate strategy on the part of the subject' and is therefore quite automatic. It is regarded as sensory rather than attentional in origin, that is, inhibition arises from the sensory information presented at the cued location and not necessarily from the covert orienting produced by the cue. They concluded that 'some part of the pathway from the cued location is reduced in efficiency by the cueing', inhibition being the inevitable consequence of the presentation of <u>any</u> visual stimulus in the periphery. On the basis of this model Hockey and Posner (1980) predicted that the addition of a demanding secondary task such as counting backwards in threes would disrupt the facilitatory (attentional) component but would not affect the inhibitory (sensory) component of externally-controlled orienting (see section 5.3).

There are several ways in which the facilitatory component might be expected to change under dual task conditions. For example, the additional load may prevent attention being allocated entirely to the cued location so that facilitation may still occur at the early SOA but be reduced in magnitude. Alternatively, facilitation may occur at a later SOA if the extra cognitive load either delays or slows down the movement of attention to the cued location. If the results of the experiments with counting backwards in threes as the secondary task are now considered, it appears that there is some evidence for the latter possibility. Both the results from the second session of Hockey and Posner's (1980) study and from the original version of experiment 5.2 (Figure 5.2) can be interpreted in terms of a *delayed* facilitatory component occurring at an SOA of 300 rather than 100 msec. However, the results from the extended version of experiment 5.2 (Figure 5.3) are more difficult to explain in such terms unless it is assumed that facilitation is normally maximal at an SOA of *less* than 100 msec so that a small delay would result in an *increase* in facilitation at 100 msec. This assumption receives some support from the results of a study by Tsal (1983) which indicated that approximately 85 msec is required for attention to move to a direct cue appearing 4.2 degrees from fixation.

There are at least two problems involved in interpreting these results in relation to models of externally-controlled orienting. If facilitation and inhibition are separate, independent processes (Posner and Cohen, 1980; Cohen, 1981), then the invalid-valid difference graphs reflect the net reaction time effects, that is, the sum of facilitation and inhibition. So for any particular SOA it is possible to make relative but not absolute judgments about the size of the facilitatory and inhibitory components. If, however, inhibition is a consequence of externally-controlled orienting (as will be argued in later chapters) and facilitation is delayed under cognitively-demanding conditions, then the SOAs used in the experiments may be inappropriate for testing the model. Despite these problems it is possible to draw some tentative conclusions from the data. Posner and Cohen's model would predict that in the divided attention condition the overall invalid-valid reaction time difference would be smaller than, or the same as that in the undivided attention condition (that is, assuming a reduction or a delay in facilitation respectively). This is because inhibition (being attributed to sensory rather than attentional factors) would be unaffected by the additional task whereas facilitation (being attentional and therefore competing for limited capacity) might be reduced or delayed. Both versions of experiment 5.2 (see Figures 5.2 and 5.3) reveal an increase in the overall invalid-valid difference which is evidence against the model of Posner and Cohen (1980), the results being more consistent with the view that inhibition is dependent upon facilitation. Experiment 5.3 was designed to investigate further the two models of externally-controlled covert orienting presented above by employing secondary tasks which varied the demands of fixation.

5.4 Experiment 5.3

Several visual concurrent tasks were used in experiment 5.3 which required predictable and unpredictable pursuit eye tracking of a slowly-moving spot inside the central box. In the unpredictable case, at the moment when the peripheral box brightened, the fixation spot jumped to a different position within the central box and the subject was required to follow the movement with a small saccade. In the predictable conditions, the spot continued to move smoothly. Jonides (1981) suggested that the effectiveness of a direct cue in producing covert orienting lies in its similarity to visual stimuli that elicit reflexive saccades. So a direct cue in the periphery captures attention because it exploits a predisposition of the visual system to respond to salient events beyond the fovea. However, if overt orienting is required to the central fixation point at the same time as a direct cue is presented in the periphery, this may have the effect of abolishing facilitation because the orienting system will be dominated by the fixation requirements. If this is the case, it is important to know whether or not inhibition is also abolished in order to decide between the models discussed in section 5.3.2.

5.4.1 Method

5.4.1.1 Subjects

Fifty subjects each participated in a single session lasting approximately 10 minutes. They were divided equally between five experimental conditions.

5.4.1.2 Apparatus and Stimuli

The apparatus and stimuli were as described for experiment 4.1 in section 4.2.1.2. However, the black fixation point was removed from the front of the oscillscope screen. In its place a single spot of the same intensity as those making up the rest of the display was presented inside the central box. Five experimental conditions were used which differed in the activity of this fixation point. For the 'Random Eye Movements' condition it was not presented at all. In the two smooth pursuit conditions the spot moved sinusoidally either horizontally ('Horiz') or vertically ('Vert') within the central box at a rate of approximately 0.5 Hz. For the remaining two conditions the spot moved in one dimension (horizontal or vertical) until the presentation of the direct cue in the periphery. It then jumped to moving in the other dimension until a detection response to the target appearing in the peripheral box had been made. At this point the spot returned to its original tracking dimension. So for one condition the intertrial tracking dimension was horizontal and the within-trial dimension was vertical ('H-V'), and for the other condition these were reversed ('V-H'). In this way a small saccade was required both at the trial onset and offset. These conditions are illustrated in the upper panel of Figure 5.4.

5.4.1.3 Design and Procedure

In the first condition (Random Eye Movements) the subject was asked to perform the simple detection task of experiment 4.1 (as described in section 4.2.1.3) while allowing his eyes to move wherever he wished. Informal reports from a pilot study indicated that subjects only moved their eyes for one block of trials, fixating on the central box during subsequent blocks (see also section 2.8). For this reason the 10 subjects in the first condition were only required to participate in one block of trials.

For the remaining four conditions each subject participated in two blocks of trials. The subject was required to track the movements of the fixation point inside the central box with his eyes. He was not informed of the precise relationship between the timing of the jumping of the spot and the occurrence of the direct cue in the second two conditions. Although these visual concurrent tasks were difficult, most subjects reported

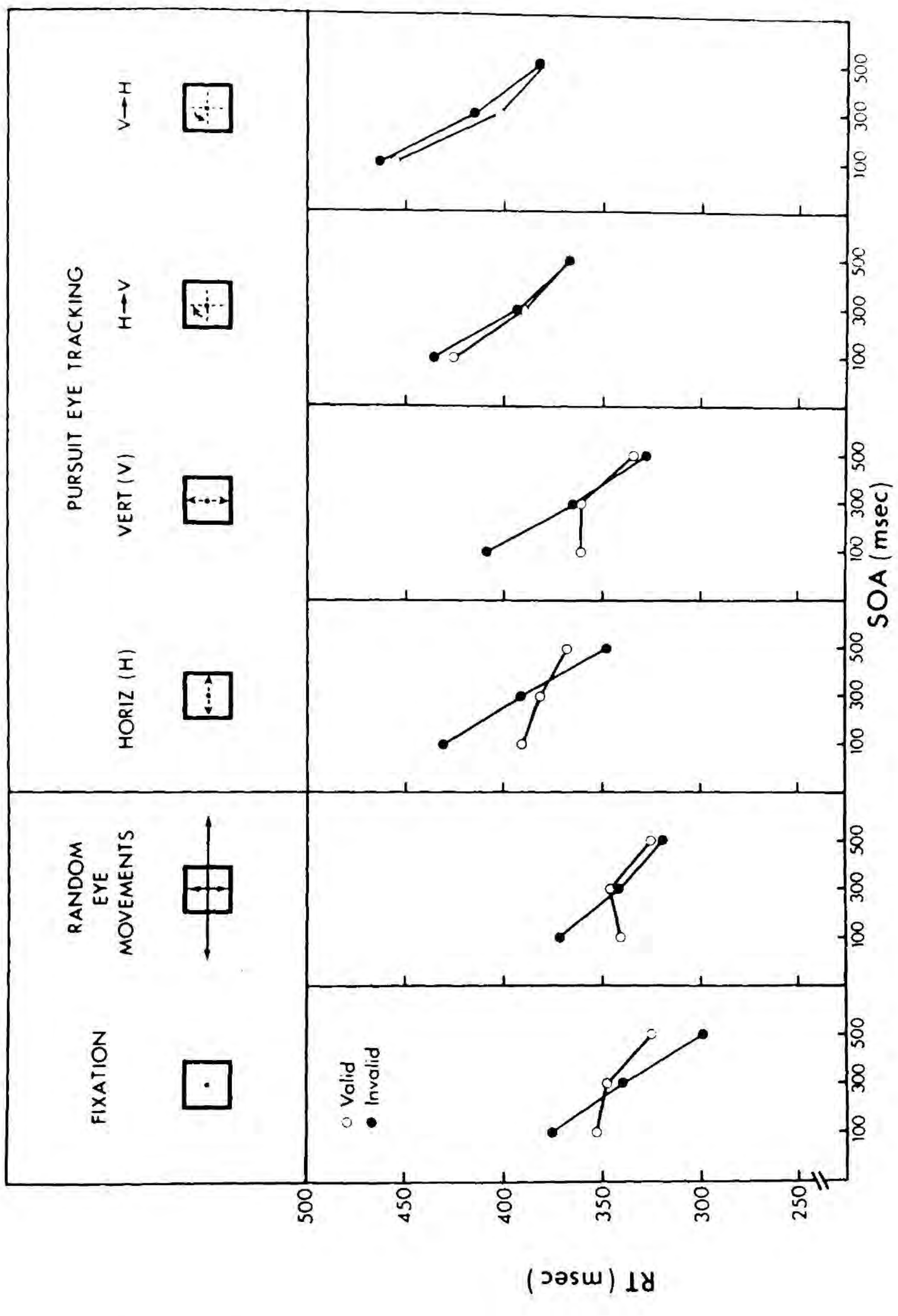


Figure 5.4 Results of experiment 5.3.

that they were able to follow the movements of the spot throughout the experimental session. [This is in agreement with the results of Malmstrom, Randle, Murphy, Reed and Weber (1981) who examined performance over six minutes on visual tracking tasks of horizontal sinusoidally-moving targets. They found that subjects were able to keep pace with the target, that is, there was no tendency toward increasing or decreasing phase lag.] Subjects in the present experiment were again reminded that visual detection of the peripheral targets was the primary task.

5.4.2 Results and Discussion

The results are presented in Figure 5.4. For comparison purposes the data from experiment 4.1 ('Fixation') are also included. With the exception of the random eye movements condition (where only one block was run), the means of the medians from the two blocks for each group of 10 subjects are presented. A separate analysis of variance was carried out for each condition with SOA (100, 300 and 500 msec) and trial-type (invalid and valid) as fixed effects factors. The anticipation rate was less than 4% for every condition.

For the random eye movements condition the effect of SOA was significant [$F(2,18)=5.43$, $p<0.05$], the effect of trial-type approached significance [$F(1,9)=3.69$, $p<0.1$], and there was a significant interaction between the two

[F(2,18)=7.26, p<0.01]. Overall reaction time for both the fixation and the random eye movements conditions was 340 msec. For the SOA of 100 msec there is more (but not significantly more, t=1.13,df=22,p>0.1,2-tailed test) facilitation in the random eye movements condition than in the fixation condition. This can be attributed to the benefit of foveal processing of early valid targets, assuming that in the random eye movements condition the subject made a saccade to the direct cue in the periphery. The explanation for the results at the SOAs of 300 and 500 msec is not clear because of the difficulty in specifying subsequent eye position. The subject may have saccaded to the centre following its brightening, but some subjective reports indicated that the central box was not fixated during a block because it never contained a target. Cohen (1981) reported that a once-foveated stimulus undergoes inhibition when the eyes are moved to a new location. The similarity of the reaction times to later valid targets between the fixation and random eye movements condition suggests that following a saccade to the direct cue, the eyes moved elsewhere, leaving the cued location inhibited. If the subject made a saccade to the opposite box, invalid targets would then benefit from foveal processing. However, it can be seen from Figure 5.4 that reaction time to invalid targets is increased at 500 msec with respect to the invalid trials in the fixation condition. Following an initial saccade to the direct cue in the periphery, there were probably large individual differences in eye movement activity, including a saccade to the brightening of the central box, a saccade to the opposite box (after a failure to find a target in the cued one), or no saccade at all. Therefore without accurate eye movement records and because invalid and valid targets are not necessarily equidistant from fixation when eye movements are allowed, further interpretation of these results would be speculative. The main conclusion from the random eye movements condition in relation to the divided attention studies is that the requirement to move the eyes freely does not increase overall reaction time, but may affect the pattern of facilitation and inhibition in ways that might be predictable from an analysis of eye position.

Turning to the conditions where eye tracking was the secondary task, the overall reaction times were 384, 359, 397 and 416 msec for the H, V, H-V and V-H conditions respectively. Thus in comparison with the fixation condition, overall reaction time is increased by 32 msec when the subject is also required to track a smoothly-moving central spot and by 67 msec when the spot moves in an unpredictable way. This is in agreement with Williams (1982) who found that 'peripheral visual processing is impaired more when the subject must also process a high foveal (cognitive) load as opposed to a low level of foveal load'.(p691) Although it appears that tracking a fixation point moving along the horizontal dimension <u>during</u> a trial (conditions H and V-H) interferes more with the primary task than vertical tracking (conditions V and H-V), the overall difference of 22 msec failed to reach significance on a 2-tailed t-test [t=1.38, df=38, 0.1<p<0.2]. The patterns of results from the two smooth pursuit eye tracking tasks (H and V) are very similar. For the H condition the analysis of variance revealed significant effects of SOA [F(2,18)=22.63, p<0.0001], trial-type [F(1,9)=6.18, p<0.05] and an interaction between the two [F(2,18)=29.42, p<0.0001]. Similarly, for the V condition there were significant effects of SOA [F(2,18)=24.29, p<0.0001], trial-type [F(1,9)=16.26, p<0.005] and an interaction between them [F(2,18)=35.33, p<0.0001]. Compared to the fixation condition there is increased faciliatation at 100 msec, a small amount at 300 msec and reduced inhibition at 500 msec. This is seen more clearly in the differences graph shown in Figure 5.5. The pattern is very similar to that found in the extended version of experiment 5.2 (see Figure 5.3). It was suggested in section 5.3.2 that a possible explanation for these results is that the facilitatory component is either slowed down or delayed because of the demands of the secondary task. If facilitation is maximal at an SOA of less than 100 msec in the undivided attention condition, then a small delay would result in increased facilitation at 100 msec. The range of SOAs used in the present experiment makes further speculation difficult (particularly regarding inhibition). However, it is important to note that the requirement to move the eyes smoothly within the central box does not abolish externally-controlled covert orienting (as inferred from the presence of facilitation).

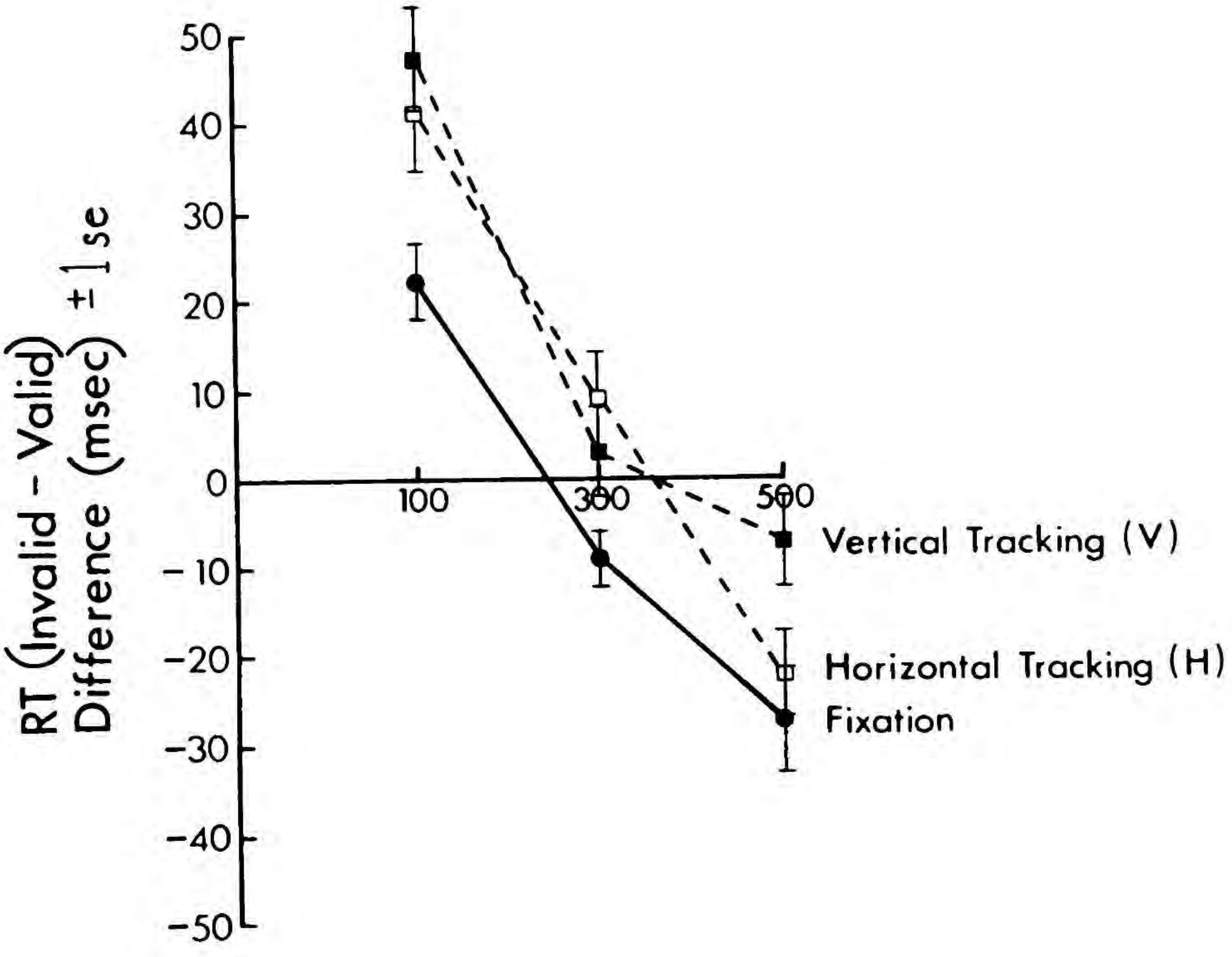


Figure 5.5 Invalid-valid differences from experiments 4.1 (fixation condition) and 5.3 (smooth pursuit eye tracking conditions only).

When saccadic eye movements were required within the central box (H-V and V-H conditions) rather than smooth pursuit, overall reaction time was increased by 35 msec (although the error rates were identical). In addition, the requirement to prepare a small saccade at the moment when the direct cue occurs in the periphery either delays externally-controlled orienting until after 500 msec or abolishes it altogether. Although it appears that there may be evidence of a small amount of facilitation at the early SOAs, this was not confirmed by the analyses of variance. For the H-V condition there was a significant effect of SOA [F(2,18)=29.75, p<0.0001], but not of trial-type [F(1,9)=1.69, p>0.1], and there was no interaction between the two [F(2,18)=0.24, p>0.1]. Similarly, for the V-H condition there was a significant effect of SOA [F(2,18)=31.84, p<0.0001], but not of trial-type [F(1,9)=1.88, p>0.1], and there was no interaction [F(2,18)=0.84, p>0.1]. It is therefore concluded that the requirement to orient overtly to the central task prevents covert orienting to the direct cue in the periphery. In addition, there is no later inhibitory effect which provides support for the view that inhibition is <u>dependent</u> upon prior orienting. Cohen (1981) claimed that only the facilitatory process is an active one and that under dual task conditions facilitation would be attenuated, while the inhibitory component would continue to exert its full influence. However, the results presented here argue against this. When facilitation is prevented, inhibition does not occur, but if there is facilitation, then inhibition generally follows as a consequence. The only possible exception to the latter conclusion is the random eye movements condition where it is likely that following an eye movement to the cued location, foveal processing may compensate for inhibition. [Posner, Cohen and Rafal (1981) also have evidence that under certain conditions the conscious allocation of attention can overcome the inhibitory effect. This will be considered in more detail in chapters 6 and 9.]

5.5 General Conclusions

The first conclusion that can be drawn from the results of these divided attention studies is that the pattern of facilitation and inhibition produced by the addition of a secondary task cannot be predicted from the overall increase in reaction time. For example, for both versions of experiment 5.2 (which differed mainly in the number of trials given to each subject), the increase was about 160 msec and yet a comparison of Figures 5.2 and 5.3 reveals that they produced different patterns of facilitation and inhibition. Similar patterns resulted from secondary tasks which increased overall reaction time by 150 msec (Figure 5.3) and by 32 msec (Figure 5.5). Despite an overall reaction time increase of 50 msec in experiment 5.1, the facilitation-inhibition pattern was unaffected by a dichotic monitoring task although it was dramatically changed by an unpredictable tracking task (conditions H-V and V-H of experiment 5.3) which increased reaction time by a similar amount (67 msec). In section 5.1 a distinction was made between capacity and structural interference. It is possible that the overall reaction time differences reflect the additional demands on general capacity made by the secondary task (for example, Logan, 1978; 1979; 1980b), whereas a change in the pattern of facilitation and inhibition may indicate competition for the specific resource of orienting. Certainly the most dramatic results are those from experiment 5.3 where it appears that facilitation can be abolished if the direct cue in the periphery occurs at the same time as a discontinuity in a central tracking task which requires the programming and execution of a small saccadic eye movement (that is, externally-controlled overt orienting). This provides tangential support for Jonides' (1981) view that a direct cue in the periphery captures attention because of its similarity to stimuli that elicit reflexive saccades. Indeed, when eye movements were encouraged, an increase in facilitation and subjective reports suggested that subjects did move their eyes to the cued location. However, if the eye movement preparation system is occupied by the requirement to respond to the highly-demanding central task of the refixation of a bright spot following its sudden movement, covert orienting to the direct cue in the periphery cannot simultaneously occur.

Although some of the results are difficult to interpret because of the limited number of SOAs used, they are generally inconsistent with the model of externally-controlled covert orienting proposed by Posner and Cohen (1980) and developed by Cohen (1981). They argued that the facilitatory and inhibitory components are independent and can be attributed to attentional and sensory factors respectively. Thus, under divided attention conditions their model would predict either no change or a decrease in the overall invalid-valid reaction time difference (corresponding to either a delay or a reduction in facilitation, inhibition being unaffected). However, the results of the experiments presented in this chapter generally show an increase in the overall invalid-valid difference with the addition of a secondary task. This is more consistent with the view that inhibition occurs as a consequence of externally-controlled covert orienting. Thus if the facilitatory component is delayed under divided attention conditions, inhibition will be similarly delayed and may not occur until after the longest SOA used in the present experiments. Further support for the view that inhibition is dependent upon facilitation will be provided in chapter 8.

To conclude, externally-controlled covert orienting does not occur automatically in response to an event in the periphery as it can be prevented or delayed by certain secondary tasks. The next chapter explores further properties of the facilitatory and inhibitory components involved in externally-controlled covert orienting.

CHAPTER 6

Further Characteristics of Externally-Controlled Orienting and its Consequences

6.1 Introduction

This chapter considers the time courses and the effects of repetition on the facilitatory and inhibitory components of externally-controlled orienting. Such an investigation is important in order to compare orienting with other phenomena and to specify more precisely the conditions necessary for its occurrence. The experiments presented in the previous chapter demonstrated that externally-controlled covert orienting does not occur automatically in response to every event in the visual periphery. Experiment 6.1 was designed to investigate whether or not orienting can be affected by factors other than those discussed in chapter 5. Experiments 6.2-6.4 are concerned with the spatial and temporal parameters of the inhibitory component and were conducted in order to test the possible explanations of inhibition (for example, masking and habituation) which were described in section 1.6.

6.2 Experiment 6.1

Posner (1982) traced the study of externally-controlled orienting to the orientation reaction (OR) as described by Sokolov (1963). The 'neuronal model' theory proposed that an incoming stimulus is analysed at the cortical level and a comparison is made with a neuronal model constructed by prior experience. An OR occurs when there is a disconfirmation of the central model and can be considered as a set of physiological changes elicited by the detection of novel or significant stimuli. Kahneman (1973) described four components of the OR : 1) a transient effort to process and analyse the alerting stimulus, 2) inhibition of ongoing activity, 3) an orientation toward probable sources of future significant information and 4) a transient increase in arousal (p47-48). The aim of experiment 6.1 was to investigate the effect of cue repetition on externally-controlled covert orienting, as one of the most important characteristics of the OR is habituation with repetition. This does not imply that the stimulus is no longer analysed, but that because the subject has come to expect the stimulus, the OR occurs only when the characteristics of the stimulus violate expectations (Kahneman, 1973).

The order of presentation of the cues in experiment 4.1 was randomised with the restriction that within a block of 120 trials, 60 cues were on the left and 60 on the right (see section 4.2.1.3). The present experiment investigated the effect on externally-controlled orienting of three non-random cue sequences. They differed according to the number of consecutive trials in which the same cue was presented. It was predicted that an increase in the 'cue run length' would lead to a decrease in facilitation as a result of habituation of the orienting response.

6.2.1 Method

6.2.1.1 Subjects

28 subjects each participated in a single experimental session of 10 minutes. 10 subjects were randomly assigned to the first condition, 10 to the second condition and the remaining 8 to the third condition.

6.2.1.2 Apparatus and Stimuli

These were as described for experiment 4.1 in section 4.2.1.2.

6.2.1.3 Design and Procedure

Each subject participated in two blocks of 120 trials. For all three conditions a block was divided into 40 trials of each SOA (100, 300 and 500 msec). These were further divided so that targets appeared 20 times on the left and 20 times on the right. For each block of trials the SOAs and target locations were randomised.

The three conditions differed according to cue run length in the following way. For the first condition (cue run length = 1), the cue on each trial merely alternated between the left and the right, starting with the left. In the second and third conditions the cue run lengths were 5 and 30 respectively; for example, in the second condition five cues on the left were followed by five cues on the right, and so on. This pseudorandomisation of cue location, target location and SOA led to slightly unequal numbers of trials in a block of the six experimental types (3 SOAs x 2 trial-types). However, there was no overall systematic bias in trial distribution because of the use of a different sequence of target locations and SOAs for each block.

The computer printed out the cue location, target location, SOA and reaction time separately for each trial, in addition to the usual summary data at the end of every block. All other procedural details, including the instructions given to the subject, were identical to those of experiment 4.1 (see section 4.2.1.3).

6.2.2 Results and Discussion

For all three conditions the subjects reported that they were unaware of the cueing procedure. The percentage anticipation rates were 3.0, 3.6 and 2.8 for cue run lengths of 1, 5 and 30 respectively.

For each cue run length, the means of the medians from the two blocks for each subject were put into a separate analysis of variance with SOA and trial-type as fixed effects factors. The overall means are presented in Figure 6.1 for the three conditions in addition to the data from experiment 4.1 where the cue order was randomised (included for comparison). It appears that facilitation does indeed decrease with increasing cue run length. However, the separate analyses of variance were very similar. There were significant effects of SOA [all three F ratios being greater than 1 with $p<0.0005$], but not of trial-type [$p>0.05$], and all three interactions between SOA and trial-type were significant [$p<0.01$]. To confirm that the pattern of facilitation and inhibition did not change as a function of cue run length, a further analysis of variance was carried out with cue run length as a between-subjects factor and with repeated measures on the within-subjects factors of SOA and trial-type. This revealed that there was no overall effect of cue run length [$F(2,25)=0.83$, $p>0.1$], or of trial-type [$F(1,125)=3.61$, $p>0.05$], but a highly significant effect of SOA [$F(2,125)=84.06$, $p<0.0001$]. The crucial overall three-way interaction between cue run length, SOA and trial-type failed to reach significance [$F(4,125)=1.58$, $p>0.1$], the only significant interaction being that between SOA and trial-type [$F(2,125)=37.22$, $p<0.0001$].

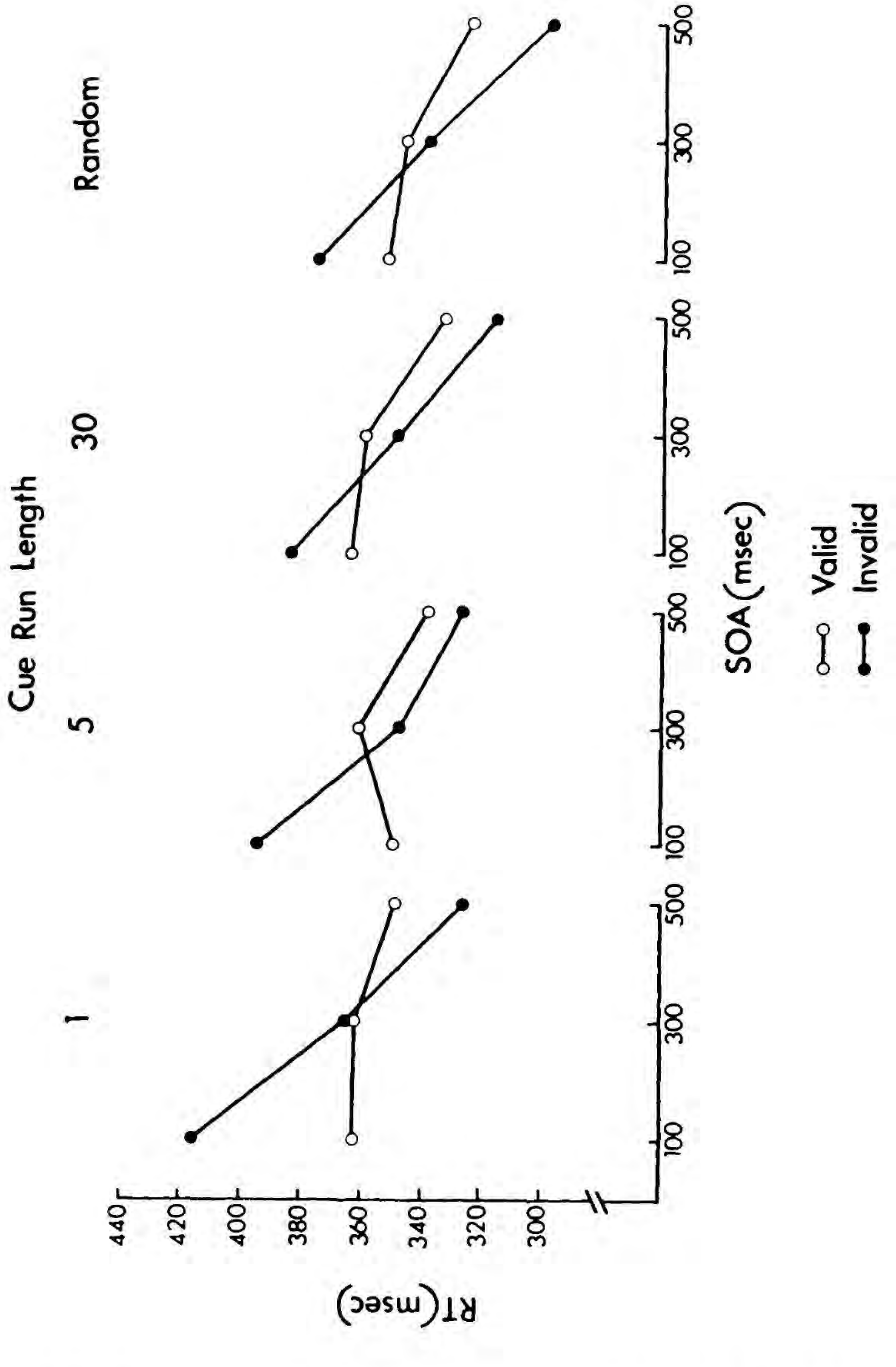


Figure 6.1 Results of experiments 6.1 (Cue Run Lengths of 1, 5 and 30) and 4.1 (Random).

It appears that externally-controlled covert orienting occurs as a result of both random and non-random direct cueing. However, the location of the target remained random throughout a block so it is possible that orienting to the target itself may in some sense reset the system. Although the cue sequences were very different in the four conditions (including experiment 4.1), the total number of successive events in a block (both cues and targets) occurring in the same location was approximately equal. So if the appearance of both cues and targets results in externally-controlled orienting, then over a block of 120 trials the subject is required to orient to the opposite location to that of the previous event on 120 occasions on average and this is true for all four conditions. This may account for the failure to find an effect of cue run length on orienting.

However, this conclusion leads to the possibility that if externally-controlled orienting occurs to targets, the subject should be slower to respond to those appearing in the same location as on the previous trial than to those in the opposite location, because of the resultant inhibition. There is some evidence to suppose that inhibition as a consequence of orienting to the previous target may last long enough to affect the next reaction time. The slow responses to the invalid trials at the SOA of 100 msec for the cue run length of 1 (more than 20 msec slower than the next slowest condition) could be explained if these trials were still being inhibited from the cue of the previous trial. This would be the case for every invalid trial for the cue run length of 1, but for only a small proportion of invalid trials in the other conditions.

The possibility of there being inhibition caused by orienting to the previous target was investigated by reanalysing the data from the present experiment. The trials from the cue run lengths of 5 and 30 were further divided into those where the target location was the same as on the previous trial and those where the target location changed. In order to ensure that only one location was affected by the cue, only the trials where the cue was in the same location as on the previous two trials were used. For the cue run length of 5 this led to the loss of two-fifths of the data. Also, because this further analysis was not anticipated when the experiment was designed, the numbers of trials of each type were not equal. Consequently, the results from two subjects in the cue run length of 5 had to be deleted from this analysis because of their asymmetrical distribution of trials.

The medians over the two blocks were put into two separate analyses of variance with target location (same or different compared to the previous trial), SOA (100, 300 and 500 msec) and trial-type (invalid and valid) as fixed effects factors. The overall means are presented in Figure 6.2. For the cue run length of 5 there were significant effects of target location [$F(1,7)=22.58$,

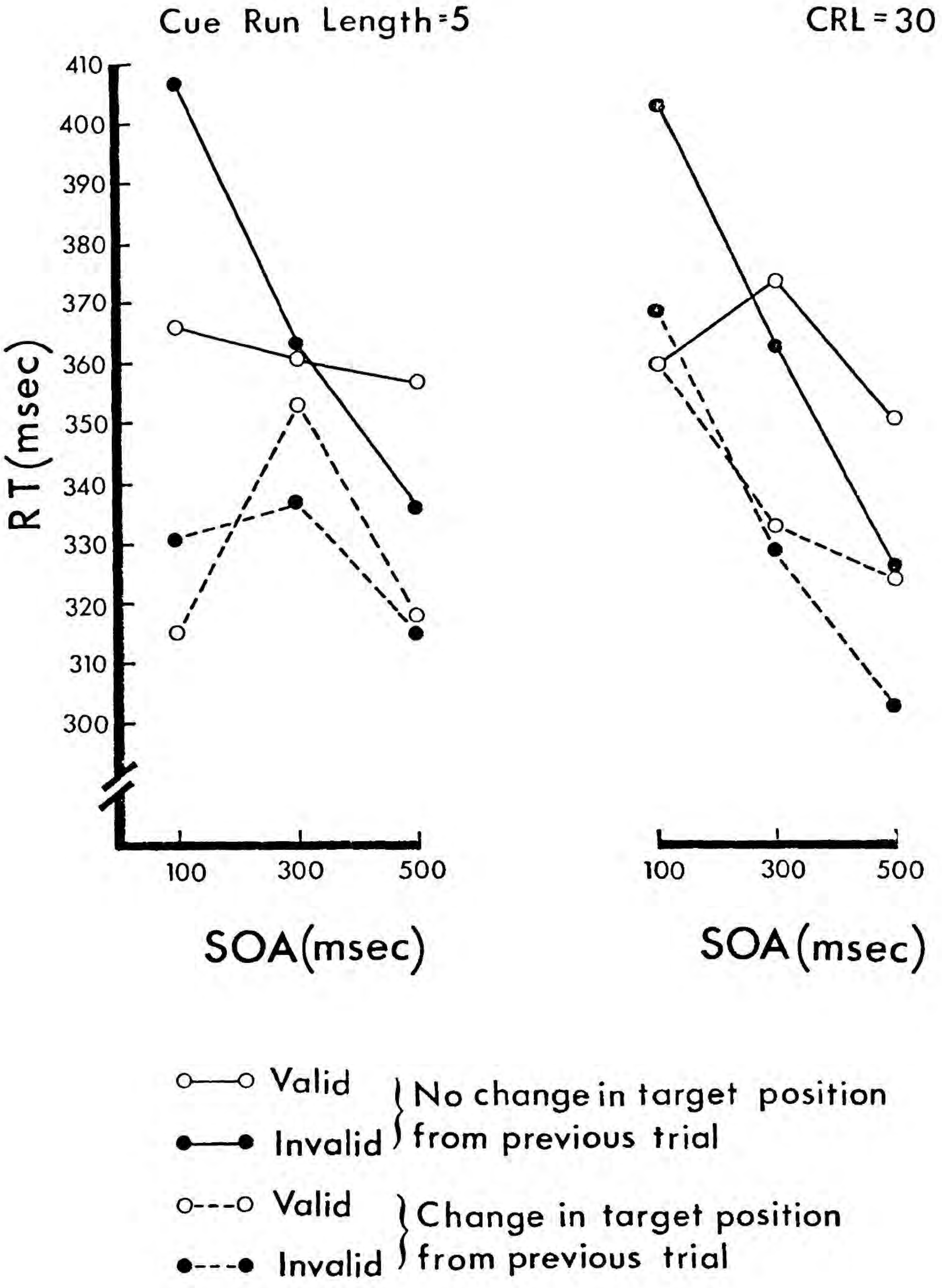


Figure 6.2 Further analysis of the results from experiment 6.1.

p<0.005], and SOA [F(2,14)=15.54, p<0.0005], but not of trial-type [F(1,7)=2.31, p>0.1]. The only significant interaction was that between SOA and trial-type [F(2,14)=10.04, p<0.005], although the interaction between target location and SOA approached significance [F(2,14)=3.01, p<0.1]. Similarly for the cue run length of 30 there were significant effects of target location [F(1,7)=11.92, p<0.05], and SOA [F(2,14)=12.51, p<0.005], but not of trial-type [F(1,7)=0.14, p>0.1]. Both the interactions between SOA and trial-type [F(2,14)=9.56, p<0.005] and between target location, SOA and trial-type [F(2,14)=4.41, p<0.05] were significant.

The overall effects of target location on reaction time (37 and 27 msec for cue run lengths of 5 and 30 respectively) confirm the suggestion that orienting to the target on the previous trial results in inhibition to respond to the next target if it appears in the same location. In a cue-target paradigm the subject is required to avoid responding to the cue but to make a speeded detection response to the target. Harvey (1980) argued that the inhibitory effect can be attributed to response inhibition to the cue which is still present when the target appears (see section 1.6). However, as inhibition can be caused by an event that required a response (that is, a target), Harvey's explanation in terms of response inhibition which relies on the cue-target distinction is therefore inadequate. The average delay between one target and the next was 750 msec, so there is evidence that the inhibitory effect lasts some considerable time. This was investigated further by experiment 6.2.

If the results from the cue run length of 30 (which represent nearly twice as much data as the cue run length of 5) are considered in more detail, it is clear that both locations (left and right) can be inhibited at the same time. At the SOA of 500 msec there is both inhibition caused by the previous target (as indicated by the difference between no change and change in target position from previous trial), and by the present cue (as indicated by the invalid-valid difference), which may or may not be in the same location. This is an important finding in relation to Posner and Cohen's (1980) double-cueing experiment (as described in section 1.6) and also experiment 8.1. It will be argued that two locations can exhibit maximal facilitation and inhibition only if orienting occurs successively to each one. In the present experiment, the events (both cues and targets) appeared separately in time so that externally-controlled orienting occurred to each event. However, in the double-cueing experiments the two locations are cued simultaneously, thereby reducing orienting and its consequences. This will be discussed further in chapter 8.

6.3 Experiment 6.2

It has been demonstrated that orienting to a target in the periphery results in subsequent inhibition, which lasts some time. Experiment 6.2 was designed to investigate the time course of the inhibitory effect using a different procedure. Instead of a cue-target paradigm, the subject was required to respond to single target events which occurred at various intervals and distances from the previous one. In this way, by recording reaction time to a target as a function of the location and the timing of the last target, inhibition, if observed, would be due to orienting to the last target rather than to a cue. Again, if inhibition occurs using this target-target procedure rather than the cue-target procedure employed so far, Harvey's (1980) response inhibition explanation must be discounted.

6.3.1 Method

6.3.1.1 Subjects

Six subjects participated in a single experimental session lasting approximately 10 minutes. They were all familiar with simple reaction time experiments.

6.3.1.2 Apparatus and Stimuli

The IBM computer (see section 2.3.1) was used to control the experiment. The stimuli were all targets and were the small squares of four dots as described in section 2.4.2. They appeared 4.2 degrees above, below, to the left and to the right of the central fixation point on the oscilloscope.

6.3.1.3 Design and Procedure

Each subject participated in two blocks of trials. A block began with the usual reminder on the screen of the requirement to keep the eyes on the central fixation point throughout the block. To begin, the subject pressed the single key and after five seconds the first target appeared. At the end of a block (approximately two minutes), the screen went blank until the next block was ready, which was signalled by the return of the fixation instructions. When the subject was ready to continue, a key press started the second block. The subject's task was the simple detection of targets and these were equally likely to appear in any one of the four locations. Each target remained on the screen until the subject responded with a single key press. There was a response-stimulus (R-S) interval of 300, 400, 500 or 900 msec before the onset of the next target and these were randomised. Within a block of 240 trials, there were 60 of each R-S interval.

The subject was informed of the targets' locations and probabilities and was told that the targets would occur at random intervals following each response. In addition the subject was encouraged to be stimulus-driven, that is, to avoid responding when there was no target on the screen.

The data were analysed in the following way. For each R-S interval, the trials were split into three types: 'same', 'adjacent' and 'opposite'. These refer to the spatial relationship between the locations of the current and the previous target. For example, a left target which followed a right target was coded as opposite, whereas it was an adjacent trial if it followed a target above fixation. The first trial of each block was deleted from the analysis as it was not, of course, preceded by a target. Trials following anticipation errors (that is, responses before or during the first 100 msec of target presentation) were also deleted. Because each target was equally likely to occur, there were twice as many adjacent trials as either same or opposite trials.

6.3.2 Results and Discussion

The overall anticipation rate was 4%. The reaction times were put into an analysis of variance with block (first and second), R-S interval (300, 400, 500 and 900 msec) and trial-type (same, adjacent and opposite) as fixed effects factors. There was no effect of block

[F(1,5)=0.25, p>0.1] or any interaction involving it, and so this factor will not be discussed further. The overall means are presented in Figure 6.3. There were significant effects of R-S interval [F(3,15)=19.52, p<0.0001], and trial-type [F(2,10)=25.47, p<0.0005] and there was a significant interaction between them [F(6,30)=3.90, p<0.01]. The effect of R-S interval is equivalent to the effect of SOA which has been discussed in previous experiments. From Figure 6.3 it can be seen that the trial-type effect can be attributed to the slow responses to same trials compared to adjacent and opposite ones. The subject is therefore slower to respond to a target which appears in the same location as on the previous trial than in either an adjacent or opposite location. (For the R-S intervals of both 300 and 400 msec, adjacent trials were slower than opposite trials for five of the six subjects. The adjacent-opposite differences were not consistent for the two longer R-S intervals.) The interaction between R-S interval and trial-type can be seen from Figure 6.3 as the result of a decrease in the inhibitory effect over time.

There are three important conclusions to be drawn from this experiment. First, as predicted from the results of experiment 6.1, it is clear that inhibition occurs in a target-target as well as in a cue-target paradigm, providing further evidence against the response inhibition explanation of Harvey (1980).

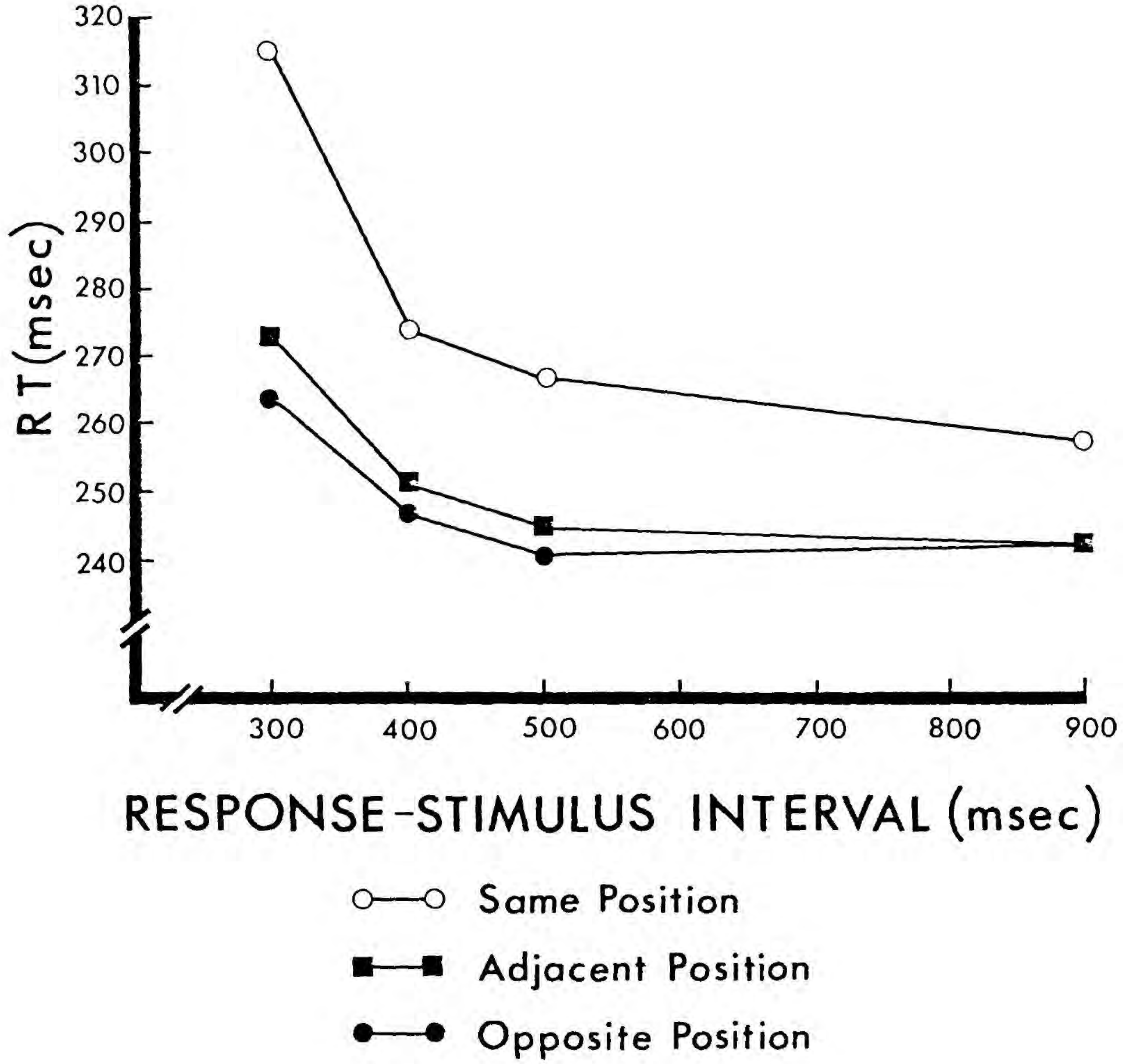


Figure 6.3 Results of experiment 6.2.

Secondly, inhibition lasts for some considerable time so that it is unlikely that any form of visual masking or persistence can account for the effect (see also section 1.6). [It is assumed that the inhibitory component identified in experiment 4.1 using a cue-target paradigm is the same as that described in the present target-target experiment. Some support for this comes from a study by Spencer (1983) which was based on experiment 4.1 but used a larger range of SOAs, that is, from 50 to 1000 msec. The invalid-valid differences were -26 and -16 msec at the SOAs of 500 and 1000 msec respectively, thus demonstrating that inhibition in the cue-target paradigm also lasts for some time. There are difficulties involved in making absolute comparisons between the effects observed in experiments 4.1 and 6.2 because SOA is not directly equivalent to R-S interval. Nevertheless, the large amount of inhibition (51 msec) at the earliest R-S interval in the present experiment is surprising when it is compared to 27 msec at the SOA of 500 msec in experiment 4.1. This could possibly be attributed to the longer duration of the previous event (approximately 260 msec compared to the cue of 100 msec) or to the fact that the subject was obviously more aware of the previous event in the present experiment, or to both factors.]

Thirdly, the lack of a substantial difference between the adjacent and opposite types of trial (equivalent to the similarity between neutral and invalid trials in experiment 3.2C) suggests in agreement with Posner and

Cohen (1980) that the inhibitory effect is not due to the realignment of attention towards the opposite location. However, although adjacent trials were much faster than same trials, they were slightly slower than opposite trials, at least for the R-S intervals of 300 and 400 msec. There is therefore some evidence that reaction time decreases with increasing distance from the previously-stimulated location. Further support for this comes from the results of a pilot study which was based on the present experiment. Two stimulus arrangements were used (shown at the top of Figure 6.4), and each of eight subjects participated in both conditions. The results are presented in Figure 6.4. The trials were coded in a similar way to experiment 6.2 except that adjacent trials refer to targets appearing on the same side of the visual field as the previous target and opposite trials to targets appearing on the opposite side. (In this experiment there were twice as many opposite trials as either same or adjacent trials as a result of the constraint that each target was equally likely to occur.) A comparison of the adjacent trials in the two conditions reveals that reaction time does indeed decrease with increasing distance of the target from the location of the previous target. Experiment 6.3 was therefore carried out to investigate in more detail the spatial extent of the inhibitory effect.

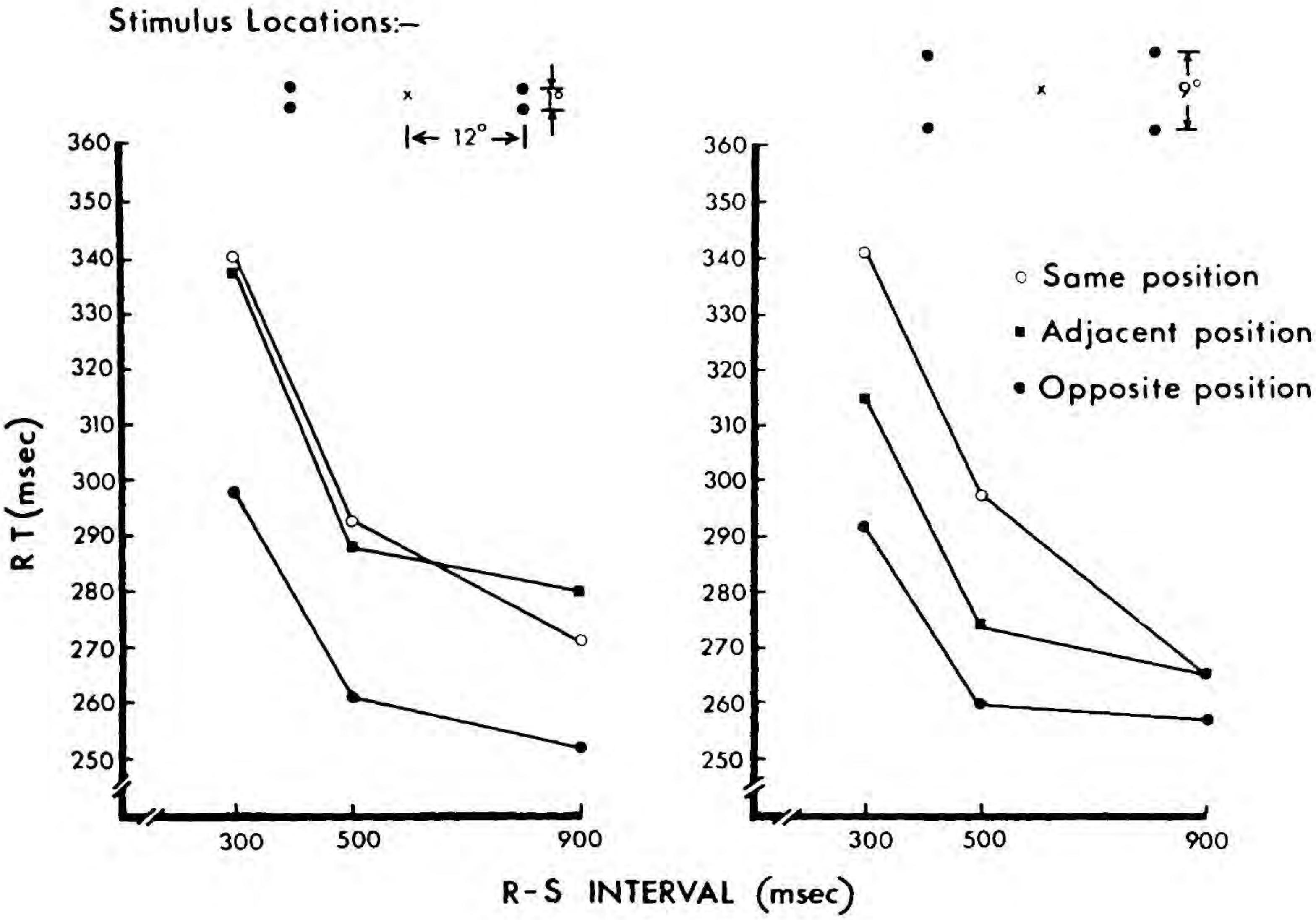


Figure 6.4 Results of a pilot study for experiment 6.3.

6.4 Experiment 6.3

This experiment used a cue-target procedure though both the cues and the targets were Light Emitting Diodes (LEDs). The effect of the brief presentation of an LED was measured by the simple reaction time to targets presented at various times and locations following the cue in an attempt to plot out the extent of inhibition in time and space.

6.4.1 Method

6.4.1.1 Subjects

Seven subjects each participated in a single experimental session lasting approximately half an hour.

6.4.1.2 Apparatus and Stimuli

The PDP 11/34 computer was used to control the experiment (see sections 2.5.1 and 2.5.2) and the method of displaying the stimuli is shown in Figure 2.5. A yellow LED acted as the fixation point while 14 red LEDs were used as cues and targets. The stimulus positions are shown in the upper panel of Figure 6.5.

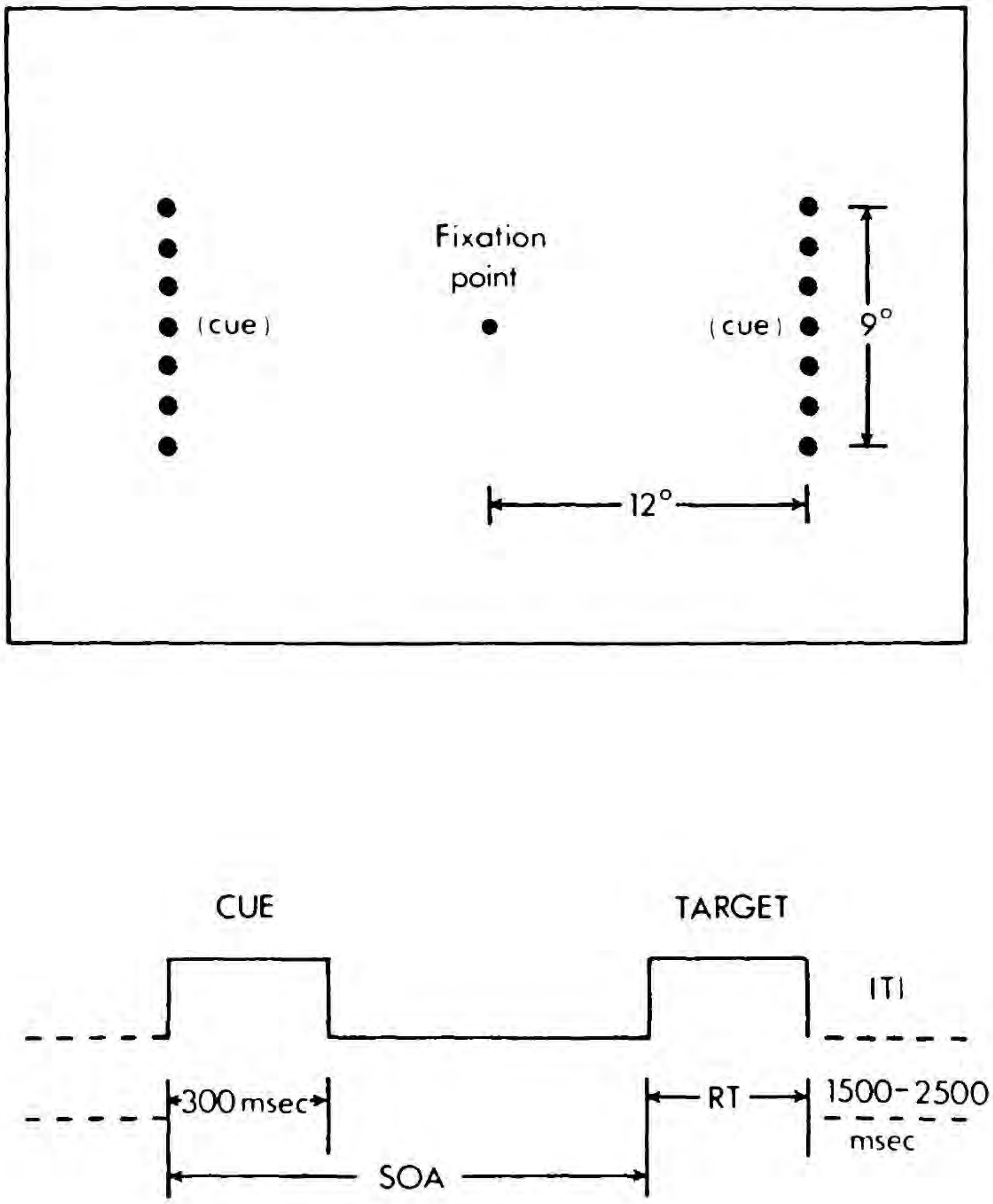


Figure 6.5 Stimulus positions and timing in experiment 6.3.

6.4.1.3 Design and Procedure

Subjects participated in three blocks of trials and were required to fixate on the central yellow LED throughout. Each block contained 140 trials which were divided in the following way. For 70 of the trials the cue was the presentation for 300 msec of the LED directly to the left of fixation (labelled 'cue' in Figure 6.5). The cue was the LED directly to the right for the remaining 70 trials. For each cue, the target appeared five times in each of the 14 positions (including that of the cue). These five trials were further divided into one of an SOA of 700 msec, two of 900 and two of 1300 msec. (Obviously an equal division was not possible - however, there was no reason to expect the particular ratio chosen to have any significant effect on the results of interest.) The order of trials was randomised for every block.

The timing is summarised in the lower panel of Figure 6.5. Each trial began with the brief presentation (300 msec) of the cue. (300 msec was chosen because it was approximately the average reaction time in experiment 6.2 and therefore the duration of the stimuli responsible for the inhibition was similar in the two experiments.) This was followed after the SOA by the target (one of the 14 LEDs). This remained on until the simple detection response of a single key press had been made. There was an intertrial interval which was randomly chosen from the range 1500 to 2500 msec.

The subject was instructed to respond only to the target but to use the brief cue as a warning signal that a target was about to appear. He was told that the cue was always either the middle left or middle right LED but that the target could be any one of the 14 LEDs, with equal probability. Consequently, the cue and the target appeared in the same location on a small proportion of trials. However, the distinction between the cue and the target was clearly understood by all the subjects. The long intertrial interval ensured that the subject was able to follow the cue-target pattern throughout a block even when mistakes were made. When the key was pressed during the SOA and up to 100 msec after the onset of the target, that trial was immediately aborted, an anticipation error was recorded and the trial was deleted from the analysis.

6.4.2 Results and Discussion

The overall anticipation rate was 2.5%. For each subject the data from the three experimental blocks were combined and overall medians for the 24 conditions (3 SOAs x 8 trial-types) were calculated. The type of trial was determined by the distance between the cue and the target. Thus type '0' represented trials where the cue and the target appeared in the same location. When the target appeared immediately above or below the cue, the trial was labelled '1', and so on, so that trials where the target appeared on the opposite side of the visual field to the cue were coded from '4' to '7'. For example, a trial was labelled 4 when the target appeared directly opposite the cue, but labelled 5 when it appeared immediately above or below the location directly opposite the cue. Because of the combination of trials above and below the horizontal midline, there were twice as many trials of the types 1, 2, 3, 5, 6 and 7 than 0 or 4.

Three separate analyses of variance were carried out on the results. It appeared from the raw data that there was no difference between the reaction times from trial-types 4-7 for all three SOAs. This was confirmed by an analysis of variance with trial-type (4, 5, 6 and 7) as a fixed effects factor. There was no significant difference between the overall reaction times of 276, 278, 275 and 273 msec for trial-types 4, 5, 6 and 7 respectively [F(3,18)=0.55, p>0.1]. Therefore the results of the four 'opposite' types of trial were combined for each subject and overall medians taken. The second analysis of variance was then performed with SOA (700, 900 and 1300 msec) and trial-type (0, 1, 2, 3 and opposite) as fixed effects factors. The overall results from the seven subjects are shown in Figure 6.6. There were highly significant effects of SOA [F(2,12)=25.89, p<0.0005] and trial-type [F(4,24)=15.46, p<0.00005] and there was an interaction between them [F(8,48)=2.70, p<0.05].

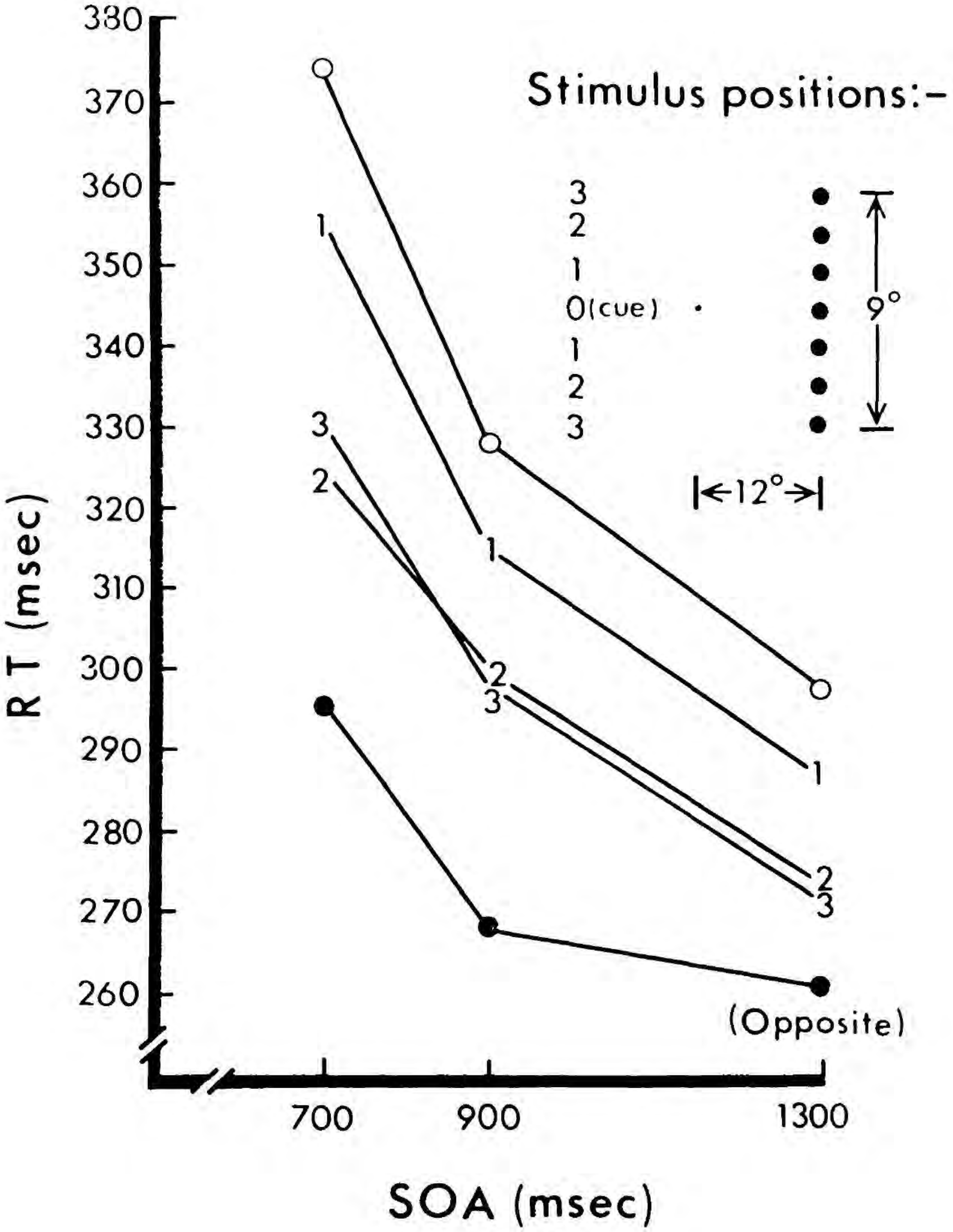


Figure 6.6 Results of experiment 6.3.

From Figure 6.6 it can be seen that 0 trials are much slower than opposite trials, which was expected from the previous experiments. Trial-types 1, 2 and 3 are all slower than opposite ones and generally reaction time decreases with increasing distance between the cue and the target. However, it can be seen from Figure 6.6 that the relationship is not linear. The reaction times for trial-types 1, 2 and 3 are all faster than would be expected if inhibition were proportional to the cue-target distance. Thus the inhibitory effect falls off quite sharply as the target appears further away from the cue.

The third analysis of variance considered only the trials where the target appeared on the same side of the visual field as the cue and was carried out with SOA (700, 900 and 1300 msec) and trial-type (0, 1, 2 and 3) as fixed effects factors. This revealed significant effects of SOA [$F(2,12)=28.78$, $p<0.0005$] and trial-type [$F(3,18)=11.11$, $p<0.0005$], but no interaction between them [$F(6,36)=1.18$, $p>0.1$]. So the spread of inhibition, that is, the wide spatial extent of the effect of a cue on the speed of detection of a nearby target, does not interact with time, at least for the SOAs used in this experiment. It might have been expected, for example, that only the detection of targets very close to the cue would be slowed down at the short SOAs, and more distant locations would be affected at the longer SOAs. However, from the results of the present experiment it appears that inhibition does not act in such a way.

By reversing LED onsets and offsets, it was possible to investigate the effect of a brief cue offset on the subsequent detection of a target offset. The experiment was identical to experiment 6.3 except that all 14 LEDs were on at the start of each trial. The cue was the offset of either the middle left or middle right LED for 300 msec and the target was the offset of one of the 14 LEDs, with equal probability. The results are shown in Figure 6.7. First it should be noted that the results for diode onset are slightly different to those shown in Figure 6.6, although as Figure 6.7 represents data from just one subject, some variability should not be unexpected. Secondly, apart from overall reaction time differences, the pattern of results is very similar for LED onset and offset. Thus inhibition is the consequence of a previous event in the periphery, rather than being specific to brightening. This is consistent with the results of Posner and Cohen (1980) which were described in the introduction (see section 1.6). They found that facilitation and inhibition occurred using the procedure described in experiment 4.1, regardless of whether the cue was the brightening or the dimming of the peripheral box.

The results of the present experiment (Figure 6.6) are highly consistent with those of Vaughan (1982). He investigated the spatial and temporal extent of the inhibitory effect around previously-fixated locations by measuring saccade latency rather than manual reaction time. The subject was asked to track unpredictable step

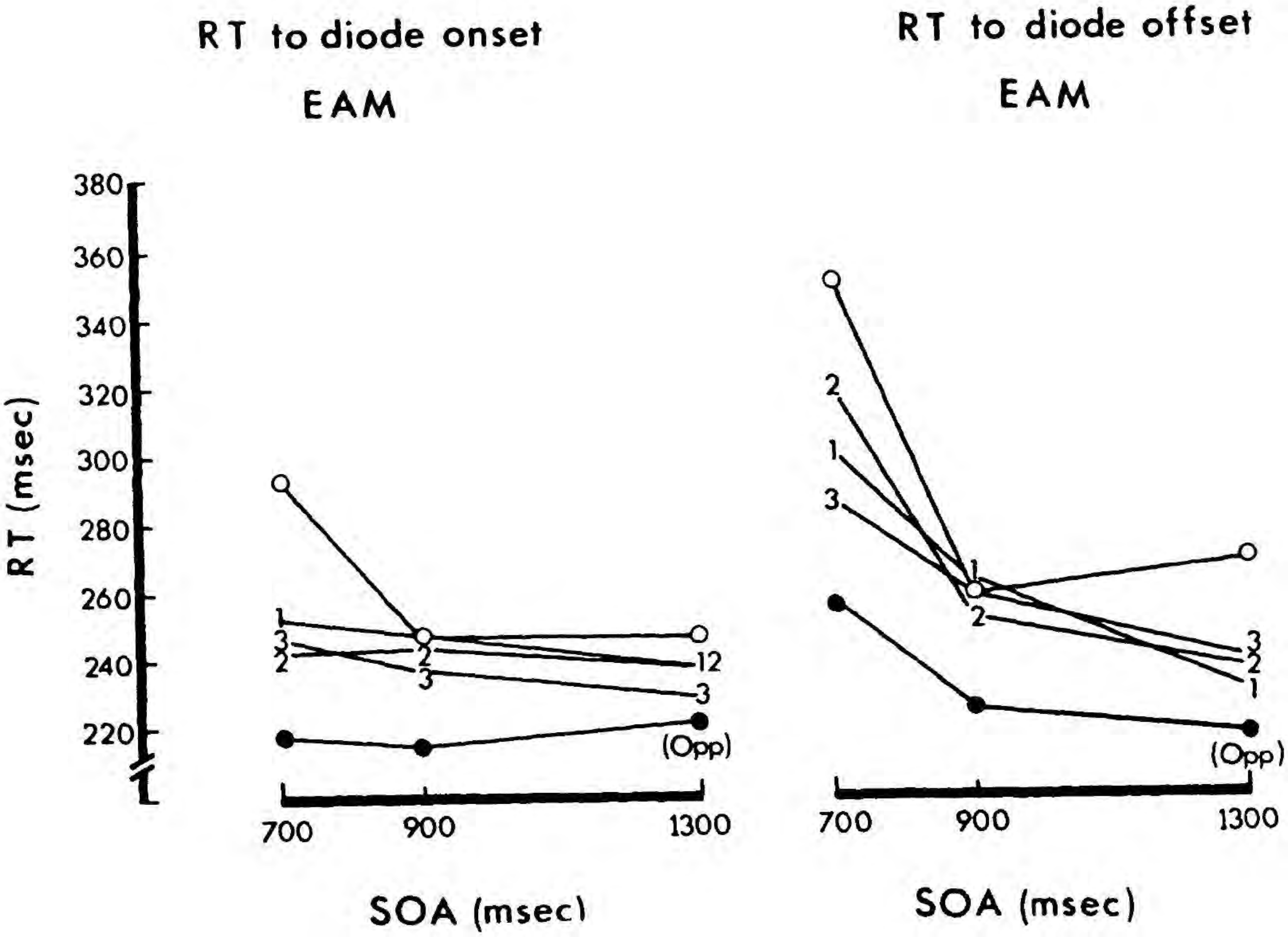


Figure 6.7 Additional results from experiment 6.3 (see Figure 6.6 for coding of trials).

displacements. Thus his procedure was similar to that of experiment 6.2 in that a series of visual targets was presented, each target requiring a response (that is, a saccade). Vaughan found that saccade latency was increased to a previously-fixated location with respect to a new location and that the effect persisted for at least 1200 msec following a saccade. Moreover, the increase depended upon the distance between the destination of the saccade and the previously-fixated location in a similar way to the present experiment (although it is difficult to make quantitative comparisons between the two experiments as different stimulus eccentricities were used). In addition, Vaughan's study extends the range of experimental conditions which result in an inhibitory effect. First, inhibition occurs for both simple and choice manual responses to a target appearing more than 300 msec after and in the same location as a direct cue in the periphery, in the absence of eye movements (Posner and Cohen, 1980; experiments 4.1 and 4.4). Secondly, saccade latency is longer to a target from a cued location in the periphery than from an uncued location (experiment 4.3). Thirdly, manual reaction time is inhibited to a target appearing in a previously-fixated location, as long as the initial saccade is externally-controlled (Cohen, 1981). Finally, saccade latency is longer to a target from a previously-fixated location than from a location not previously fixated, all saccades being under external control (Vaughan, 1982).

From these studies it can be concluded that the inhibitory effect is characterised by an inability to respond as quickly (both manually and ocularly) to a target appearing in a recently-stimulated location (either by a cue or by another target) as to one appearing in a different location. One limitation, however, of the studies described so far (with the exception of experiment 6.1) is that the trials were analysed on the basis of the spatial and temporal relationship between the target and the previous stimulus. It is quite possible that reaction time on any particular trial is dependent upon the locations and timing of the previous sequence of stimuli.

6.5 Experiment 6.4

The results of experiment 6.1 (Figure 6.2) demonstrated that reaction time to a target is affected by both the location of the cue of the current trial and the target of the previous trial. Experiment 6.4 was designed to extend this finding by an investigation of the effect on reaction time of the previous four stimulus locations. It was based on the target-target procedure of experiment 6.2, although the number of possible target locations was reduced from four to two, in order to increase the number of repetitions. The data were analysed in terms of the relationship between the current target location and those of the previous four trials. Because the results of the cue run lengths of 1, 5 and 30 of experiment 6.1 were similar (see Figure 6.1), it was predicted that inhibition would not be affected by the number of previous consecutive targets appearing at a particular location.

6.5.1 Method

6.5.1.1 Subjects

Seven subjects each participated in a single experimental session lasting five minutes.

6.5.1.2 Apparatus and Stimuli

The IBM computer was used to run the experiment (see section 2.5.1) and the method of mounting the stimuli is shown in Figure 2.4. Two red LEDs were used as targets and were placed 12 degrees to the left and right of the central fixation point.

6.5.1.3 Design and Procedure

Most of the experimental details were as given in section 6.3.1.3 for experiment 6.2. All the subjects were familiar with reaction time experiments and so were not given any practice before carrying out the block of trials. To start, the subject pressed the single key and after a delay of 5000 msec the experimental trials began. The subject was required to fixate on the centre throughout and to press the key as quickly as possible following the onset of the target, that is, either the left or the right LED. The target disappeared as soon as the response had been made. Targets occurred at three different times from the offset of the previous target : 400, 600 and 1000 msec. There were 240 trials in a block which were divided so that there were twice as many (120) of the response-stimulus (R-S) interval of 600 msec than of either of the other intervals (60 each). This distribution was used in order to ensure that there was an adequate number of trials of one R-S interval (600 msec) to enable detailed further analysis of the trials to be carried out. The order of R-S interval was randomised before each block.

As outlined in section 6.5, the aim of experiment 6.4 was to investigate the effect on inhibition of runs of targets in the same location. If the order of the 120 left and 120 right targets had been entirely random, this would have resulted in an inappropriate distribution of runs lengths for a reliable analysis, that is, a large number of short runs (of 1, 2 and 3 consecutive targets in the same location) but a small number of long runs (of greater than 5 targets in a row). A pseudorandomisation procedure was therefore adopted in which the probability of a change in target location from one trial to the next was initially set at 0.3, and then runs of more than five consecutive targets in the same location were deleted in such a way as to produce the overall probabilities shown in Figure 6.8. This shows the probability of a change in target location as a function of the number of previous consecutive targets in that location. For example,

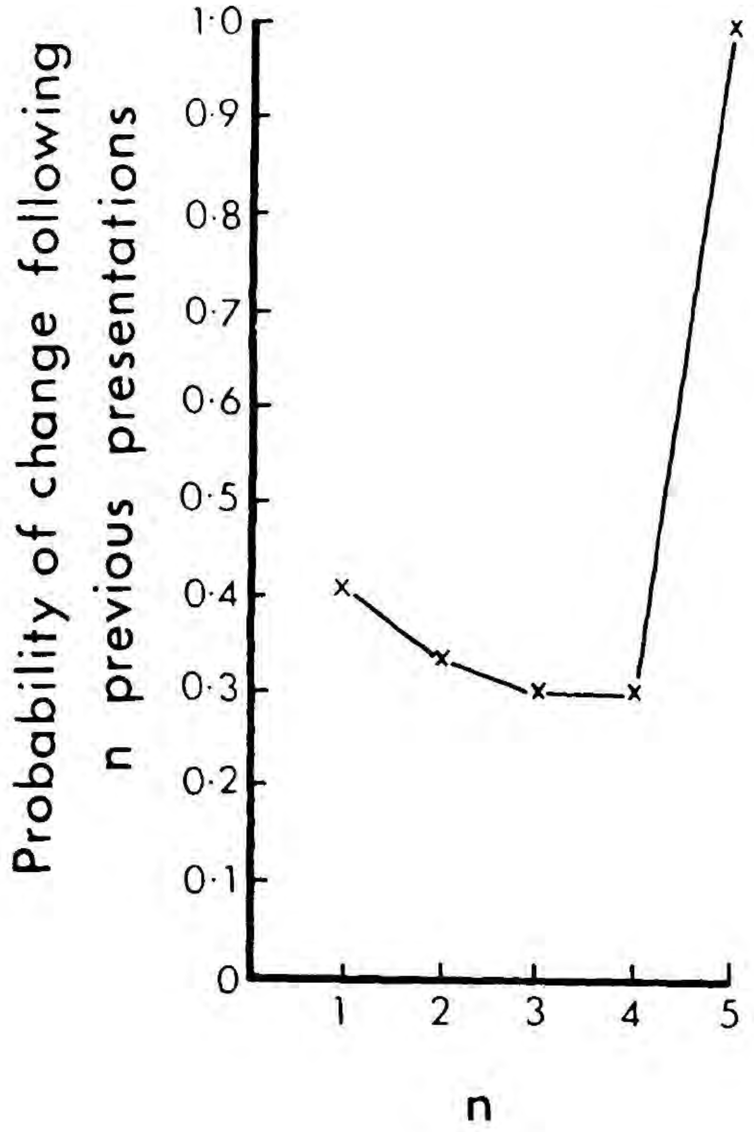


Figure 6.8 Target probabilities in experiment 6.4.

because of the run length restriction of five, the probability of a change following five previous presentations was 1. It should be noted that the pseudorandomisation was in accordance with work on subjective probability (Kahneman and Tversky, 1972; Tune, 1964; Wagenaar, 1970) in which subjects expect Bernoulli sequences to have shorter run lengths than would actually occur by chance. The subject was not informed of the probabilities and was merely told that targets would appear equally often in the two locations in a random order.

6.5.2 Results and Discussion

The anticipation rate was 1.9%. No subject noticed the run length restriction, but in fact when an anticipation was made the trial was aborted, so that runs of greater than five may have occurred very occasionally. Because the block of trials only lasted approximately three minutes, it is unlikely that the subject was aware of the probabilities shown in Figure 6.8. Initially, trials were coded as in experiment 6.2 according to the spatial relationship between the current target location and that of the previous trial, that is, into same and opposite trials. For each subject, median reaction times were calculated for each combination of R-S interval and trial-type. These were put into an analysis of variance with R-S interval (400, 600 and 1000 msec) and trial-type (same and opposite) as fixed effects factors. The overall means are shown in Figure 6.9 and the analysis of variance confirmed that there were significant effects of R-S interval [F(2,12)=20.67, $p<0.0005$], and trial-type [F(1,6)=30.23, $p<0.005$], with an interaction between them [F(2,12)=5.06, $p<0.05$].

Having established the usual inhibitory effect of increased reaction time to a target appearing in the same location as on the previous trial, the results were analysed further in the following way. The data from the R-S interval of 600 msec were split into five conditions according to the number of immediately preceding consecutive targets of the same location, that is, the number of repetitions (see Figure 6.10). For example, an alternation (from left to right, or right to left) was coded as '0' and was merely the opposite data. '1' repetition represented responses to a target following one in the same location on the previous trial. '2' repetitions indicated that there were targets in the same location on the previous two trials, and so on. For example, in a sequence of 'left, right, right, right', the second trial would be coded as 0, the third as 1 and the fourth as 2. It is important to note that the last trial would not also be included as a 1 trial. Following an error, the next five trials were deleted from the analysis.

The medians were calculated for each subject and put into an analysis of variance with the number of

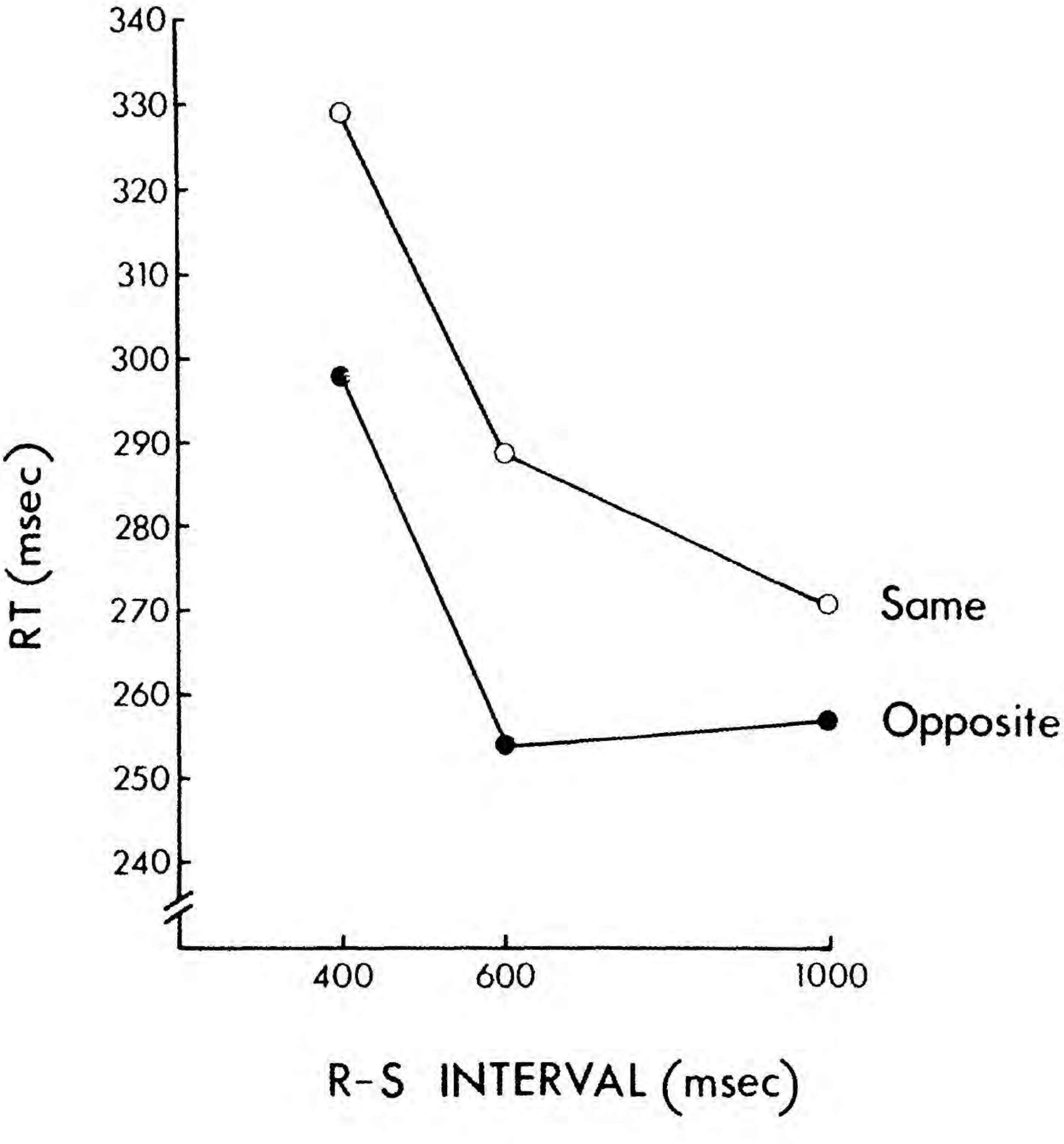


Figure 6.9 Results of experiment 6.4.

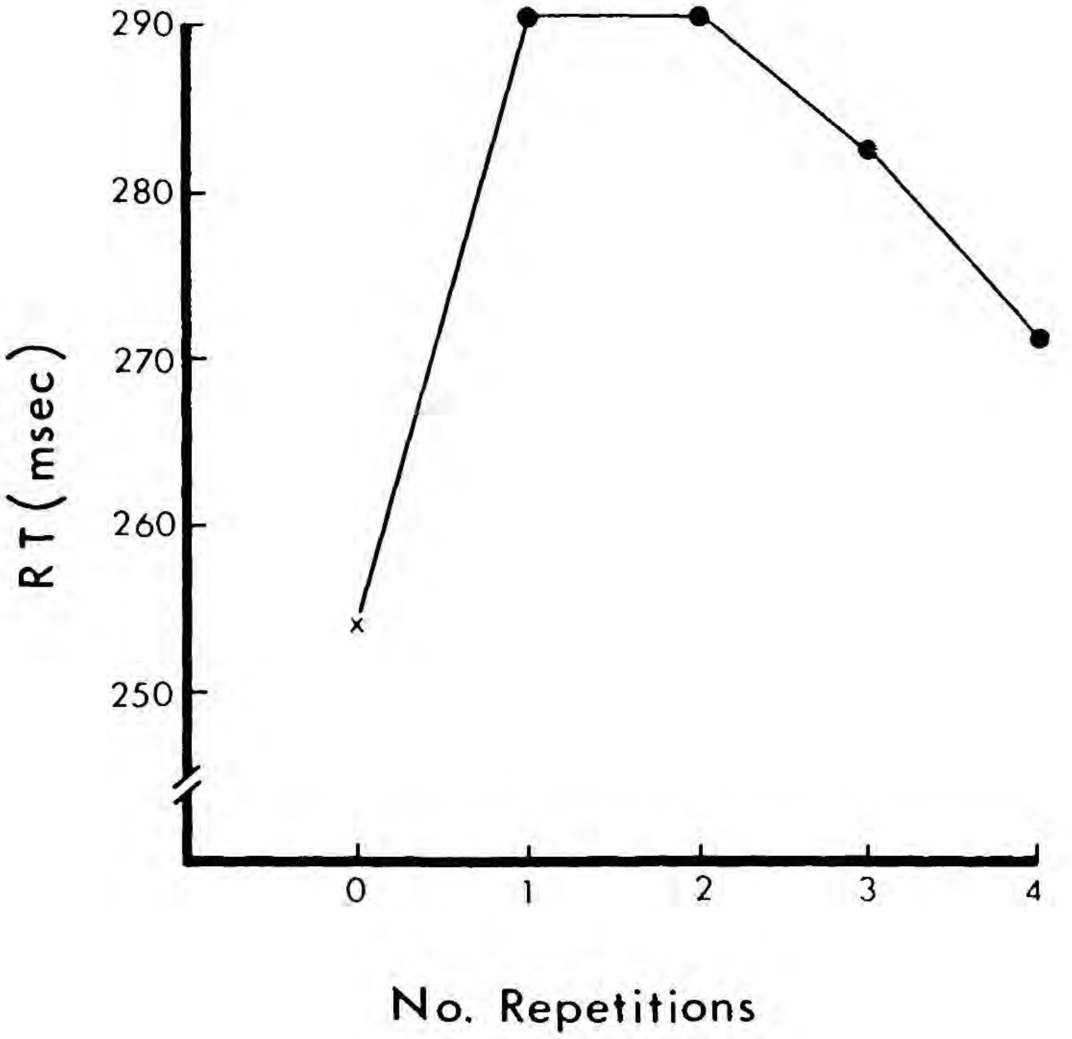


Figure 6.10 Further analysis of the results of experiment 6.4.

repetitions (0, 1, 2, 3 and 4) as the fixed effects factor. The overall means are presented in Figure 6.10. There was a highly significant effect of the number of repetitions [F(4,24)=5.45, p<0.005] and a trend analysis revealed that only the quadratic component was significant [F(1,24)=17.37, p<0.01]. It can be seen that the inhibitory effect is large for the first and second repetitions but decreases for longer runs. The difference between the 0 and 1 trial-types of 36 msec is approximately the same as the overall same-opposite difference for the R-S interval of 600 msec (see Figure 6.9) of 35 msec. This is probably a reflection of the total number of trials of each type in Figure 6.10 (309, 199, 138, 93 and 55 for 0, 1, 2, 3 and 4 repetitions respectively). Thus the faster reaction times for 3 and 4 repetitions would have little effect on the overall results of the same trials because there were far fewer of them.

In order to investigate the effect shown in Figure 6.10 in more detail it was necessary to obtain many more trials, first to increase the number of trials of the types 3 and 4, and secondly to enable some of the data to be divided further. Three subjects (who had not participated in the first version of experiment 6.4) were tested in two sessions on separate days. Each session consisted of four blocks of trials, although only the data from the last three were analysed. The trials were initially divided as before, that is, into 0, 1, 2, 3 and

4 repetitions and for the R-S interval of 600 msec only. For each session the overall medians were calculated and then the means were taken of the medians from the two sessions. The results are shown in Figure 6.11. Each data point represents at least 30 trials, the total number of trials being 1800. The results from the original version of experiment 6.4 (Figure 6.10) and those from the follow-up study (Figure 6.11) are very similar. Inhibition is maximal on the first (and possibly second) repetition but then decreases so that by the fourth repetition, the detection response is nearly as fast to a repetition as to a change.

The pattern of results cannot be explained by the target probabilities (shown in Figure 6.8). For example, the probability of a change in target location following one previous presentation was 0.414 and yet reaction time was shorter in response to a change than to a repetition (0 compared to 1). It is unlikely that a consideration of the pseudorandomisation of target presentation would lead to an explanation for the results because the seven subjects in the original version of experiment 6.4 only participated in a single block of trials which would be an inadequate sample in order to calculate the probabilities. (It was noted earlier that the run length restriction was not obvious to the subject, particularly as runs of greater than five did occasionally occur due to the abortion of trials when anticipations were made.) However, following the initial increase in reaction time from a

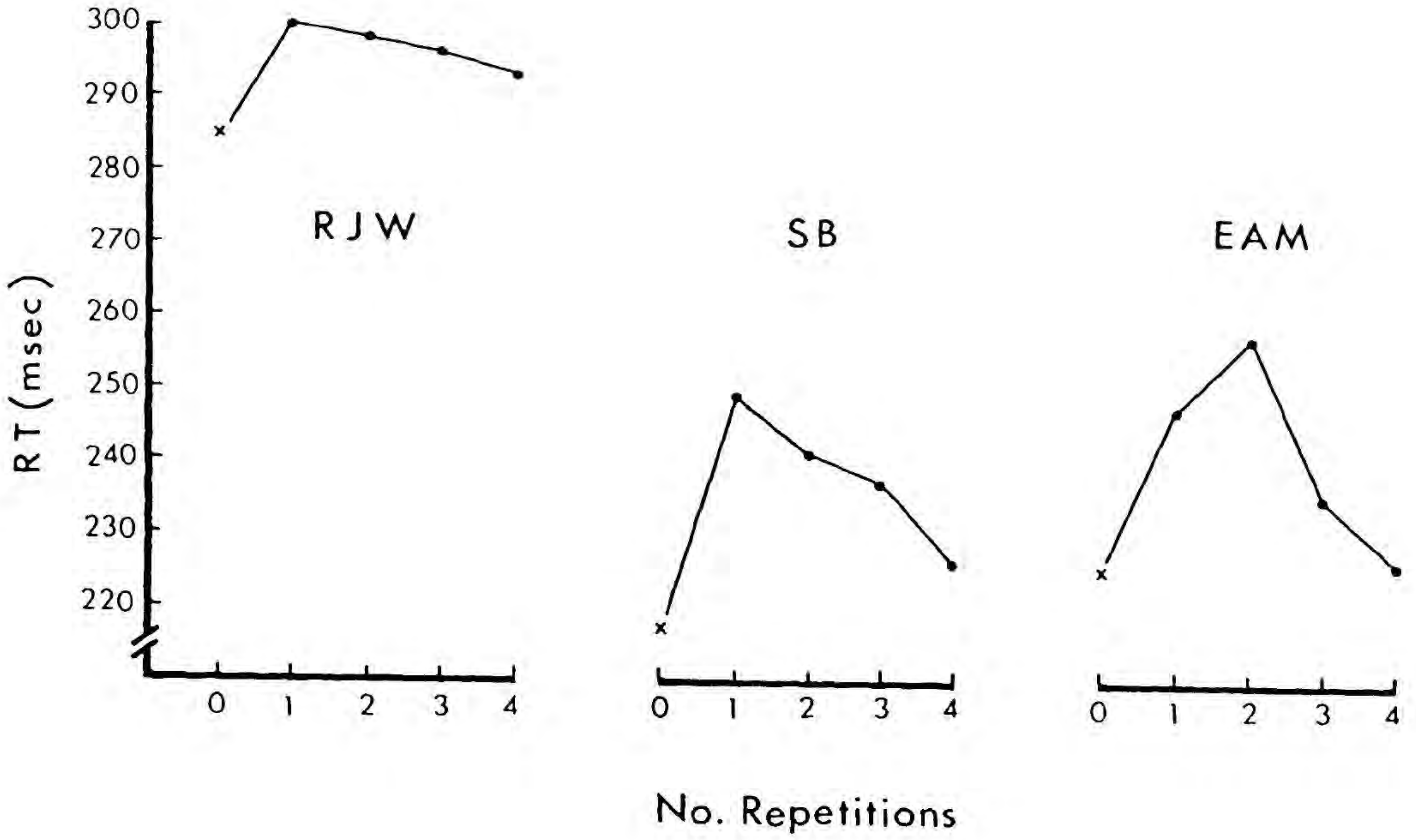


Figure 6.11 Results of extensive version of experiment 6.4.

change in target location to the first repetition (0 to 1), the subsequent decrease in the inhibitory effect may be explained in terms of the subject's expectancies. RJW reported that once a target had been repeated, his expectation was that it would continue to be repeated. It seems that the inhibitory effect may have been counteracted by the gradual realignment of conscious attention with the location of the repeating stimulus. This predicts that reaction time to a change in target location would depend upon the number of repetitions in the previous location, because as chapter 3 demonstrated, the benefits of the alignment of attention (under internal control) with a location on one side of the visual field are balanced by the costs to the opposite location.

To investigate this possibility, the 'alternation' data (0 repetitions) were divided according to the number of repetitions preceding an alternation (1, 2, 3, 4 and 5). For example, the final trial in the target sequence 'LRLLLLR' was coded as 4 repetitions preceding an alternation. Medians were taken for each session and the means of the two medians are presented in Figure 6.12. The total number of trials represented is 790, each data point being the average of at least 20 trials. First, it should be noted that subject EAM was aware of the run length restriction of five which may account for the very short reaction time to an alternation following five repetitions. Secondly, the decrease in reaction time from 1 to 2 repetitions preceding an alternation observed for

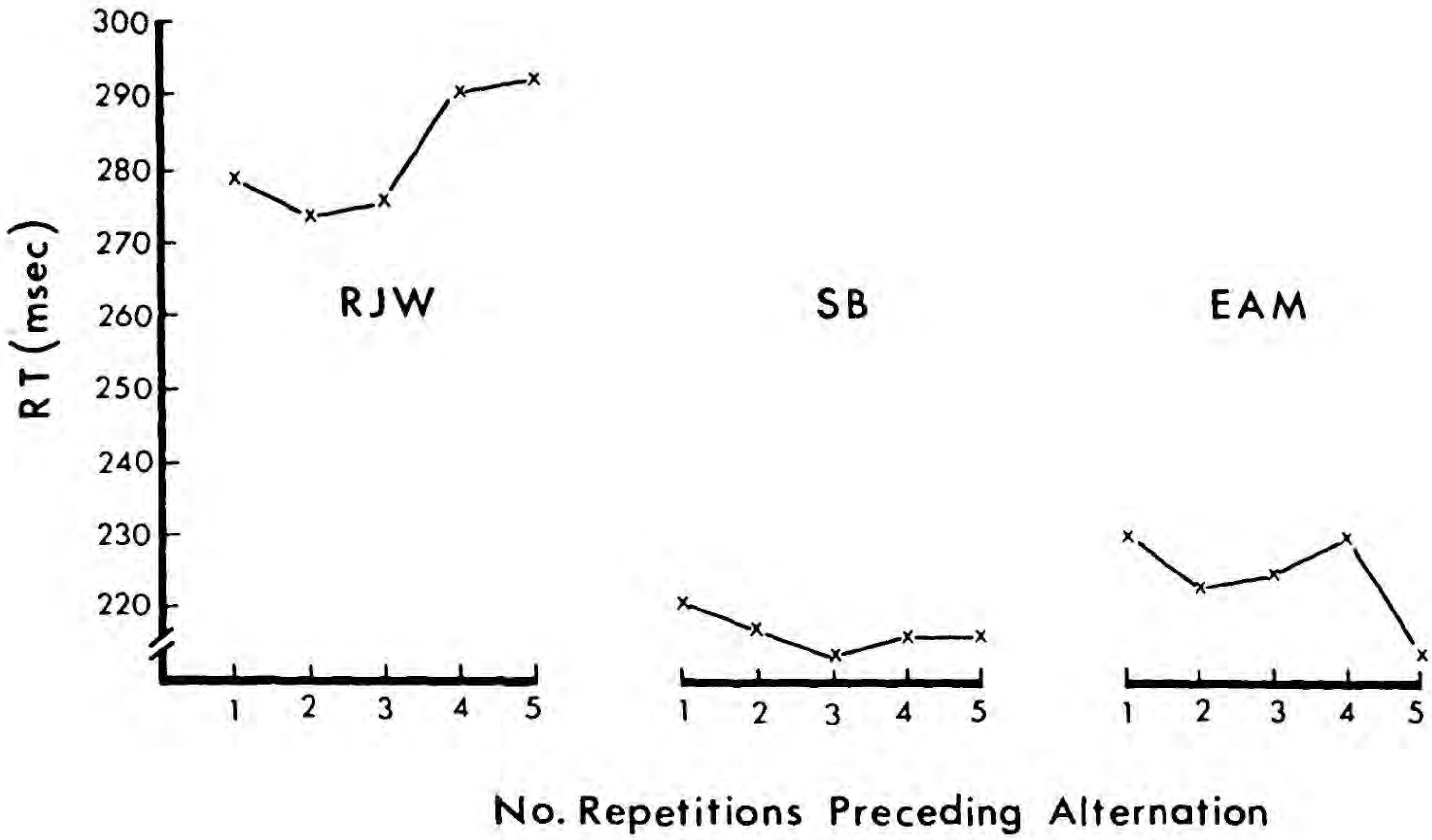


Figure 6.12 Further analysis on the results of the extensive version of experiment 6.4.

all three subjects can be explained by the fact that an alternation following 1 repetition could occur as quickly as 1200 msec after the previous-but-one target. The results of experiment 6.1 demonstrated that two locations either side of fixation can be inhibited at the same time if orienting takes place to both, and so it is not surprising that the reaction time to an alternation following one repetition was longer than to an alternation following two repetitions. Apart from the one point in EAM's data mentioned above, there does appear to be a trend towards longer reaction times as the number of repetitions preceding an alternation increases from 3 to 5. This is particularly striking for subject RJW whose subjective report led to the suggestion that the decrease in the inhibitory effect following repeated stimulation was due to the realignment of conscious attention with the repeating target location, and therefore actively away from the alternative. The results from subjects SB and EAM are not so clear and it is certainly not the case that the decrease in reaction time to the continually-repeating target is mirrored exactly by the increase in reaction time to the alternative.

There has been considerable interest in higher-order sequential effects in choice reaction time tasks (Keele, 1969; Laming, 1969; Remington, 1969; Audley, 1973; Kirby, 1976; 1980). The tendency to respond faster to a stimulus which is the same as the one preceding it has been termed a 'repetition' effect (equivalent to facilitation). The opposite tendency, to respond faster to a stimulus which is different from the previous one has been termed an 'alternation' effect (equivalent to inhibition). Generally in 2-choice compatible tasks with repetitions and alternations equally probable, repetition effects appear to occur with R-S intervals of less than approximately half a second and alternation effects with R-S intervals of greater than half a second (Remington, 1969, being an exception). This observation that repetition effects tend to decrease and to change to alternation effects with increasing R-S interval would seem to be consistent with the results obtained on facilitation and inhibition. However, although the analyses of higher-order effects may throw some light on the results of experiment 6.4, it will be argued that they cannot provide an explanation for the inhibitory effect.

The most complete higher-order analysis for 2-choice tasks was carried out by Kirby (1976). He used R-S intervals of 50, 500 and 2000 msec and found that repetition effects changed to alternation effects as the R-S interval increased. The results for 500 and 2000 msec were very similar to those observed in the present experiment. Kirby concluded that an adequate explanation of the sequential effects must involve both subjective expectancy and some kind of 'automatic facilitation'. [Automatic facilitation can refer to either some residual activity in a more peripheral stimulus or response process which facilitates its repetition, or to a saving in processing time in the more central coding processes.] An explanation in terms of subjective expectancy alone (Laming, 1969) would have to explain why the subject's overall expectancy changes from repetitions to alternations as the R-S interval increases. From Kirby's results it appears that while expectancy operates at all R-S intervals (with the subject having an overall bias towards alternations), at short R-S intervals the main determinant of the repetition effect is some kind of automatic facilitation which dissipates over time. He concluded that sequential effects in 2-choice reaction time tasks for long R-S intervals are due to expectancy. They seem to be largely determined by a strategy of expectancy and preparation which occurs <u>prior</u> to the arrival of the stimulus. The subject is sensitive to the occurrence of patterns of both repetitions and alternations in a random sequence and is able to change his strategy from preparing for alternations to preparing for repetitions. Such a change would tend to occur when a run of alternations is discontinued and succeeded by a run of repetitions. Similarly, the repetition strategy would change to an alternation one after the repetition sequence is succeeded by an alternation sequence.

However, although this analysis provides an explanation for the decrease of inhibition with an increasing number of repetitions, it cannot explain the original inhibitory effect (that is, the alternation effect in the first-order data). The best Kirby can do is appeal to a type of gambler's fallacy, that is, a tendency to expect more alternations than repetitions in a random sequence (Kirby, 1980). A comparison of experiments 6.2 and 6.4 reveals similar overall inhibitory effects despite using different numbers of stimuli (4 and 2 respectively), thus discounting any explanation in terms of the _favouring_ of alternations. Rather, inhibition is characterised by a bias _against_ first-order repetitions. It is important to note that the size of the inhibitory effect is not dependent upon the probability of a repetition.

To conclude, the investigation of inhibition is greatly complicated by higher-order effects. LaBerge, van Gelder and Yellott (1970) recommended the use of a cueing technique where the subject can 'set himself for the cued stimulus without regard for events occurring on earlier trials'. Essentially it represents the cue-target procedure as compared to the target-target procedure used in experiments 6.2 and 6.4. They advocated a long intertrial interval (over 1000 msec) and their results indicated that sequential effects can be eliminated in the sense that performance on any trial is independent of previous events and depends only on the cue-target combination on that trial. Such a procedure was used in the remaining experiments (with the exception of experiment 7.1).

In experiment 6.1 the results from the cue run length of 30 showed as much inhibition as the shorter cue run lengths, so more insight into the reduction of inhibition with repetition observed here might be gained from a comparison of the experimental procedures involved. The first important difference is that in experiment 6.1 the targets remained random, so that although the cue appeared in the same location for 30 trials, the overall sequence of events involved as many repetitions and alternations as the shorter cue run lengths. Secondly, the subjects were not consciously aware of the cues in experiment 6.1, whereas in experiment 6.4 every event required a response. Taken together, these observations provide additional support for the conclusion that the results of experiment 6.4 are due to the subject's higher-order expectations.

A limitation of both experiments 6.1 and 6.4 is that they only involve the stimulation of symmetrical areas about the vertical midline. A further version of experiment 6.4 was therefore carried out (experiment 6.4a) where the two LEDs were positioned so that they were on the same side of the visual field but as far apart as in experiment 6.4 (see inset of Figure 6.13). Two subjects each completed four blocks of trials and the overall medians (for the R-S interval of 600 msec only) are presented in Figure 6.13. The results are very similar to those from experiment 6.4 (see Figures 6.10 and 6.11). This contrasts with the findings of Singer, Zihl and Pöppel (1977) on adaptation as described in section 1.6. They demonstrated that visual thresholds increase when targets are repeatedly presented in the periphery of the

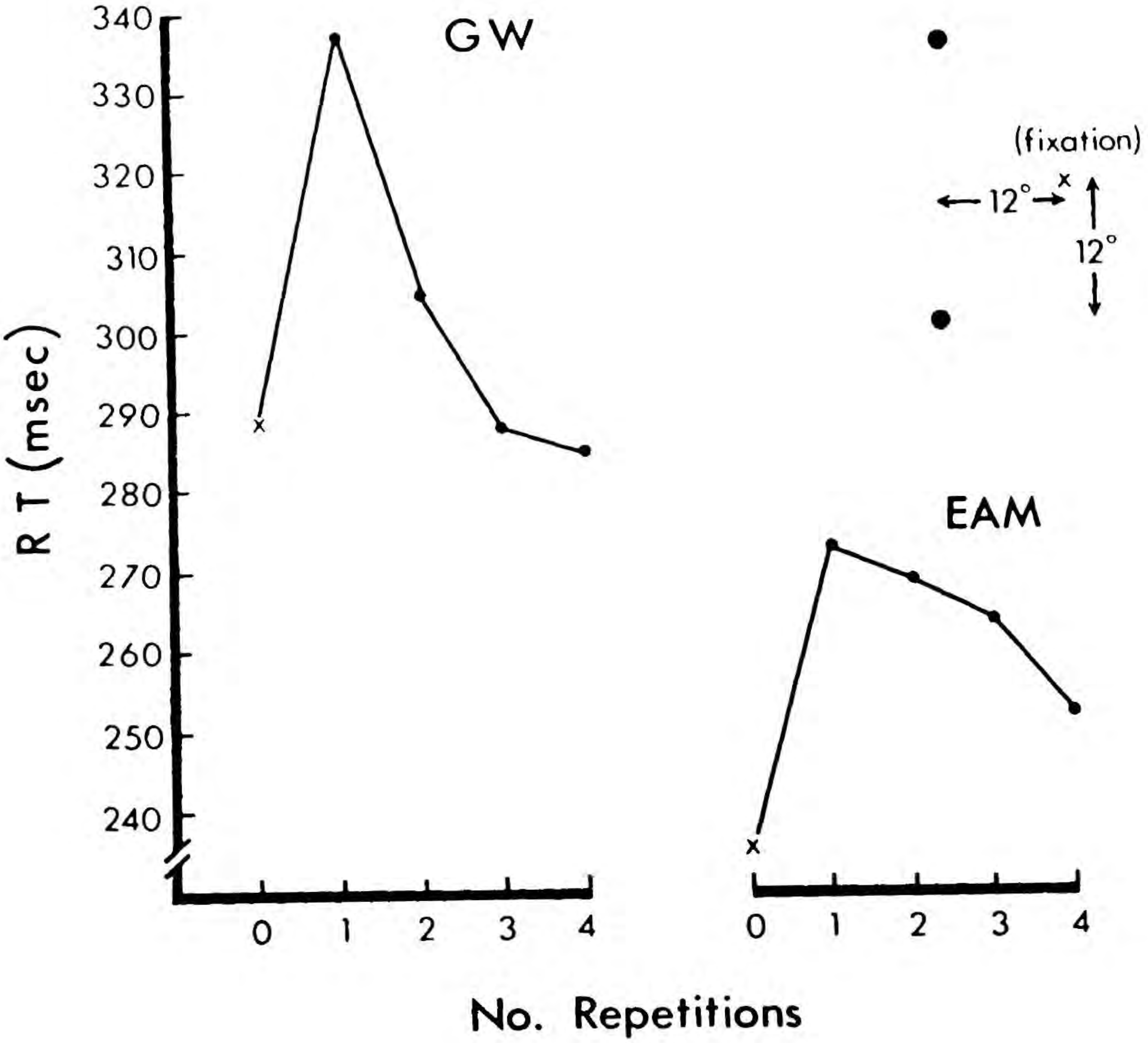


Figure 6.13 Results of experiment 6.4a.

visual field, and that this elevation can be reset by adapting a mirror symmetric area in the contralateral visual field. Stimulation in any other area causes no resetting in the adapted field. The usual amount of inhibition observed using the two locations shown in Figure 6.13 suggests that the inhibitory effect is not related to the type of adaptation described by Singer et al. Further evidence in support of this conclusion is provided by the experiments reported in chapter 7.

6.6 General Conclusions

In this chapter an attempt has been made to describe the two components of externally-controlled orienting. It has been shown that both facilitation and inhibition occur to continually repeated events, although the presence of intervening random events may 'reset' the system. However, inhibition decreases with an increasing number of repetitions using a procedure that allows the subject's higher-order expectations to influence responding. Investigations of the spatial and temporal characteristics of inhibition have demonstrated that it can last up to a second and is not restricted to the exact location of the previous event. From a comparison of experiments with 2, 4 and 14 possible target locations, it is clear that inhibtion cannot be explained by a shift of attention towards an alternative target source, rather it is a shift away from the present one. Together the results of experiments 6.1-6.4 argue against some of the explanations of inhibition which were put forward in section 1.6, for example, response inhibition as described by Harvey (1980) and masking. The next chapter reports further experiments designed to investigate other possible explanations.

CHAPTER 7

The Nature of Inhibition

7.1 Introduction

The experiments in this chapter were designed to investigate further the origin of the inhibitory effect. One of the possible explanations propsed in section 1.6 was sensory habituation. For example, Singer, Zihl and Pöppel (1977) identified a form of sensory adaptation whereby visual thresholds increase when targets are repeatedly presented in the visual periphery. Frome, MacLeod, Buck and Williams (1981) suggested that there may be more than one form of visual habituation. Their results were quantitatively similar to those of Singer et al. However, the habituation demonstrated by Frome et al did not transfer binocularly whereas the results of Singer et al showed complete binocular transfer (that is, a stimulus presented to one eye influenced the threshold at the other). Preliminary evidence against sensory adaptation of the type described by Singer et al as an explanation for the inhibitory effect was provided by experiment 6.4a. Inhibition was therefore investigated further by three studies aimed at identifying its origin. Experiment 7.1 was designed to determine whether or not the inhibitory effect is retinal. The question of its co-ordinates (retinal or environmental) was addressed by experiment 7.2, and finally, experiment 7.3 attempted to extend the inhibitory effect to a dimension other than visual space, namely colour.

7.2 Experiment 7.1

A dichoptic viewing procedure was used in experiment 7.1 to determine whether or not the inhibitory effect is mediated by monocular pathways only. Thus if the effect is entirely retinal, reaction time to a stimulus presented to one eye should not be affected by the spatial location of a previous stimulus presented to the other.

7.2.1 Method

7.2.1.1 Subjects

Five subjects participated in a single experimental session of approximately 20 minutes.

7.2.1.2 Apparatus and Stimuli

The IBM computer as described in section 2.5.1 was used to run the experiment. The stimuli were four red LEDs, with two green LEDs providing the fixation point. They were mounted as shown in Figure 7.1 so that when reflected from the two front-silvered mirrors and the green LEDs fused, the stimuli appeared 5 degrees to the left and right of fixation. The subject was seated making sure that his eyes were level with the fixation point and so that the black card partitions prevented the LEDs from

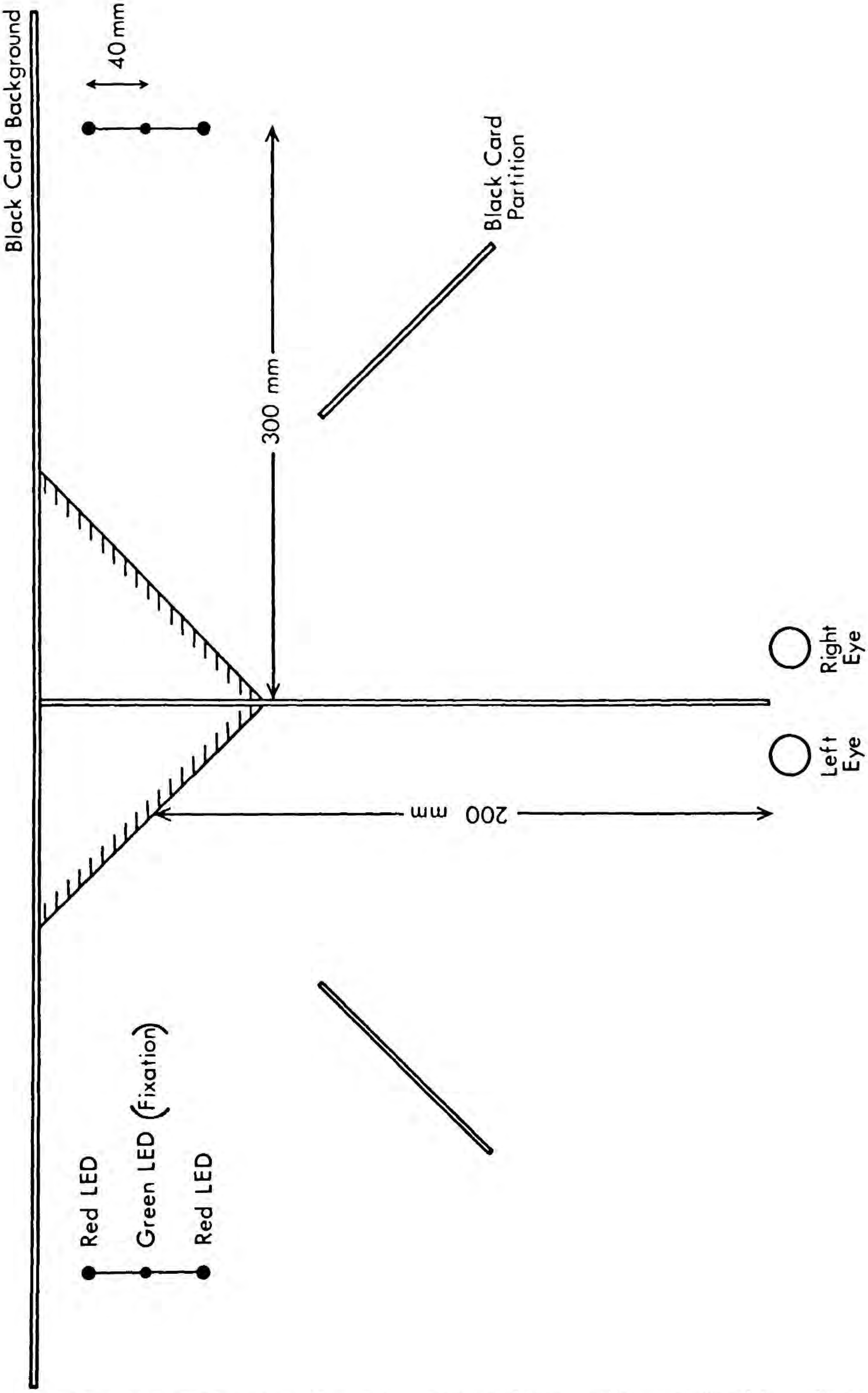


Figure 7.1 Arrangement of apparatus and stimuli for experiment 7.1.

being seen directly.

7.2.1.3 Design and Procedure

The single experimental session consisted of four blocks of trials although only the data from the last three were used in the analysis. The subject was asked to fuse the images presented to each eye so that only three LEDs could be seen. Therefore the display appeared to the subject as a red LED 5 degrees to the left and another 5 degrees to the right of a central green LED. The subject was told to fixate on the green LED(s) throughout each block of trials. A reminder was given by the experimenter of this requirement at the beginning of each block.

The target-target procedure as described for experiment 6.2 in section 6.3.1.3 was used. A block consisted of 240 trials which were divided equally between response-stimulus (R-S) intervals of 400, 600 and 900 msec. Each trial began with the presentation of one of the four red LEDs until a simple detection response of a key press had been made. The next trial began after the R-S interval, the order of R-S intervals being randomised separately for each block of trials. If a response was made during the R-S interval or within 100 msec of the target presentation, the trial was immediately aborted and an anticipation error recorded. The target was equally likely to be any one of the four LEDs, so the subject was informed that the target would appear as often on the left as on the right and that the presentation order was entirely random.

7.2.2 Results and Discussion

The overall anticipation rate was 3.7%. These trials were deleted from the analysis together with the trial following each error. The first trial of each block was also excluded from the analysis.

The trials were coded according to the spatial relationship between the location of the current target and that of the previous trial. Thus there were three types of trial : same, "same" and opposite. The first type (same) refers to trials where the target was the presentation of the same LED as on the previous trial. These were distinguished from "same" trials which appeared to the subject as the presentation of the identical LED as on the previous trial, but in fact the target was one which stimulated the opposite eye (that is, a retinal but not a phenomenal change in target location). Finally, opposite trials refer to targets appearing in the opposite location to the previous trial, that is, from left to right or right to left of fixation.

Median reaction times were put into an analysis of variance with block (first, second and third), R-S interval (400, 600 and 900 msec) and trial-type (same, "same" and opposite) as fixed effects factors. There was no effect of block [$F(2,8)=1.09$, $p>0.1$] nor was it involved in any significant interaction, so this factor will not be discussed further. The overall means are presented in Figure 7.2. [The five subjects all showed this pattern of results.] There were significant effects of R-S interval [$F(2,8)=16.53$, $p<0.005$] and trial-type [$F(2,8)=30.37$, $p<0.0005$] and there was a significant interaction between the two [$F(4,16)=3.93$, $p<0.05$]. It can be seen from Figure 7.2 that the trial-type effect is due to the difference between the opposite trials and the two types of same trials.* The interaction can be attributed to the decrease in inhibition with increasing R-S interval (also observed in experiments 6.2, 6.3 and 6.4). These results demonstrate that the inhibitory effect shows complete interocular transfer and therefore cannot be retinal. Thus sensory habituation at the retinal level can be discounted as an explanation for the inhibitory effect. However, it still would be possible to attribute the effect to sensory habituation occurring at a higher level. Experiment 7.2 was designed to investigate this by using a cue-target procedure whereby the cue and the target shared the same location in visual space but not the same sensory pathway (at any level). This was achieved by the insertion of a saccade after the cue but before the target. Thus the question of interest is whether the locus of inhibition is determined by retinal or environmental co-ordinates.

*Further analysis confirmed that "same" trials were not significantly different from same trials [$t(24)=0.78$, 0.88 and 0.17 for the R-S intervals of 400, 600 and 900 msec respectively, each $p>0.2$, 2-tailed test] but significantly different from opposite trials [$t(24)=6.70$, 4.27 and 3.40, $p<0.001$, 0.001 and 0.01, 2-tailed test, again corresponding to the R-S intervals of 400, 600 and 900 msec].

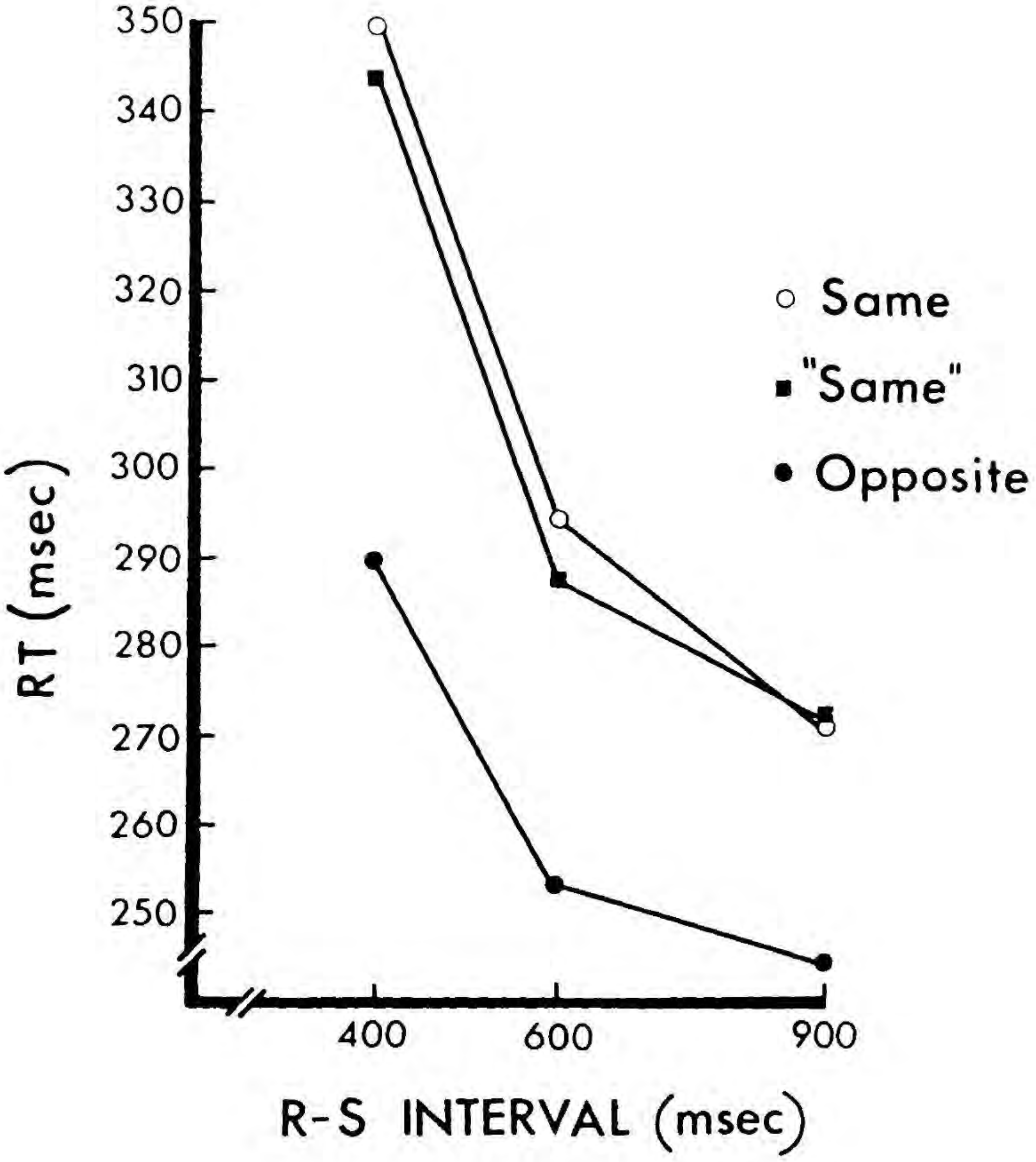


Figure 7.2 Results of experiment 7.1.

7.3 Experiment 7.2

In this experiment, the subject was required to move his eyes in between the occurrence of the cue and the target. If the inhibitory effect is environmental, then an eye movement should leave the originally-stimulated location in space most affected. However, if inhibition is determined by retinal co-ordinates, then only the target that shares its retinal location with the cue will be inhibited.

7.3.1 Method

7.3.1.1 Subjects

Five subjects each participated in a single experimental session of approximately 30 minutes.

7.3.1.2 Apparatus and Stimuli

The PDP computer was used to control the experiment (see sections 2.5.1 and 2.5.2) and the stimuli (LEDs) were mounted using the equipment shown in Figure 2.5. Four red LEDs were placed in the locations illustrated in the upper part of Figure 7.3. The two fixation points (1 and 2) were small white circles of approximately 0.5 degrees diameter. An angle-poise lamp placed at the back of the laboratory provided dim illumination so that the subject could see both fixation points clearly.

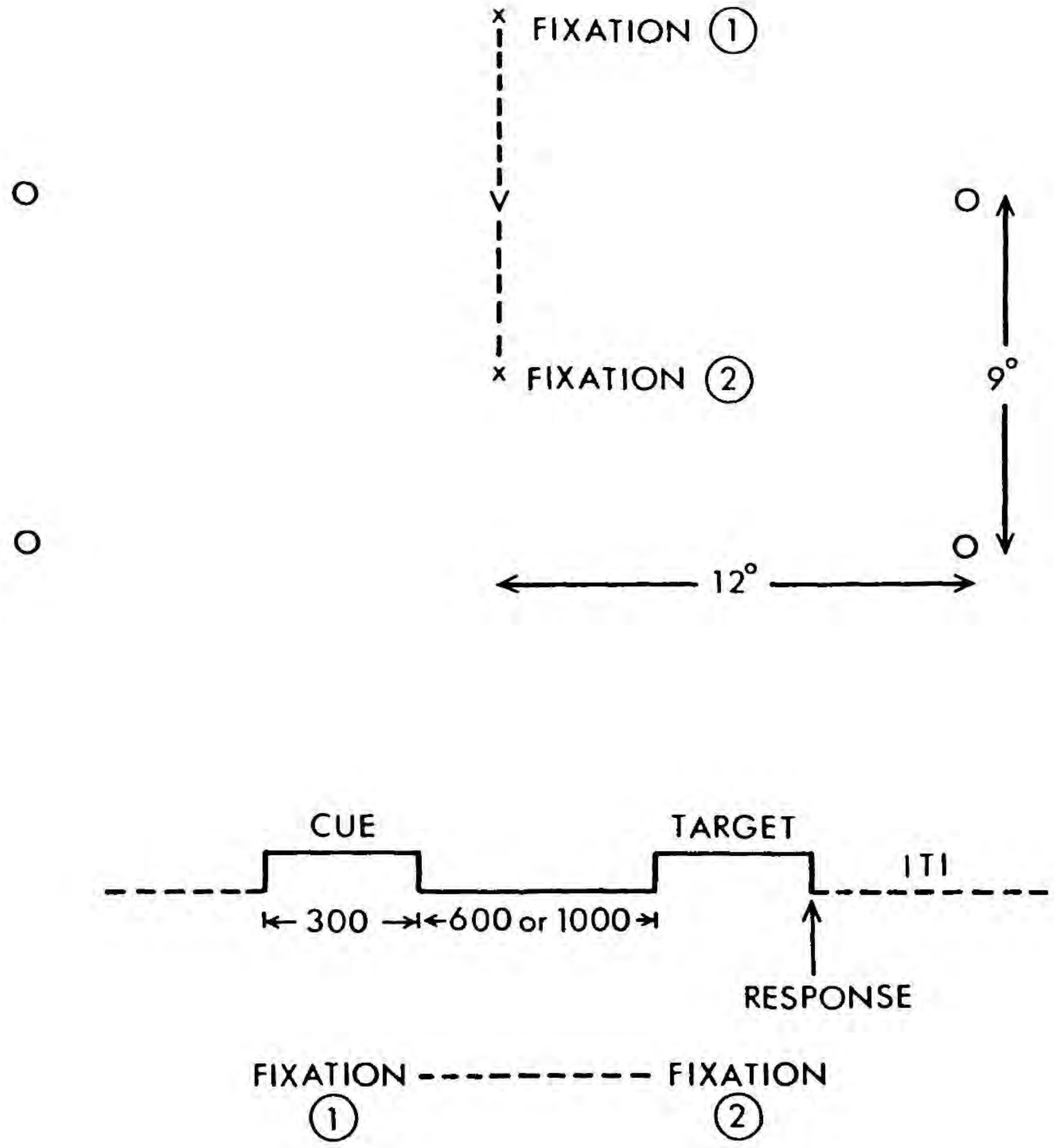


Figure 7.3 Stimulus positions and timing in experiment 7.2.

7.3.1.3 Design and Procedure

Each subject carried out three blocks of trials. The subject began each block by pressing the single key and after a pause of 2000 msec the first trial was presented. At the end of a block (approximately five minutes), the subject was allowed to rest and then start the next block, again by pressing the key.

The 140 trials in each block were divided in the following way. There were 56 and 84 trials of SOAs of 900 and 1300 msec respectively. Longer SOAs were chosen in order to ensure that the subject had sufficient time to carry out the required eye movement after the occurrence of the cue and before the presentation of the target.

The timing of the trials is summarised in the lower part of Figure 7.3. A cue-target procedure was used. At the beginning of each trial, the subject fixated on the upper fixation point (1). The cue was the brief presentation of either the upper-left or the upper-right LED (with equal probability) for 300 msec. The offset of the cue was the signal for the subject to move his eyes to the lower fixation point (2) to wait for the target. This could occur in any one of the four locations (which were equally likely), the subject's task being to press the single key as quickly as possible after the onset of the target. It should be noted that the position of the second fixation point was such that the four targets were equidistant from fixation. Following the response there was an intertrial interval which was randomly chosen from the range 1500 to 2500 msec before the onset of the next cue. During this interval, the subject was required to move his eyes back to the original fixation point (1). This procedure enabled a comparison to be made between targets that share retinal co-ordinates with the cue and those that share environmental co-ordinates. For example, following the top-left location as the cue, a comparison can be made between the reaction time to a top-left target (that is, at the same position in the environment), with reaction time to a bottom-left target (at the same position on the retina). It was stressed that the cue was merely a temporal warning signal, and that it was non-informative in terms of the location of the target. Anticipations were recorded when the subject pressed the key during the SOA and up to 100 msec after the onset of the target. The response terminated the trial.

7.3.2 Results and Discussion

The overall anticipation rate was 1.1%. The trials were divided into the two SOAs and then further coded according to the relationship between the locations of the cue and the target. For example, following a cue in the top-left location, the target could occur in the top-left ('same' trials), bottom-left ('same side' trials), top-right ('opposite' trials) or bottom-right ('diagonally opposite' trials) location.

For each subject, the results from the three blocks of trials were pooled and medians taken. These were put into an analysis of variance with SOA (900 and 1300 msec) and trial-type (same, same side, opposite and diagonally opposite) as fixed effects factors. The means are presented in Figure 7.4. There were significant effects of SOA [F(1,4)=17.19, p<0.02] and trial-type [F(3,12)=8.73, p<0.005], but there was no interaction between them [F(3,12)=0.60, p>0.1]. From Figure 7.4 it can be seen that the trial-type effect can be mainly attributed to the increased reaction time to respond to same trials compared to the other three types. Clearly the inhibitory effect is found only for targets that share environmental location with the cue. [It is interesting to note that, contrary to the results of the previous experiments, there is no decrease in the inhibitory effect between 900 and 1300 msec.]

Experiment 7.1 demonstrated that the inhibitory effect is not retinal. The present experiment has shown that explanations in terms of habituation of sensory pathways at any level must be discounted. To conclude, it appears that reaction time is increased when a subject responds to a repeated event in space, regardless of whether or not the first stimulus required a response. As the inhibitory effect does not depend upon stimuli sharing the same sensory pathways, it might be expected to generalise to other situations, that is, repetition of any stimulus attribute that is easily coded may result in a

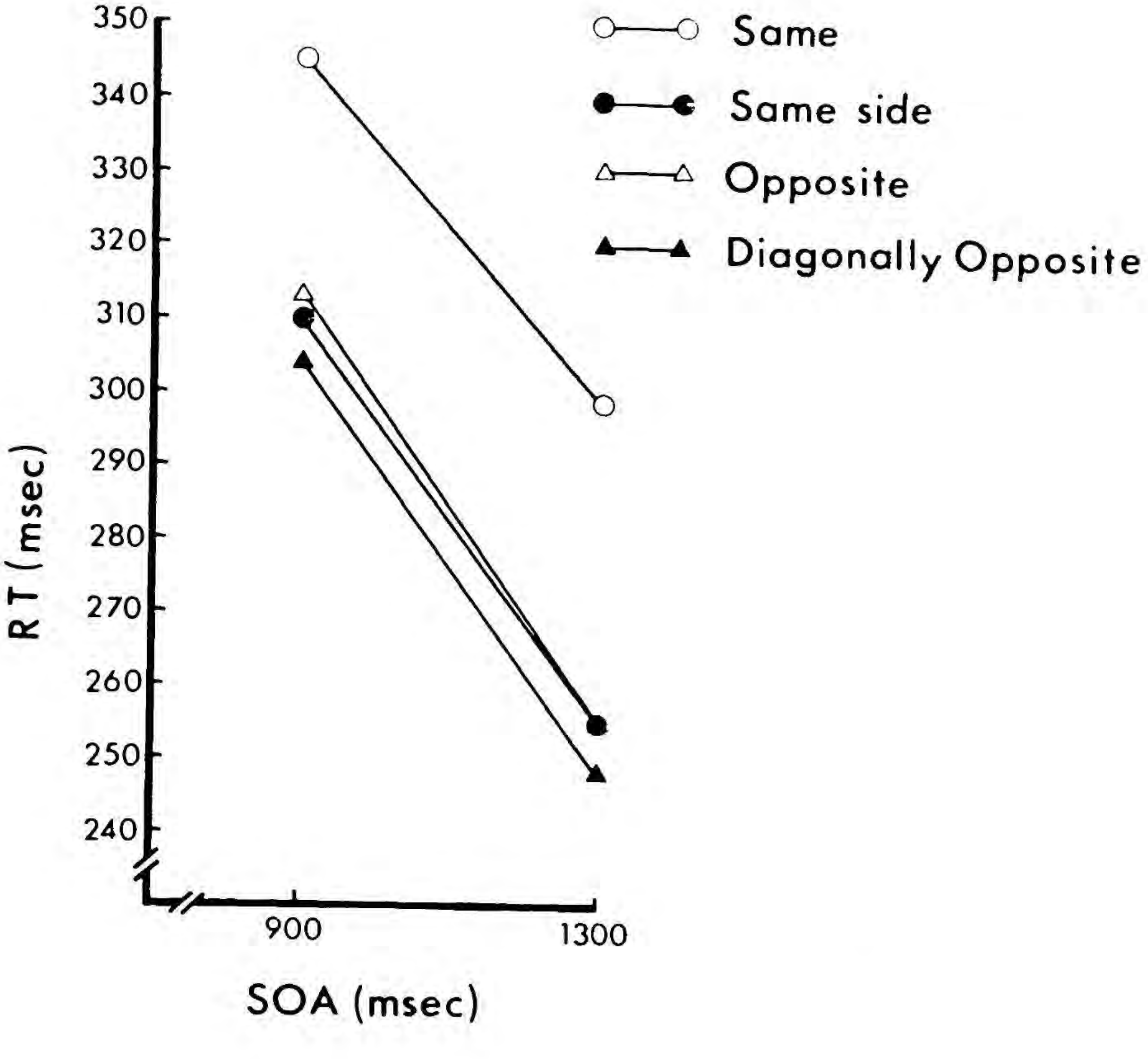


Figure 7.4 Results of experiment 7.2.

slower response.

7.4 Experiment 7.3

Experiment 7.3 used both red and green LEDs as cues and targets so that a comparison could be made between the repetition of stimulus colour and location. Colour was chosen as an additional dimension as it has been shown to be a salient aspect of a stimulus, both as a partial report cue and as a stimulus dimension that cannot be ignored even in a task in which subjects attempt to ignore the 'irrelevant' colour dimension (Egeth, 1966; Harms and Bundeson, 1983).

7.4.1 Method

7.4.1.1 Subjects

Four subjects participated in a single experimental session of approximately 30 minutes.

7.4.1.2 Apparatus and Stimuli

The PDP computer as described in sections 2.5.1 and 2.5.2 was used to control the experiment. The stimuli were LEDs mounted in the equipment shown in Figure 2.5. The central fixation point was a yellow LED. Two green and two red LEDs were used as both cues and targets and these were positioned as shown in Figure 7.5.

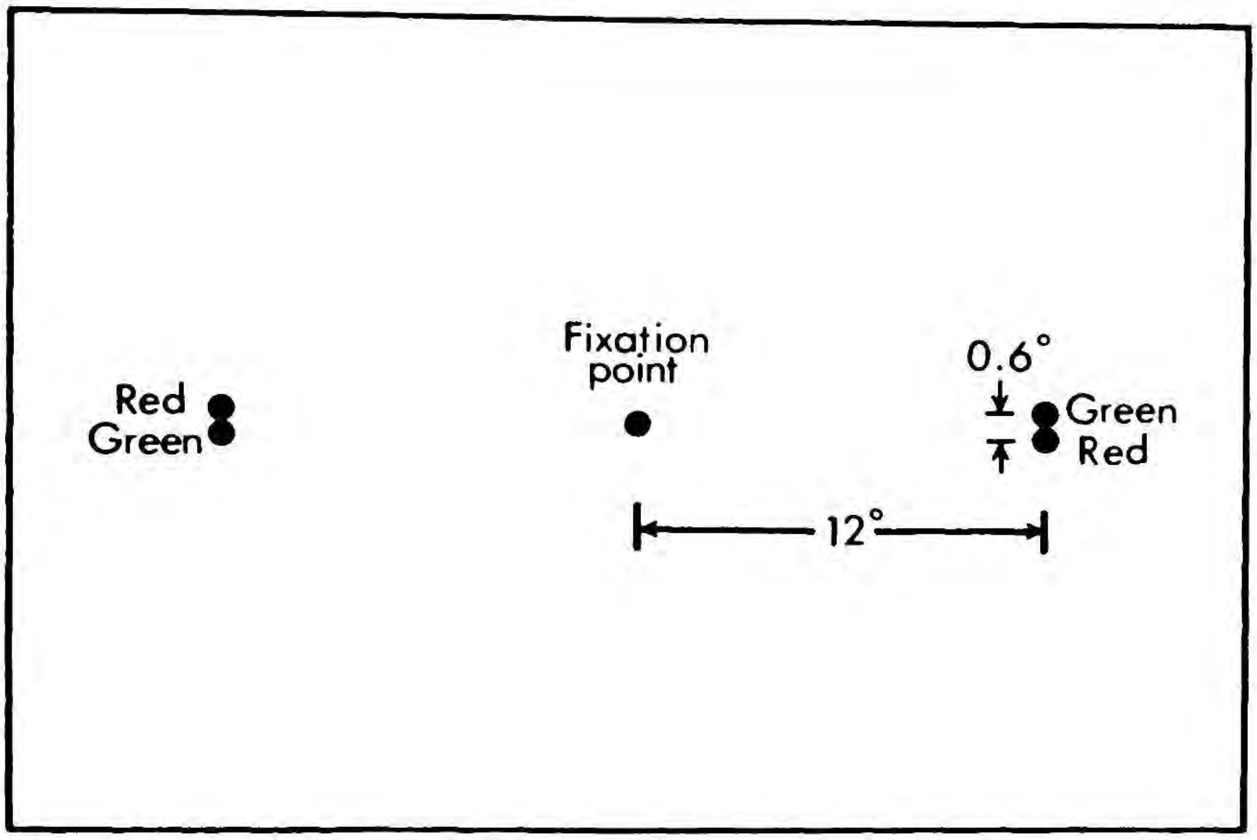


Figure 7.5 Stimulus positions in experiment 7.3.

7.4.1.3 Design and Procedure

Each subject participated in three blocks of trials. (They had all taken part in at least one previous simple reaction time experiment and so were not given any practice.) Each block contained 140 trials. These were divided so that the cue was equally likely to be any one of the four LEDs. This also applied to the target distribution. Three SOAs were used, 700, 900 and 1300 msec, and these occurred with a frequency ratio of 1:3:1. The SOAs were distributed in this way in order to keep the experimental session as short as possible while ensuring an adequate number of trials of one SOA (900 msec) for further analysis. The SOAs of 700 and 1300 msec were therefore included merely to prevent the anticipations that certainly would have occurred if just one SOA had been used. Before the beginning of each block, the order of trials was randomised.

Figure 6.5 summarises the timing of each trial. The cue was the presentation (for 300 msec) of one of the four LEDs. This was followed after the SOA by the target which again was one of the four LEDs. With the exception of the instructions, all the other experimental details were as described for experiment 6.3 in section 6.4.1.3. In addition to the usual instructions regarding the requirement to fixate on the central LED throughout a block of trials, the subject was told that both the colour and the location of the cue were non-informative in terms of predicting either the colour or the location of the target. The cue was therefore to be regarded merely as a temporal warning signal.

7.4.2 Results and Discussion

As indicated above, only the data for the SOA of 900 msec were analysed. The overall anticipation rate was less than 1%. For each subject the data from the three experimental blocks were combined. The trials were divided into four types depending on the relationship between the cue and the target : 'same location (L) and colour (C)', 'same L, different C', 'different L, same C', and 'different L, different C'. (Although the centres of the red and green LEDs on the same side of fixation were in fact 0.6 degrees apart, they were considered as occupying the same spatial location for the purposes of defining the four types of trial.)

Medians were calculated for each subject and put into an analysis of variance with location (same and different) and colour (same and different) as the fixed effects factors. The overall means are presented in Figure 7.6. The analysis of variance revealed that there was a significant effect of location [$F(1,3)=12.61$, $p<0.05$], a marginally - significant effect of colour [$F(1,3)=9.74$, $p<0.06$] but no interaction [$F(1,3)=1.40$, $p>0.1$]. Because the red and green LEDs on the same side of fixation had to be separated by 0.6 degrees, the small difference of 6

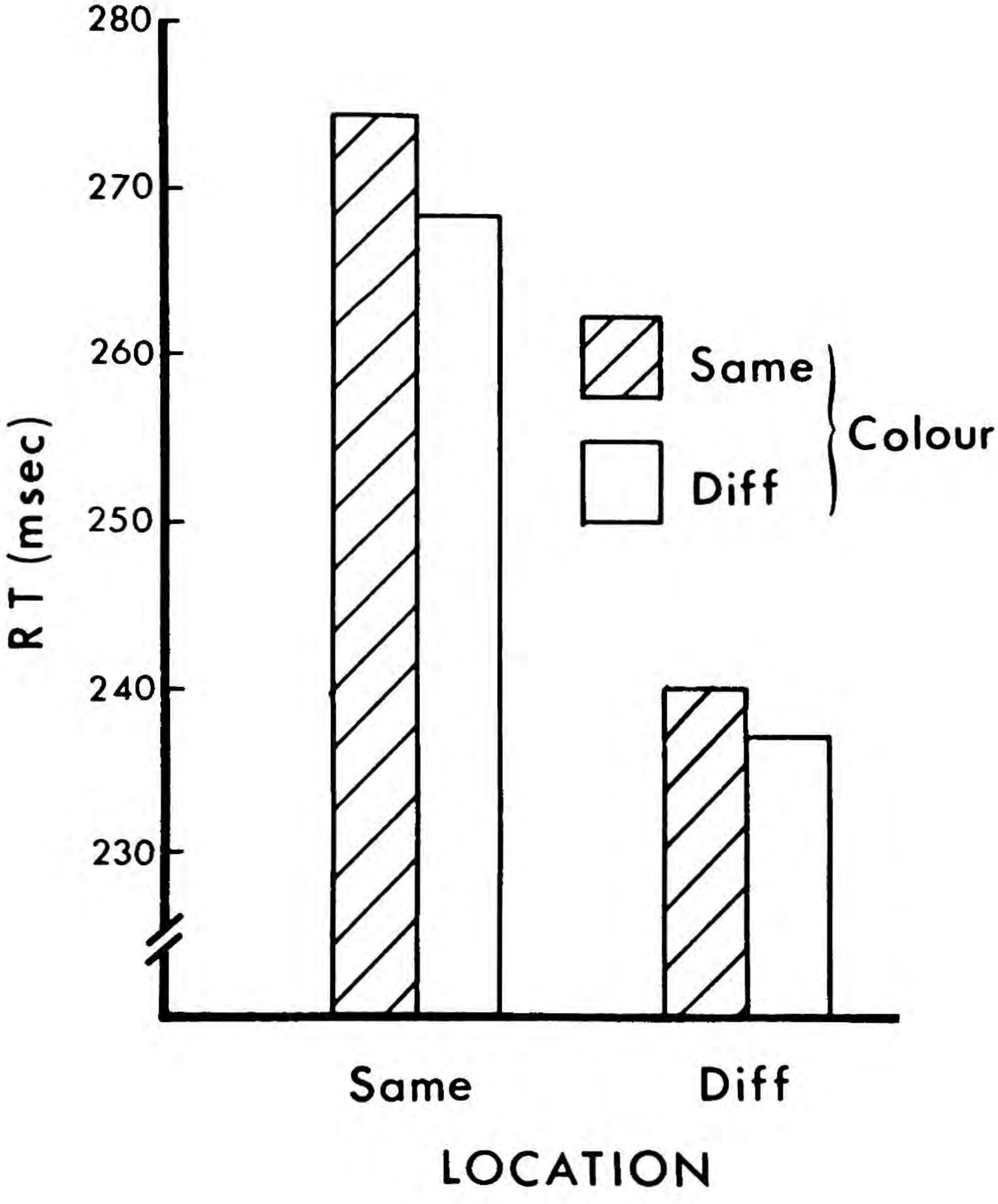


Figure 7.6 Results of experiment 7.3.

msec between the same and different colour for the same location was expected from the results of experiment 6.3 where reaction time to a target in exactly the same location as the cue ('0' trial-type) was 12 msec slower than to a target just over one degree away from the cue ('1' trial-type) for an SOA of 900 msec.

The results of the present experiment demonstrate that if the cue and the target share the same location, almost as much inhibition is observed when they are different colours as when they are the same colour. Similarly, for spatially separate cue-target pairs, responses are very nearly as fast to a colour repetition as to a change in colour between the cue and the target. Thus inhibition does not appear to generalise to dimensions other than space.

7.6 General Conclusions

The experiments presented in this chapter have provided evidence against an explanation of inhibition in terms of habituation of sensory pathways. Experiment 7.1 demonstrated that the inhibitory effect shows complete interocular transfer. Also, inhibition requires that the cue and target share environmental but not necessarily retinal co-ordinates (experiment 7.2). Finally, the spatial nature of the inhibitory effect is emphasised by the results of experiment 7.3 which demonstrated that the repetition of target location but not colour produces inhibition.

It has already been suggested that the facilitatory component is attentional in origin and occurs as a result of externally-controlled covert orienting. Inhibition appears to occur as a consequence of such orienting, but not as a result of the need to prevent responding to the cue. Rather, it is seen as a reluctance to respond manually and ocularly to a stimulus appearing in the same or nearby location in the periphery as a previous one that produced covert orienting, regardless of whether or not the first stimulus required a response. By employing different techniques, the final experimental chapter attempts to provide converging evidence in support of these possibilities.

CHAPTER 8

Further Methods of Investigation

8.1 Introduction

The effects of internally-controlled covert orienting have been measured using a variety of techniques, for example, introspection (Helmholtz, 1925), manual reaction time (Posner, Nissen and Ogden, 1978), reflex modification (DelPezzo and Hoffmann, 1980), signal detection (Bashinski and Bacharach, 1980), visual evoked potentials (Eason, Oakley and Flowers, 1983) and clinical studies (Posner, Cohen and Rafal, 1981). It was suggested in section 1.4 that the behavioural, electrophysiological and clinical evidence converges on the conclusion that the human visual system has a mechanism for selectively processing information from attended spatial locations. However, with the exception of the detailed analysis of errors in experiment 4.3, all the experiments on externally-controlled orienting presented in chapters 4-7 have used speed of response (that is, simple and choice manual reaction time and saccade latency) as the dependent variable. In addition to overall measures of response speed, other analyses have been of considerable theoretical value in the study of information-processing, for example, reaction time distributions (Burbeck and Luce, 1982), practice effects (Fitts and Switzer, 1962), individual differences (Grice, Spiker and Nullmeyer, 1979) and the perception of temporal order (Sternberg and Knoll, 1973). Further insight into the facilitatory and inhibitory components of externally-controlled covert orienting might therefore be gained both from an investigation of different aspects of the data already presented (introduced by experiment 8.1) and from a study of the effect of direct cueing on a non-speeded response (experiment 8.2).

8.2 Experiment 8.1

Experiment 8.1 was based on Posner and Cohen's (1980) double-cueing experiment (see section 1.6) which was designed to investigate the nature of the inhibitory effect. In addition to single direct cues in the periphery (similar to those used in experiment 4.1), they included trials in which both the left and right peripheral boxes brightened simultaneously. Their results demonstrated reduced facilitation at an SOA of 80 msec but as much inhibition at an SOA of 500 msec for double-cued as compared to single-cued trials. They suggested that the reduced facilitation was consistent with their earlier conclusion (Posner, Snyder and Davidson, 1980) that attention under internal control cannot be divided effectively between two locations either side of fixation. However, because inhibition was not similarly reduced by double-cueing, Posner and Cohen concluded that the inhibitory effect is due to the sensory stimulation in the periphery and not to the externally-controlled orienting produced by the cue. Contrary to this conclusion, there was some evidence from the results of the unpredictable eye tracking conditions of experiment 5.3 (see section 5.4.2) that inhibition does not occur if facilitation is abolished. In addition, Posner (personal communication) has some preliminary evidence that the simultaneous cueing of four locations (above, below, to the left and to the right of fixation) results in neither a facilitatory nor an inhibitory effect. Therefore, because of the theoretical significance of the double-cueing experiment, it was considered necessary to provide a replication of Posner and Cohen's result.

The first attempt was similar to experiment 4.1 (see section 4.2) with the addition of two further trial-types : double-cued trials where both the left and right boxes were brightened simultaneously, and centre-cued trials where the central box brightened in place of the single direct cue in the periphery. As usual, following each cue the target was equally likely to appear in the left as in the right box. The results for the SOA of 100 msec were as expected, that is, valid trials being faster than invalid ones, with double-cued and centre-cued trials falling approximately midway between the two. For the centre-cued trials, attention should remain at the centre until the appearance of the target in one of the peripheral boxes, so that the response should not be as fast as if attention were aligned with the target location (valid trials), nor as slow as if it were aligned with the location on the opposite side (invalid trials). The reduced facilitation for double-cued compared to valid trials is consistent with Posner and Cohen's findings described above. However, it could be attributed to maximal facilitation at one peripheral location on half of the trials. If this were the case, the reaction time distributions for double-cued trials would be bimodal and therefore have larger variances than single-cued trials. This was easily tested by an analysis of variance on the semi-interquartile ranges of the four trial-types for the SOA of 100 msec. The overall means of the ranges for the 10 subjects were 47, 52, 45 and 45 msec for invalid, valid, centre-cued and double-cued trials respectively and there was no significant difference between them [$F(3,27)=0.76$, $p>0.1$]. Thus it can be concluded that on double-cued trials, orienting does not occur to one peripheral box only as though the other box had not been cued. [This represents the first example of the additional information that can be gained from the analysis of a reaction time measure other than central tendency.]

At the SOAs of 300 and 500 msec there was no difference between the invalid and valid trials, that is, no evidence of an inhibitory effect. [It should be noted that the invalid-valid difference at the SOA of 500 msec in Posner and Cohen's double-cueing experiment was only 10 msec.] Because of the absence of inhibition, the crucial comparisons involving the double-cued trials could not be made. The only methodological change made from experiment 4.1 was the inclusion of the double-cued and centre-cued trials, so the reason for the lack of an inhibitory effect is not clear. One possibility is that inhibition was occurring *after* the longest SOA (500 msec). Experiment 8.1 was therefore conducted as a further attempt to replicate Posner and Cohen's double-cueing experiment using the LED cue-target procedure (see experiments 6.3, 7.2 and 7.3) with SOAs of 700, 900 and 1300 msec. Thus experiment 8.1 was concerned with the effect of double-cueing on the inhibitory effect only.

8.2.1 Method

8.2.1.1 Subjects

Four subjects each participated in a single experimental session lasting approximately 30 minutes.

8.2.1.2 Apparatus and Stimuli

The PDP computer was used to control the experiment (see sections 2.5.1 and 2.5.2). The stimuli were mounted as shown in Figure 2.5 and were two red LEDs placed 12 degrees to the left and 12 degrees to the right of a central fixation point (a yellow LED).

8.2.1.3 Design and Procedure

Each subject participated in three blocks of trials and was required to fixate on the central LED throughout. A block contained 140 trials which were divided in the following way. For 46 of the trials the cue was the presentation of the LED on the left of fixation for 300 msec. The cue was the LED on the right for 47 of the trials and for the remaining 47 trials the cue was the presentation of both LEDs simultaneously for 300 msec. The target was equally likely to be either the LED on the left of fixation or the one on the right. The 140 trials were divided between three SOAs (700, 900 and 1300 msec) with a ratio of 1:2:2. [The unequal division of SOAs was due to the randomisation program used - see also section 6.4.1.3.] The order of trials was randomised before each block.

The timing was as for experiment 6.3 (shown in Figure 6.5 and described in section 6.4.1.3). The subject was instructed in a similar way, that is, to respond only to the target but to use the brief cue (which could be the left, right or both LEDs) as a warning signal that a target was about to appear (either the left or the right LED with equal probability).

8.2.2 Results and Discussion

The overall anticipation rate was 2.0%. For each subject the data from the three experimental blocks were combined and overall medians for the 9 conditions (3 SOAs x 3 trial-types) were calculated. The three trial-types were same, double and opposite corresponding to a target in the same location as a cue, a target following a double-cue, and a target in the opposite location to a cue respectively. These medians were put into an analysis of variance with SOA (700, 900 and 1300 msec) and trial-type (same, double and opposite) as fixed effects factors. The overall means are shown in Figure 8.1, and the analysis of variance revealed that there were significant effects of SOA [$F(2,6)=9.72$, $p<0.02$] and trial-type [$F(2,6)=21.41$, $p<0.005$], but no interaction [$F(4,12)=1.52$, $p>0.1$]. The usual inhibitory effect is shown by the same-opposite difference. The double-cue, however, produces less inhibition than a single cue (same trials) but more than no cue (opposite trials) and this was the case for all the subjects. The conclusion from this experiment is that contrary to the results of Posner and Cohen (1980), the simultaneous stimulation of more than one location results in reduced inhibition. This is an important result as the inhibitory effect appears to be reduced by about the same amount as the facilitatory effect, that is, both are approximately halved by double-cueing compared to single-cueing. This provides further support for the suggestion made in chapter 5 that inhibition occurs as a

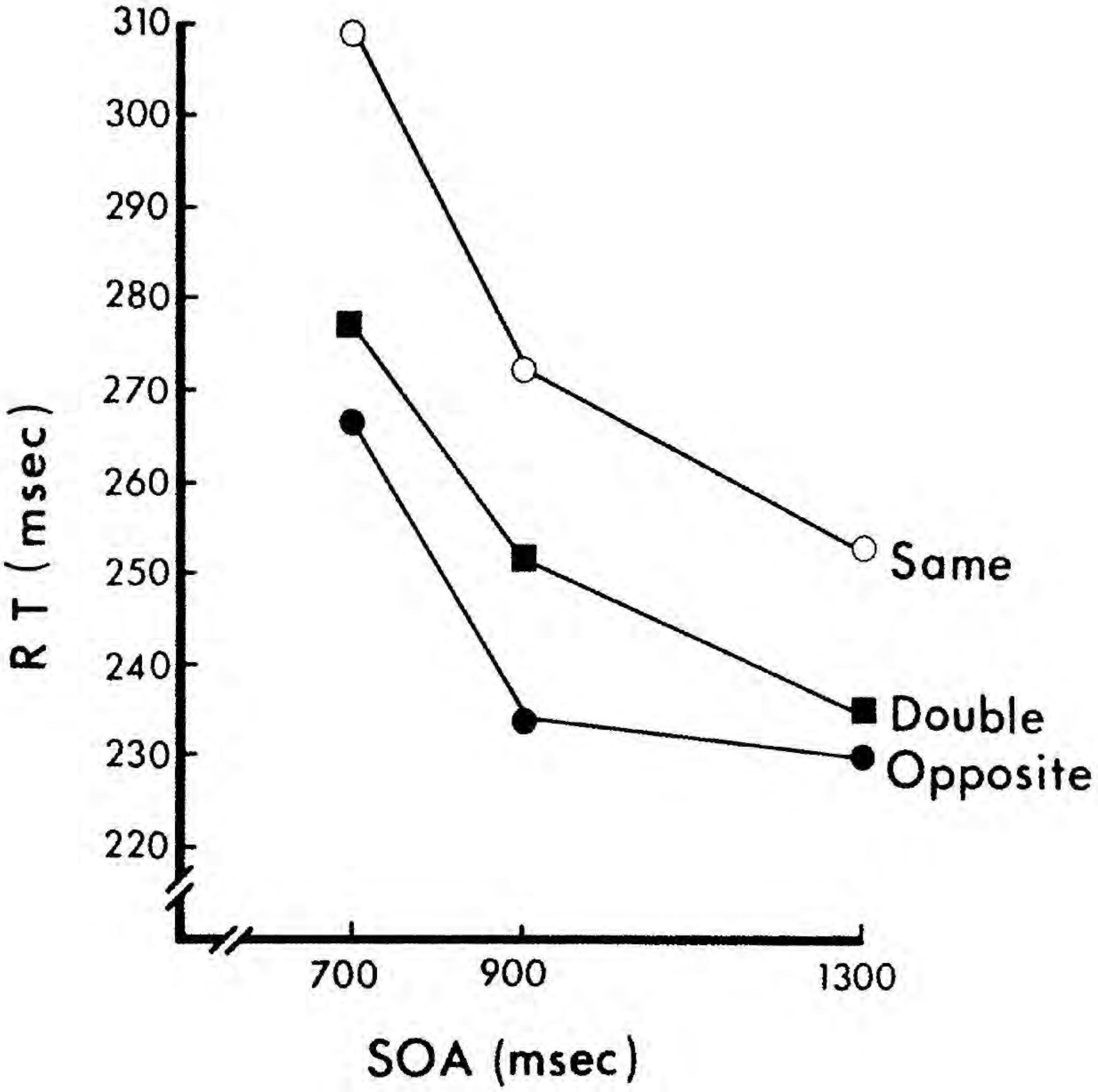


__Figure 8.1__ Results of experiment 8.1.

direct consequence of externally-controlled orienting rather than as the inevitable result of sensory stimulation in the periphery.

8.3 Reaction Time Distributions

It was suggested in section 8.2 (with respect to the first attempt to replicate Posner and Cohen, 1980) that the reduced facilitation on double-cued trials could be the result of full facilitation at one location on half of the trials. As a test of this possibility (which predicts that the reaction time distributions for double-cued trials would be bimodal and therefore more variable than single-cued trials), the semi-interquartile ranges (SIQRs) for the four trial-types were compared. They were not significantly different, the conclusion being that on double-cued trials attention is not shifted to one side only. It would therefore be predicted that the SIQRs of the reaction times for the three trial-types of experiment 8.1 would also be similar. This was tested by an analysis of variance on the SIQRs with SOA (700, 900 and 1300 msec) and trial-type (same, double and opposite) as fixed effects factors. The overall means are presented in Table 8.1 and the analysis of variance confirmed that there were no effects of SOA [$F(2,6)=0.01$, $p>0.1$], or trial-type [$F(2,6)=0.31$, $p>0.1$] and there was no interaction between them [$F(4,12)=0.49$, $p>0.1$]. An example of the reaction time distributions (for the SOA of 900 msec) is shown in Figure 8.2 for the four subjects. (The distributions for

		SOA (msec)		
		700	900	1300
TRIAL - TYPE	SAME	19.5	23.3	23.3
	DOUBLE	20.3	19.5	19.3
	OPPOSITE	21.5	17.3	18.3

Table 8.1 SIQRs from experiment 8.1.

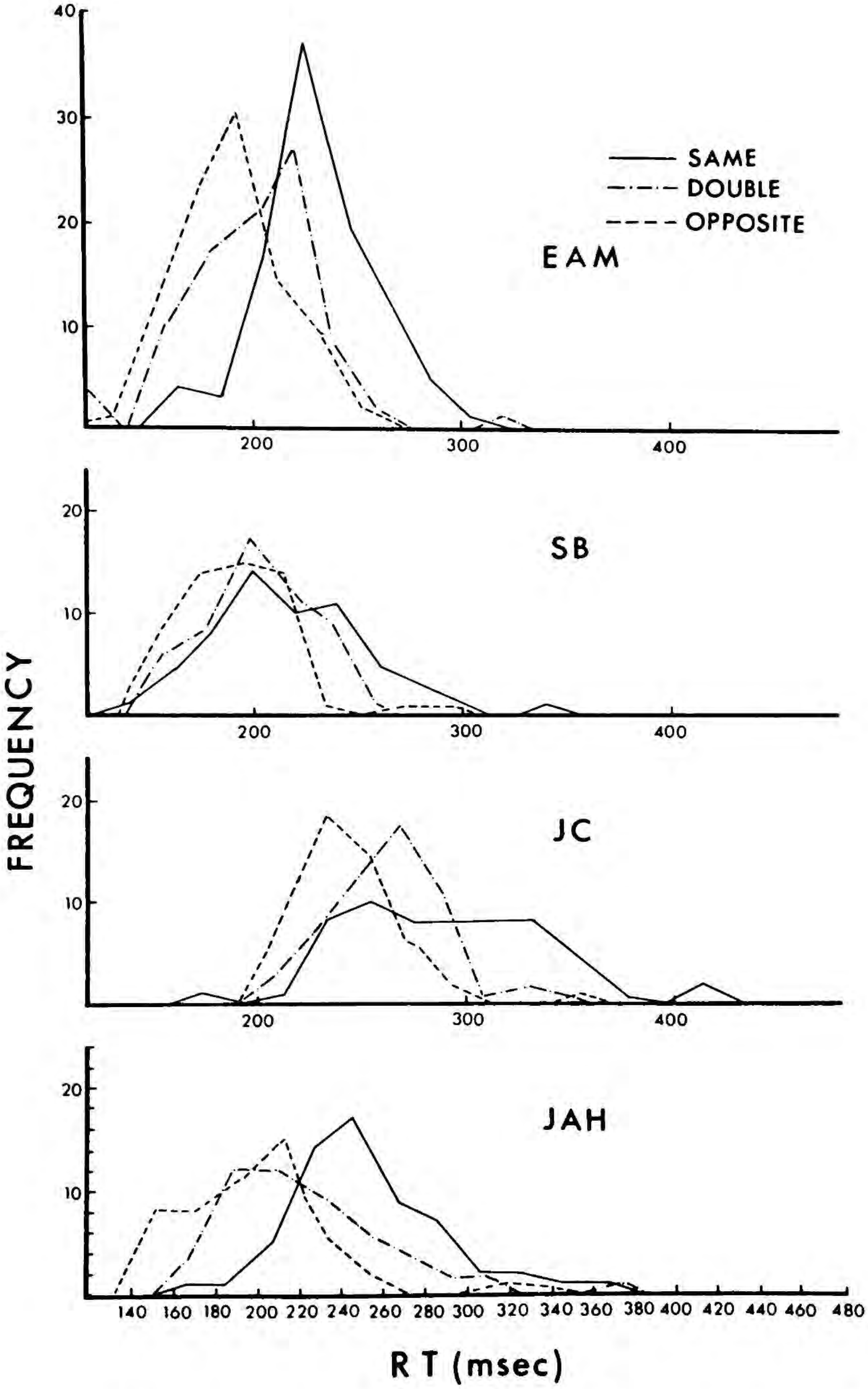


Figure 8.2 Reaction time distributions from experiment 8.1 (for the SOA of 900 msec only).

subject EAM include data from two additional blocks of trials.) It can be seen that the shapes of the distributions (with the exception of subject JC) are indeed similar for the three types of trial.

[The SIQRs for the first repliction attempt (as described in section 8.2) were more than double those in experiment 8.1. There are several possible reasons for this. First, the SOAs were very different (100 msec compared to 700 msec and above). As a result, overall reaction time was approximately 385 msec for the SOA of 100 msec in the first replication attempt, whereas most reaction times in experiment 8.1 were below 300 msec. The relationship between median reaction time and SIQR will be discussed later, but generally as median reaction time increases, so does the SIQR. The second possible explanation for the different SIQRs concerns the two procedures used. The intertrial intervals were much greater in experiment 8.1 which could account for the reduced variability in the response times. Thirdly, in addition to there being fewer trials, the subjects in the first replication attempt were less familiar with simple reaction time experiments than those in experiment 8.1.]

Some insight into the nature of inhibition may be gained from further analysis of the SIQRs of the reaction time distributions. It has already been established that median reaction time to a target appearing in the same location as a cue is slower than to one from a different location for SOAs of greater than 500 msec. For example, in experiment 8.1 responses on same trials were 35 msec slower than those on opposite trials. However, the SIQRs were very similar (22 and 19 msec for same and opposite trials respectively), suggesting that inhibition adds a constant to reaction times, resulting in a simple lateral translation of the distribution (see Figure 8.2). This is very surprising in view of recent theories of reaction time which predict that SIQR should increase as median reaction time increases (Rabbitt, 1981; Grice, Nullmeyer and Spiker, 1982). For example, as the intensity of an auditory stimulus is decreased, both the mean reaction time and the variance increase (Burbeck and Luce, 1982). In order to obtain some quantitative data on this, the results from all the cue-target experiments using SOAs of 700, 900 and 1300 msec were reanalysed (that is, experiments 6.3, 7.3 and 8.1). For each subject the overall median reaction times were obtained for each SOA (700, 900 and 1300 msec) regardless of the relationship between the cue and the target. Median reaction time was then plotted against SIQR for each of the 11 subjects. [Some subjects had participated in more than one of the three experiments although only their data from experiment 6.3 were used. Because it was the first of the three experiments to be conducted, the analysis was based on data from subjects who were approximately equally familiar with the simple reaction time task.] The scatterplots and linear regression lines are shown in Figure 8.3. The correlation co-efficients are 0.913, 0.899 and 0.852 for

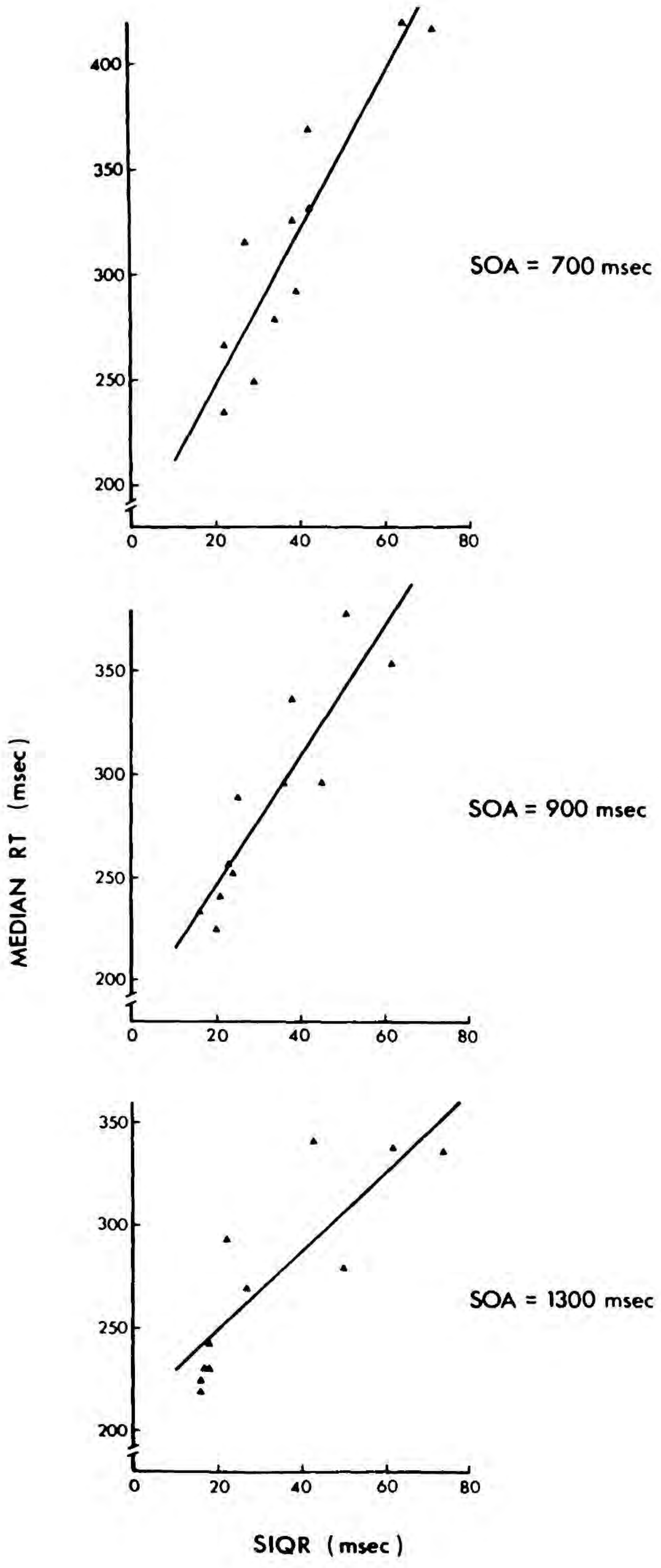


Figure 8.3 Scatterplots and linear regression lines of median reaction time against SIQR.

SOAs of 700, 900 and 1300 msec respectively. It can be seen that SIQR increases as median reaction time increases. Also the slopes of the regression lines (3.69, 3.13 and 1.92) decrease with increasing SOA.

The results shown in Figure 8.3 provide a baseline for interpreting the analyses of reaction time distributions. For example, the slopes of the regression lines in Figure 8.3 indicate that for a median reaction time difference of 40 msec, the corresponding difference in the SIQR should be 11, 13 and 21 msec for SOAs of 700, 900 and 1300 msec respectively. Returning to the SIQR data from experiment 8.1 summarised in Table 8.1, it can be seen that although the median reaction times are very different for the three trial-types (see Figure 8.1), the SIQRs are almost identical. It must be concluded that the inhibitory effect produces reaction times that are longer but <u>less</u> variable than would be predicted from the general relationship between median reaction time and SIQR. This was investigated further by analysing the SIQRs from the remaining experiments which used the cue-target procedure with LEDs as stimuli (that is, experiments 6.3, 7.2 and 7.3). First, the SIQRs from experiment 6.3 were put into an analysis of variance with SOA (700, 900 and 1300 msec) and trial-type (0, 1, 2, 3 and opposite) as fixed effects factors. The overall means are presented in Table 8.2 and the analysis of variance confirmed that there was no effect of SOA [$F(2,12)=0.91$, $p>0.1$] nor of trial-type [$F(4,24)=0.76$, $p>0.1$] and there was no interaction between

		SOA (msec)		
		700	900	1300
TRIAL - TYPE	0	36.1	33.0	39.1
	1	31.6	30.1	34.9
	2	37.0	31.2	41.7
	3	38.9	28.4	32.4
	OPP	35.4	31.9	32.1

Table 8.2 SIQRs from experiment 6.3.

them [F(8,48)=0.47, p>0.1]. Therefore, although the median reaction times showed evidence of a large inhibitory effect (see Figure 6.6), this was not reflected in a corresponding change (as predicted by Figure 8.3) in the SIQRs. Secondly, the SIQRs from experiment 7.2 were put into an analysis of variance with SOA (900 and 1300 msec) and trial-type (same, same side, opposite and diagonally opposite) as fixed effects factors. Figure 8.4 shows the overall means and the analysis of variance revealed that the effect of SOA approached significance [F(1,6)=6.22, p<0.07], there was a significant effect of trial-type [F(3,12)=6.03, p<0.01] and the interaction between the two approached significance [F(3,12)=3.30, p<0.06]. If the SIQRs shown in Figure 8.4 are compared with the median reaction times (see Figure 7.4) it can be seen that this is the first evidence of an increase in SIQR for an increase in median reaction time in accordance with the data of Figure 8.3 (particularly for the SOA of 1300 msec). Experiment 7.2 investigated the locus of the inhibitory effect by asking the subject to make an eye movement after the occurrence of the cue but before the presentation of the target. The results demonstrated that the inhibitory effect is determined by environmental co-ordinates. The increased variability of reaction times to inhibited stimuli may be due to the execution of the eye movement and therefore possibly to the additional recoding requirement.

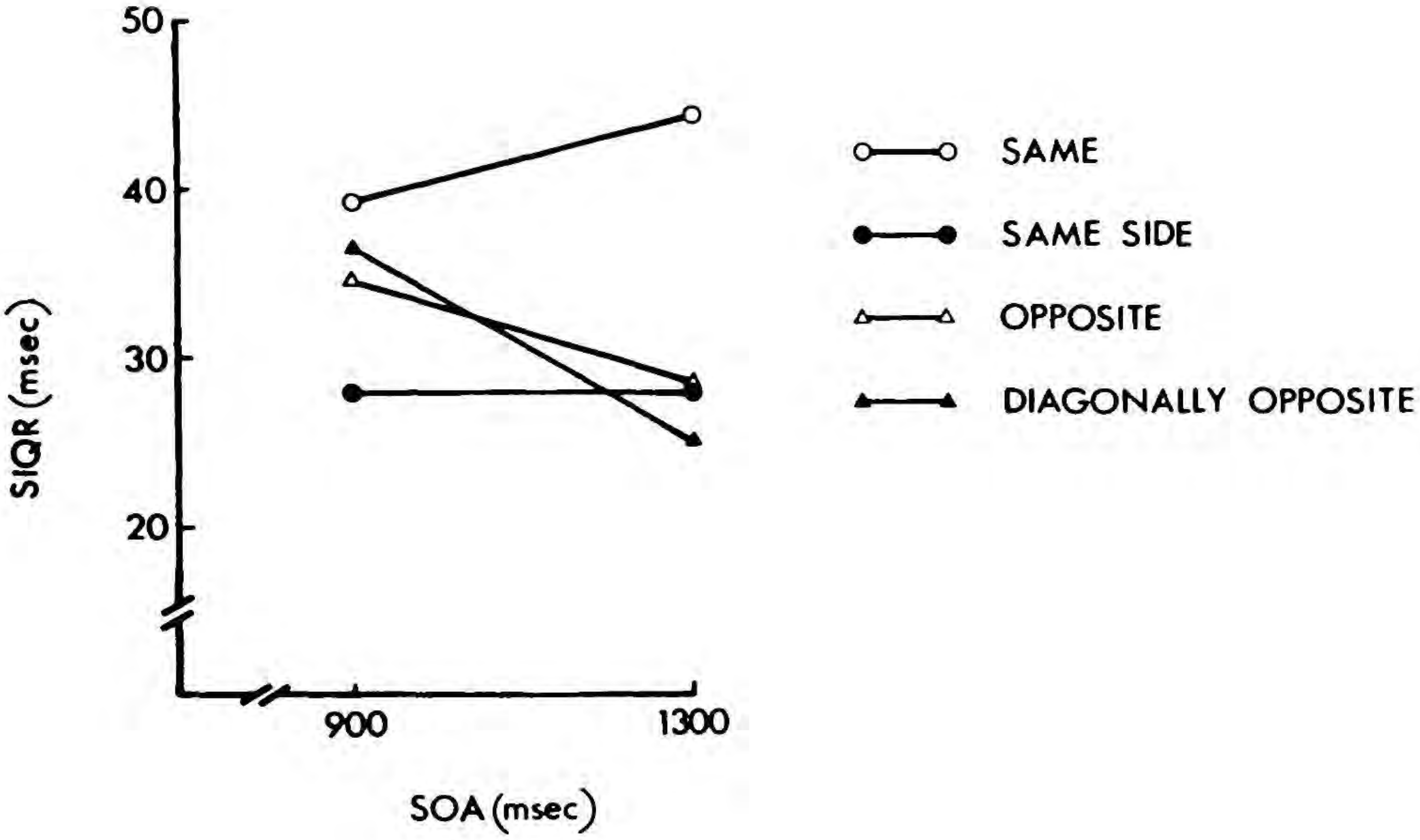


Figure 8.4 SIQRs from experiment 7.2.

The reaction time distributions for same and diagonally opposite trial-types are presented in Figure 8.5 for the SOA of 1300 msec only. [These data were considered to be more reliable and therefore more suitable for further detailed analysis than those from the SOA of 900 msec for two reasons. First, it was noted in section 7.3.1.3 that there were more trials of the SOA of 1300 msec than of 900 msec. Secondly, it is almost certain that the required eye movement would have been completed before target presentation for the longer SOA.] The most striking feature of the distributions shown in Figure 8.5 is that they are consistent with predictions made by Ashby (1982), based on the subtractive method of Donders (1868). This assumes that information-processing can be viewed as a series of successive stages, so that overall reaction time is the sum of the times required by each of the stages between stimulus and response. Therefore if one task requires all the processing stages of another with the addition of one, then the duration of the extra stage can be obtained from the difference of the mean reaction times of the two tasks. This of course assumes that the extra stage has no effect on the duration of any other stage (that is, 'pure insertion'). A further assumption often made is that the duration of the extra processing stage is random with an exponential distribution. Ashby (1982) demonstrated that these two assumptions lead to the conclusion that the reaction time distributions must intersect only at the <u>mode</u> of the distribution requiring the extra processing stage. From Figure 8.5 it can be

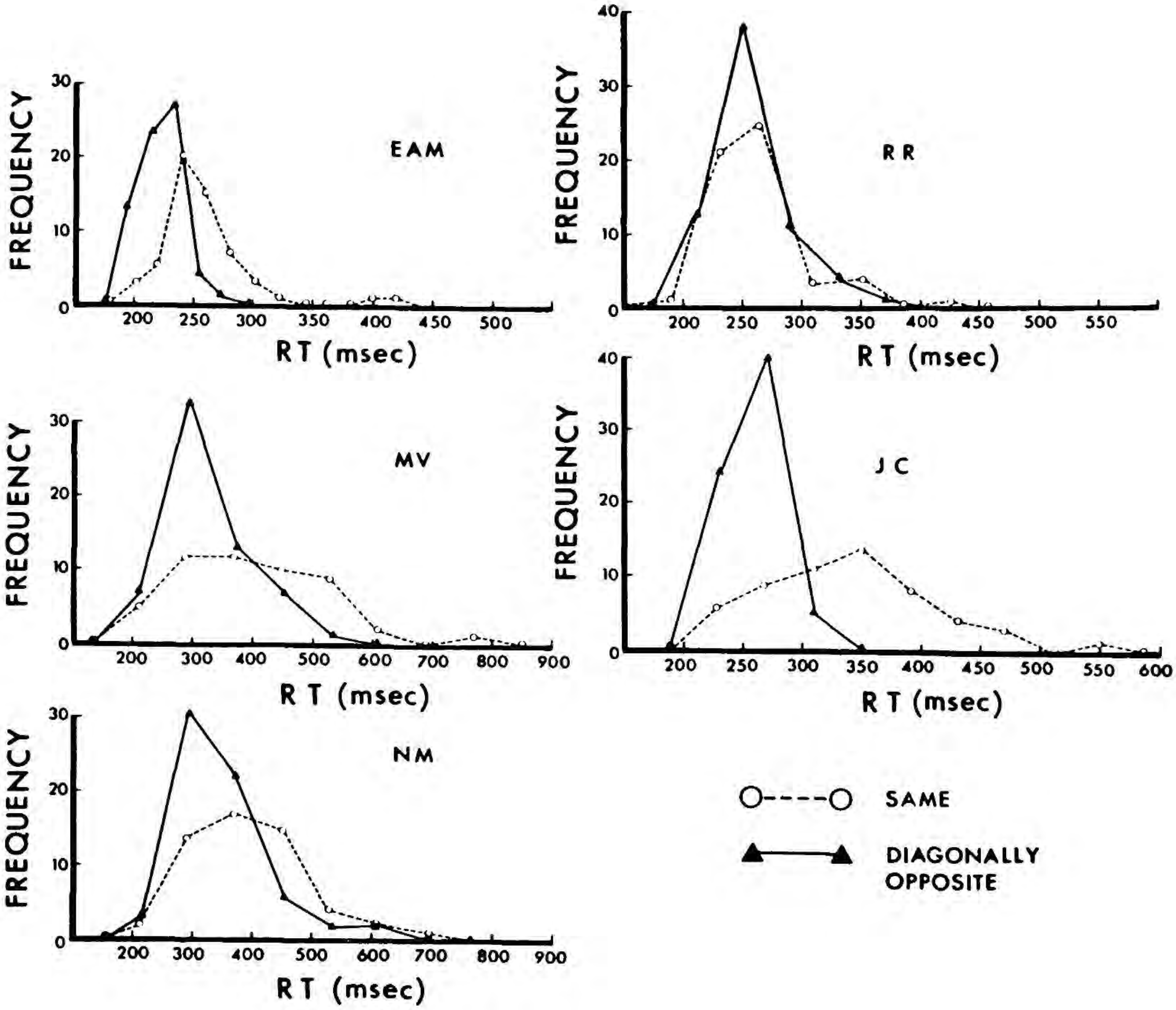


Figure 8.5 Reaction time distributions from experiment 7.2 (SOA = 1300 msec).

seen that this is a reasonable description of the data from at least three of the five subjects (EAM, MV and NM). However, any general conclusions drawn from this analysis in support of a possible stage model of inhibition must be regarded as tentative for the following reasons. First, although the overall reaction time difference between same and diagonally opposite trial-types at the SOA of 900 msec was almost as large as at 1300 msec (see Figure 7.4), the SIQRs were very similar (see Figure 8.4). Secondly, the results of experiment 7.2 were unusual in that the inhibitory effect did not decrease between the SOAs of 900 and 1300 msec (compare Figure 7.4 with Figures 6.6 and 8.1). These results will be discussed further following analyses of SIQRs from three other experiments.

The SIQRs from experiment 7.3 were put into an analysis of variance with location (same and different) and colour (same and different) as fixed effects factors. The overall means were 23.8, 21.5, 19.0 and 16.0 msec for trial-types same L and C, same L and diff C, diff L and same C, and diff L and C respectively. The analysis of variance revealed that there was a marginally significant effect of location [$F(1,3)=8.96$, $p<0.06$], but no effect of colour [$F(1,3)=1.30$, $p>0.1$] and there was no interaction between them [$F(1,3)=0.04$, $p>0.1$]. For an SOA of 900 msec, a difference in reaction time of 33 msec (the overall effect of location - see Figure 7.6) should correspond to a difference in SIQR of approximately 10.5 msec (from Figure 8.3). This is twice the observed difference of 5.1 msec, so again there is evidence that reaction time to a target appearing in the same location as a cue is longer than to one in a different location but less variable than would be expected from the general relationship between median reaction time and SIQR.

Although the relationship between median reaction time and SIQR has only been plotted for experiments using the cue-target procedure and SOAs of 700, 900 and 1300 msec (Figure 8.3), the following two analyses were conducted on data from two other experiments taken to represent the other procedures used. Experiment 4.1 demonstrated both facilitation and inhibition by using a cue-target procedure but including much shorter SOAs. The SIQRs from experiment 4.1 were put into an analysis of variance with block (first and second), SOA (100, 300 and 500 msec) and trial-type (invalid and valid) as fixed effects factors. There was no effect of block [$F(1,13)=1.49$, $p>0.1$] and block was not involved in any interaction. The overall means (across the two blocks) are presented in Figure 8.6. There was a highly significant effect of SOA [$F(2,26)=22.24$, $p<0.00005$] but no effect of trial-type [$F(1,13)=1.41$, $p>0.1$]. There were no significant interactions. From Figure 8.6 it is clear that the effect of SOA is due to the large SIQRs for the SOA of 100 msec which was discussed above with respect to the first attempt to replicate Posner and Cohen's (1980) double-cueing experiment. Despite the large reaction time differences between invalid and valid trials (see Figure

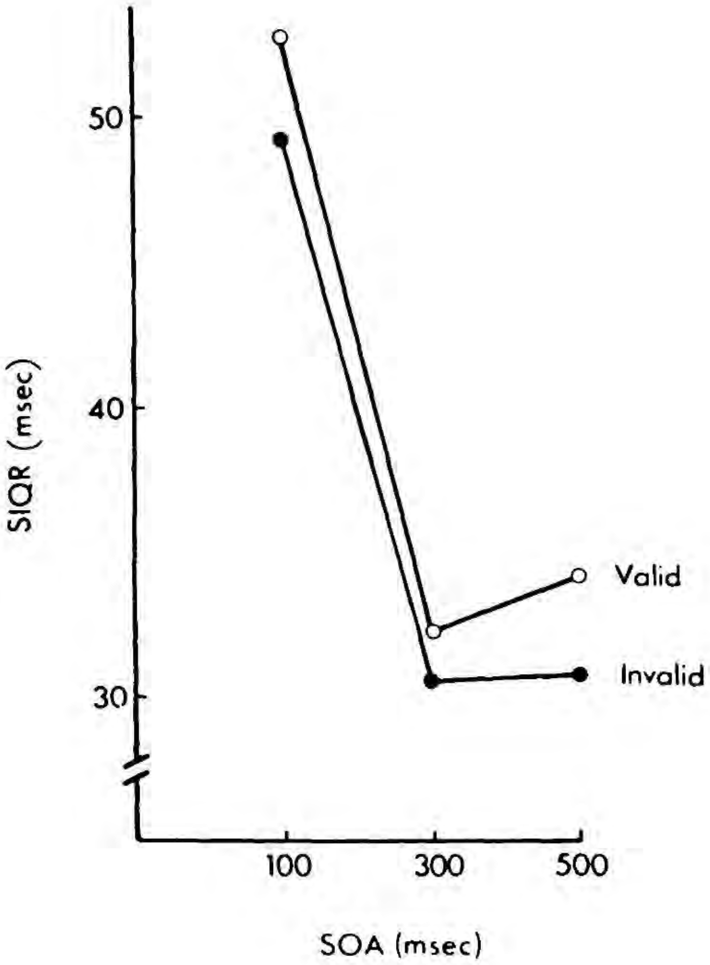


Figure 8.6 SIQRs from experiment 4.1.

4.2), the SIQRs are very similar, in agreement with the results of experiments 6.3 and 8.1. Indeed the SIQR for valid trials is larger than for invalid trials at the SOA of 100 msec even though the median reaction time is considerably smaller.

Finally, the SIQRs from experiment 6.2 (which used a target-target procedure) were put into an analysis of variance with block (first and second), R-S interval (300, 400, 500 and 900 msec) and trial-type (same, adjacent and opposite) as fixed effects factors. This revealed that there was no effect of block [$F(1,5)=0.49$, $p>0.1$], nor was it involved in any interaction. The means are presented in Figure 8.7. There were significant effects of R-S interval [$F(3,15)=5.70$, $p<0.01$] and trial-type [$F(2,10)=13.26$, $p<0.002$] but no significant interactions. Although there are difficulties involved in attempting to relate R-S interval and SOA, the results suggest that in a target-target procedure the inhibitory effect is associated with both increased reaction time and SIQR in accordance with the relationship specified by Figure 8.3.

The conclusion from the results of these analyses of SIQRs is far from clear. Some experiments have revealed much smaller SIQRs than expected for responses to stimuli in the same location as the previous one (experiments 4.1, 6.3, 7.3 and 8.1), while others (experiments 6.2 and 7.2) have demonstrated that the SIQRs were increased but by no more than would be expected for an increased reaction

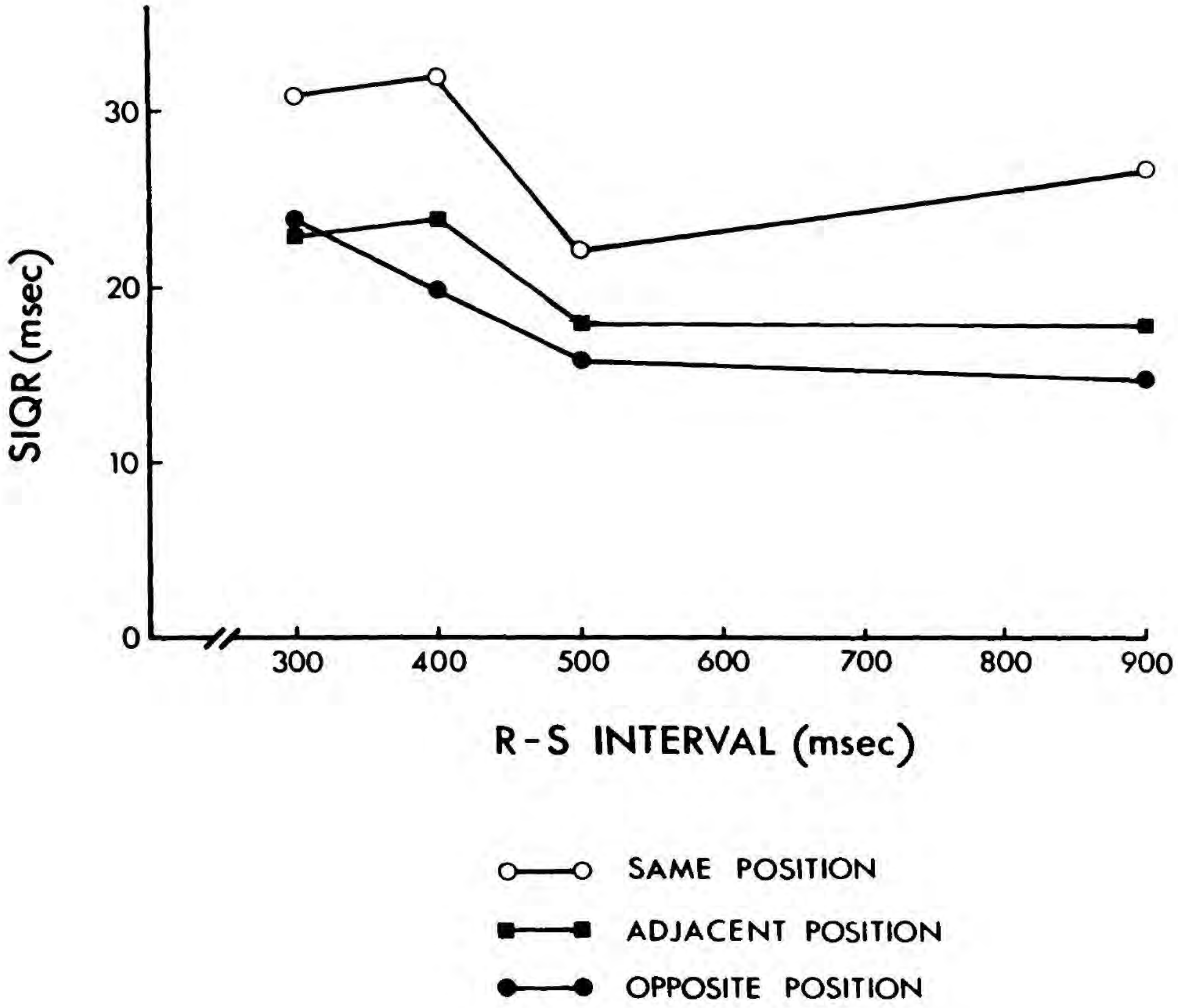


Figure 8.7 SIQRs from experiment 6.2.

time. (It should be noted that very similar results were obtained for standard deviations as the measure of variability. SIQRs were preferred because in general reaction times are not normally distributed.) Further work is obviously required before any conclusions regarding the nature of inhibition can be made from such analyses of reaction time distributions. However, it should be noted that the results from experiments 4.1, 6.3, 7.3 and 8.1 are particularly difficult to accommodate within any current model of reaction time. For example, Grice, Nullmeyer and Spiker (1982) proposed a variable criterion theory in which the excitatory strength (E) leading to response initiation grows as a negatively - accelerating exponential function of the time following stimulus onset. When E reaches the criterion value (which varies from trial to trial according to a normal distribution), the response is evoked. The theory predicts that reaction time variability should increase for an increase in central tendency. This is also true of stage models (for example, Ashby, 1982) which were discussed earlier in the the present section with respect to the results of experiment 7.2. It is therefore difficult to explain the observation that both the facilitatory and inhibitory components are generally characterised by changes in central tendency but not in variability of reaction times. However, the present section should be regarded as an example of the potential value of the analysis of an aspect of the data often ignored by work in the area of visual attention.

8.4 Practice Effects

The investigation of a further factor, namely that of practice, was prompted by the results of a small study based on experiment 6.2. The target-target procedure was used with four LEDs positioned at the four corners of a square (rather than a diamond) around fixation. The visual angle between each of the LEDs and fixation was 7 degrees. Seven subjects participated in a single session lasting approximately 15 minutes, which was divided into two experimental blocks of 240 trials. Three R-S intervals were used : 400, 600 and 900 msec. The results revealed that there were significant effects of block and trial-type with an interaction between them. For example, at the R-S interval of 600 msec overall reaction time decreased by 16 msec from the first to the second block. In addition, the inhibitory effect (- the increase in reaction time to a target appearing in the same location as a previous one compared to a different location) was 24 and 13 msec for the first and second blocks respectively. From these results it might be concluded that inhibition is reduced by practice, perhaps because the subject learns to ignore the irrelevant spatial aspects of the task. However, the decrease in overall reaction time between the two blocks was accompanied by an increase in the error rate by a factor of two. Thus the change in both speed and accuracy may account for the reduction of the inhibitory efffect, the subject becoming less stimulus-driven during the course of an experimental session.

The data from experiment 8.1 were reanalysed in order to investigate further whether or not the size of the inhibitory effect changes as a function of practice. The 30-minute experimental session was made up of three blocks of trials, each lasting approximately eight minutes. In the analysis presented in section 8.2.2, the results from the three blocks were combined and overall medians calculated. To investigate the possibility of a practice effect, the results were reanalysed by putting the medians from each block into an analysis of variance with block (first, second and third), SOA (700, 900 and 1300 msec) and trial-type (same, double and opposite) as fixed effects factors. This revealed no significant effect of block [$F(2,6)=1.06$, $p>0.1$] and block was not involved in any interaction. There were significant effects of SOA [$F(2,6)=10.95$, $p<0.02$] and trial-type [$F(2,6)=17.89$, $p<0.005$] and there was no interaction between them. The crucial three-way interaction was also insignificant [$F(8,24)=1.34$, $p>0.1$] confirming that the inhibitory effect was constant over the 30-minute session.

The analysis of other experiments supports the conclusion that inhibition is not affected by practice. Experiment 6.4 involved two experimental sessions of 30 minutes on separate days. Each session contained 960 trials and there was no evidence that the size of the inhibitory effect changed during a session, or between sessions. The analyses of variance conducted on the results of experiments 4.1, 6.2 and 7.1 included block as a factor. In all cases there was no effect of block, nor was it involved in any interaction. It should be noted that experiments 6.2 and 6.4 used the same target-target procedure as the pilot study described above and so it must be concluded that the block effect and interaction found in the latter study are unusual and can be attributed to the finding that the subject reacted quicker but less accurately later compared to earlier in the session. Such a change in the trade-off between speed and accuracy results in responding that is less under the control of stimulus conditions, thereby reducing the inhibitory effect.

To conclude, facilitation and inhibition are not affected by practice, at least for experimental sessions of up to 30 minutes including nearly 1000 trials. Harvey (1980) also found no effect of practice and concluded that 'response inhibition' (equivalent to the inhibitory effect described here) is not dependent on strategies specific to early stages of practice. This contrasts with the results of Rabbitt and Vyas (1979). Their task was similar to that of experiment 6.2, that is, to respond with a single key to the onset of any one of four lights. However, the R-S interval was between 6 and 10 seconds. They found that for the first 100 trials reaction time was faster to a stimulus repetition than to a change, but the effect disappeared by the third 100 trials. The results demonstrated that early in a session, and for very long R-S intervals, identification of one signal prepares or alerts the subject to identify a subsequent identical signal faster than any other. Rabbitt and Vyas concluded that as subjects become familiar with a stimulus set they cease to activate internal representations of particular individual stimuli and instead activate internal representations of stimulus sets. Practiced subjects in their task appear to cease to differentiate one signal from another.

Miller (1982) obtained similar results to Rabbitt and Vyas (1979) using two reaction time tasks. The first required the subject to press a single key when either a visual or an auditory stimulus was presented (bimodal detection). The second was a visual search task in which two letters were presented, one to the left and the other to the right of fixation. The subject had to respond by pressing one key if either or both were the target letter and another key if neither was the target. Although for both tasks the R-S interval was not specified, from an analysis of Miller's procedure it can be concluded that it was approximately 7.5 seconds (and therefore similar to that of Rabbitt and Vyas). A comparison was made between reaction time to targets presented on the same channel* (the two channels being auditory and visual in the first task and left and right of fixation in the second task). For both tasks there was a significant reaction time advantage for targets presented on the same channel as on

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*as on the previous trial and reaction time to those presented on the opposite channel the previous trial. This channel repetition effect was found to be smaller in the visual search task than in the bimodal detection task. In addition, it was smaller for practiced subjects than for unpracticed subjects, in agreement with the results of Rabbitt and Vyas. Miller suggested that 'detecting a signal on one channel causes more attention to be brought to that channel for the next trial'(p272). It may be that following the facilitatory and inhibitory effects of externally-controlled orienting (which occur for SOAs and R-S intervals of between 100 and 1300 msec), attention (under internal control) returns to the previously-stimulated channel after an interval of more than 6 seconds. However, unlike facilitation and inhibition which remain constant over an experimental session, the long-term channel repetition effect occurs only in the early stages of practice. It is therefore seen as a reflection of a subjective preference with very long R-S intervals to examine the previously-stimulated channel first, which disappears with practice as the subject realises that such a strategy is inappropriate when the target is equally likely to appear on either channel (see also Vervaeck and Boer, 1980). The possibility that the facilitatory and inhibitory components of externally-controlled orienting may be influenced by active strategies will be discussed in chapter 9.

8.5 Individual Differences

In section 5.3.2 it was suggested from the results of correlations on the data from experiment 4.1 that there is a tendency for fast subjects to exhibit more facilitation at the SOA of 100 msec and less inhibition at the SOA of 500 msec than slow subjects. Any conclusions drawn from these observations must be regarded as speculative as the correlations were only marginally significant [$0.05<p<0.1$ in all cases]. However, they are interesting in view of the results of several other experiments in chapters 4 and 5. For example, the pattern of facilitation and inhibition for the choice manual response (experiment 4.4, Figure 4.6) was similar to that for the simple response (experiment 4.1, Figure 4.2) although overall reaction time was increased by approximately 200 msec (which is much greater than the difference between fast and slow subjects in experiment 4.1). In addition, the most consistent finding from the divided attention studies in chapter 5 was that a secondary task increased both the overall reaction time and the overall invalid-valid difference (that is, more facilitation and less inhibition). The results of the choice reaction time experiment can be explained by assuming that externally-controlled orienting is unaffected by the choice response requirement and that the late decision process merely adds a constant to overall reaction time. It was concluded in chapter 5 that the addition of a secondary task may delay externally-controlled orienting or indeed abolish it altogether, depending on the nature of the additional task. The individual differences data are more difficult to interpret. For example, it is not the case that the size of the facilitatory and inhibitory effects are simply proportional to overall reaction time, as fast subjects are characterised by more facilitation at 100 msec than slow subjects. [It should be noted that the interaction between SOA and trial-type in experiment 4.1 was not a result of facilitation only for some of the subjects and inhibition only for others. There was facilitation at the SOA of 100 msec for 13 of the 14 subjects and the same was true of inhibition at the SOA of 500 msec (- see section 4.2.2).] An investigation of the relationship between the amount of inhibition and overall reaction time at SOAs of greater than 500 msec is required in order to test the possibility that fast subjects are generally less inhibited throughout. However, the experiments using longer SOAs involved very few subjects (each with a different error rate) compared to experiment 4.1 so that correlational analysis was considered inappropriate. It is suggested that an extensive study of individual differences across a large range of SOAs would provide useful insight into externally-controlled covert orienting.

8.6 Experiment 8.2

The final method of investigation employed a different technique, that of temporal order judgment. Various attempts have been made to relate reaction time and temporal order measures (Roufs, 1963; Gibbon and Rutschmann, 1969; Rutschmann, 1973; Coltheart, 1980; Long and McCarthy, 1982). Most studies found remarkable agreement between the two measures. Rutschmann (1973) noted that the results from a visual temporal order paradigm on the effects of stimulus intensity conformed strikingly with predictions based on reaction time measures of latency. Similarly, Long and McCarthy (1982) observed that the relative effects of manipulating stimulus variables are equivalent across reaction time and asynchrony tasks of visual persistence. However, there have been studies which have failed to find such agreement. Sternberg and Knoll (1973) suggested that these discrepancies 'can be understood by an analysis of the concept of perceptual latency that recognises the internal response to a pulse as being spread out in time'. Thus it is possible that one feature of the internal response might be used for initiating the reaction time response ('time to reach criterion') and another feature might serve as the time marker in a temporal order judgment ('time of peak response'). Because of this, quantitative and even qualitative differences between the two measures should not be unexpected. However, relative to pulsed stimuli, onsets and offsets may provide fewer alternative features of the internal response that might be used to register time of occurrence. Sternberg and Knoll therefore recommended the use of onsets or offsets as stimuli with long durations in order to avoid duration cues that are correlated with temporal order. Experiment 8.2 employed a procedure which incorporated this suggestion.

It has already been suggested that the facilitation of manual reaction time is attentional in origin and occurs as a result of externally-controlled covert orienting. The 'prior entry' hypothesis (see, for example, Sternberg and Knoll, 1973) states that, given two simultaneous events, the attended event will be reported as occurring earlier in time than the unattended one. This was described by James (1890) in the following way :

> 'It has long been noticed, when expectant attention is concentrated upon one of two sensations, that the other one is apt to be displaced from consciousness for a moment and to appear subsequently; although in reality the two may have been contemporaneous events.'(p409)

It is therefore predicted that the facilitatory effect should also occur in a temporal order judgment paradigm. However, inhibition seems to affect a later stage of processing and occurs as a consequence of externally-controlled orienting. At least for the manual reaction time experiments, inhibition does not occur as the result of the need to prevent responding to the cued event. Rather, it is seen as an inability to make either a manual or an ocular response as quickly to a stimulus appearing in a recently-stimulated peripheral location as to one appearing in a different location, regardless of whether or not the first stimulus required a response. Therefore it is unlikely that temporal order judgments (which do not require speeded responses) would be affected by such response inhibition. Experiment 8.2 was carried out to investigate these possibilities.

8.6.1 Method

8.6.1.1 Subjects

Two subjects participated in five experimental sessions over two days. Each session lasted approximately 30 minutes.

8.6.1.2 Apparatus and Stimuli

The experiment was controlled by the ALPHA minicomputer as described in section 2.4.1. The response box consisted of two microswitches labelled 'LEFT' and 'RIGHT'. The stimuli were based on those described in section 2.4.2 and are shown in the upper part of Figure 8.8. However, there was no central box surrounding the fixation point and brightening was achieved by approximately doubling the intensity of a box, rather than by adding extra points to the display. The targets were small crosses made up of five dots appearing at the centre of the left and right boxes. The stimuli were displayed on the Tektronix 602 display oscilloscope.

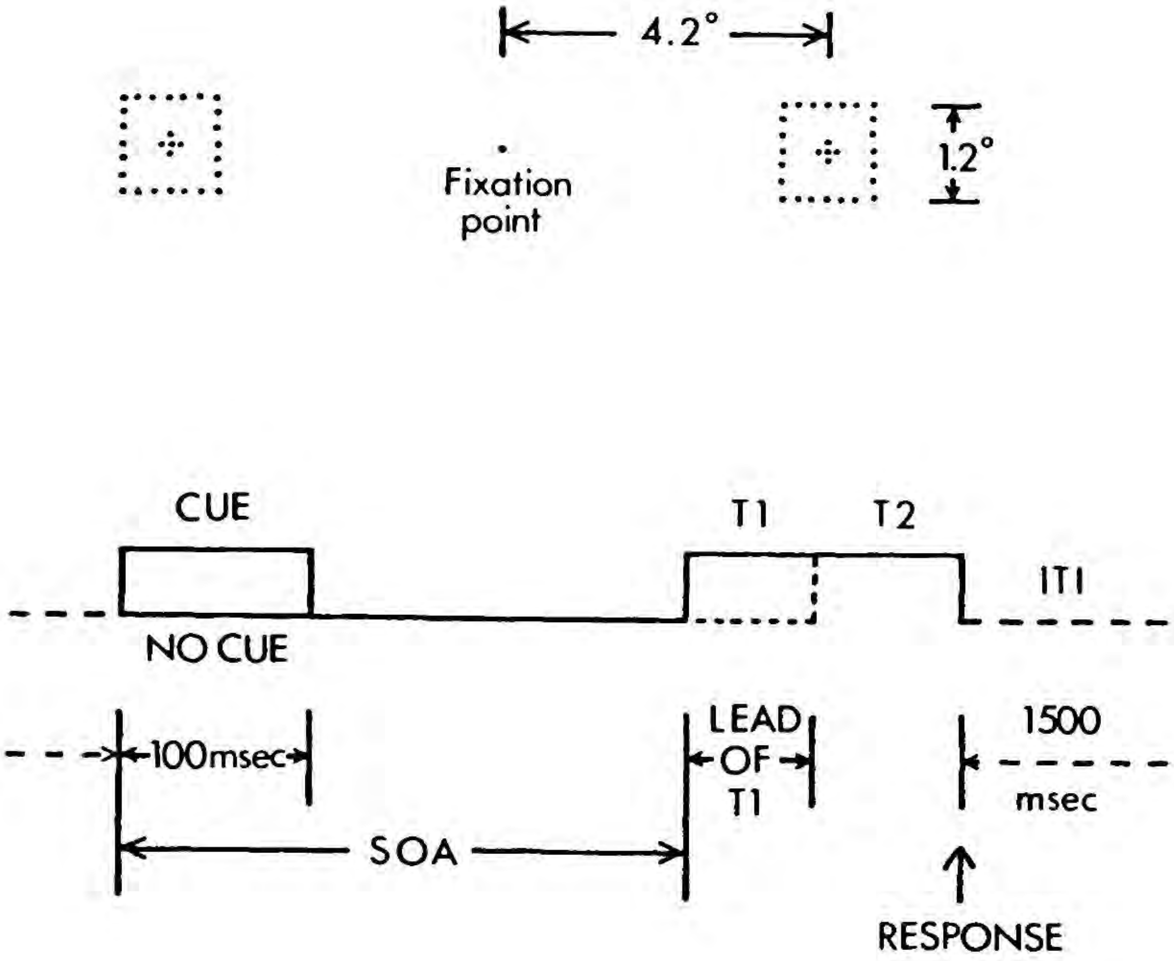

Figure 8.6 Summary of trials in experiment 8.2.

8.6.1.3 Design and Procedure

The subject was seated 50 cms from the oscilloscope, the visual angle from fixation to the centre of one of the peripheral boxes being 4.2 degrees. The left and right forefingers were placed on the left and right buttons of the response box. The subject was required to fixate on the central point throughout each session. There were five sessions, though only the data from the last four were used in the analysis.

When the subject was ready to begin, one of the response buttons was pressed. The two boxes and fixation point then appeared on the screen followed after 1500 msec by the first trial. The screen went blank after every 32 trials to allow the subject to rest until ready to continue. A button press produced the next block of 32 trials. Each session consisted of 300 trials, the first 60 being practice trials.

Figure 8.8 summarises the timing of the trials. [It should be noted that the cueing procedure was based on that of experiment 4.2 (see section 4.3.1.3), that is, there was no central cue at 300 msec.] On a third of the trials no cue was presented. The remaining two-thirds of the trials were divided equally between a cue on the left (the brightening of the left box for 100 msec) and a cue on the right. The SOA was defined as the time from the onset of the cue (or the onset of the trial in the case when no cue was presented) to the onset of the first target. Target 1 (T1) was then presented inside either the left or the right box with approximately equal probability. This was followed after an interval (the 'LEAD OF T1') by the second target (T2) which of course appeared in the other box. Both targets remained on the screen until the subject made a response. The task was to press the button corresponding to the target which appeared first. The subject was allowed as much time as required to make the decision. There was an intertrial interval of 1500 msec before the onset of the next trial. A psychophysical procedure known as APE (Adaptive Probit Estimation, see Watt and Andrews, 1981) was used to determine the target intervals (LEAD OF T1) that were tested. [APE is an adaptive version of the Method of Constant Stimuli and selects from a number of preset magnitudes in order to obtain a psychometric function.]

The five sessions differed according to SOA. The first session was regarded as practice and used an SOA of 1000 msec. The SOAs for the remaining four sessions were 100, 300, 500 and 1000 msec, the order being randomised for each subject. (Subject JEK carried out the sessions in the order 1000, 100, 300 and 500. The order for subject EAM was 300, 500, 100 and 1000.) The subject was informed that on some of the trials one of the boxes would appear to flash briefly, but that this was to be ignored as it contained no information regarding the temporal order of the targets.

8.6.2 Results and Discussion

An example of the results obtained is shown in Figure 8.9 for the SOA of 100 msec. Both the means and the standard deviations of the distributions, corresponding to the point of subjective simultaneity or PSS (50% point) and the threshold (distance from the 50% point to the 83% point) respectively were determined by Probit Analysis (Finney, 1971). All the response distributions were normal sigmoids (tested by a Chi-square test of goodness of fit). The results were further analysed by taking the means of the distributions (that is, the PSS) for the three types of cue and calculating the quantity [mean(left box cued)-mean(right box cued)]/2. This is a measure of the interval required (in msec) between the valid and invalid targets (as defined in experiment 4.1) for subjective simultaneity. The results for all four SOAs are shown in Figure 8.10. It can be seen that for both subjects the invalid target must occur <u>before</u> the valid target, particularly for the first two SOAs, in order for the two targets to appear simultaneous. The effect is large (around 70 msec) at the very short SOA and decreases to zero by 1000 msec.

To examine whether or not the changes in the means of the psychometric functions are accompanied by changes in their shape, the thresholds (that is, the standard deviations) were plotted for each cueing condition and SOA (see Figure 8.11). It appears that the thresholds for

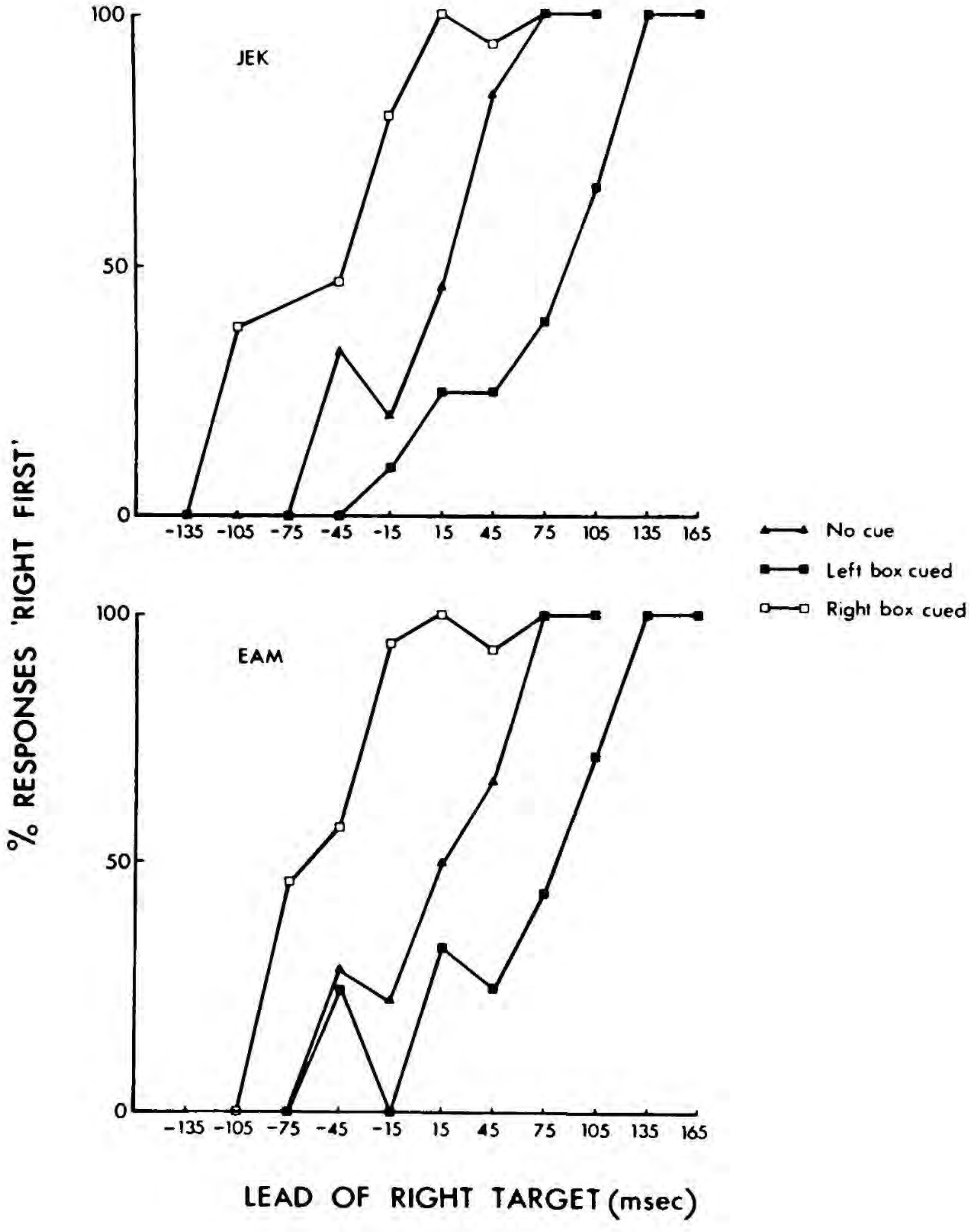

Figure 8.9 Results of experiment 8.2 (for the SOA of 100 msec only). [One data point has been omitted as it was based on just one trial.]

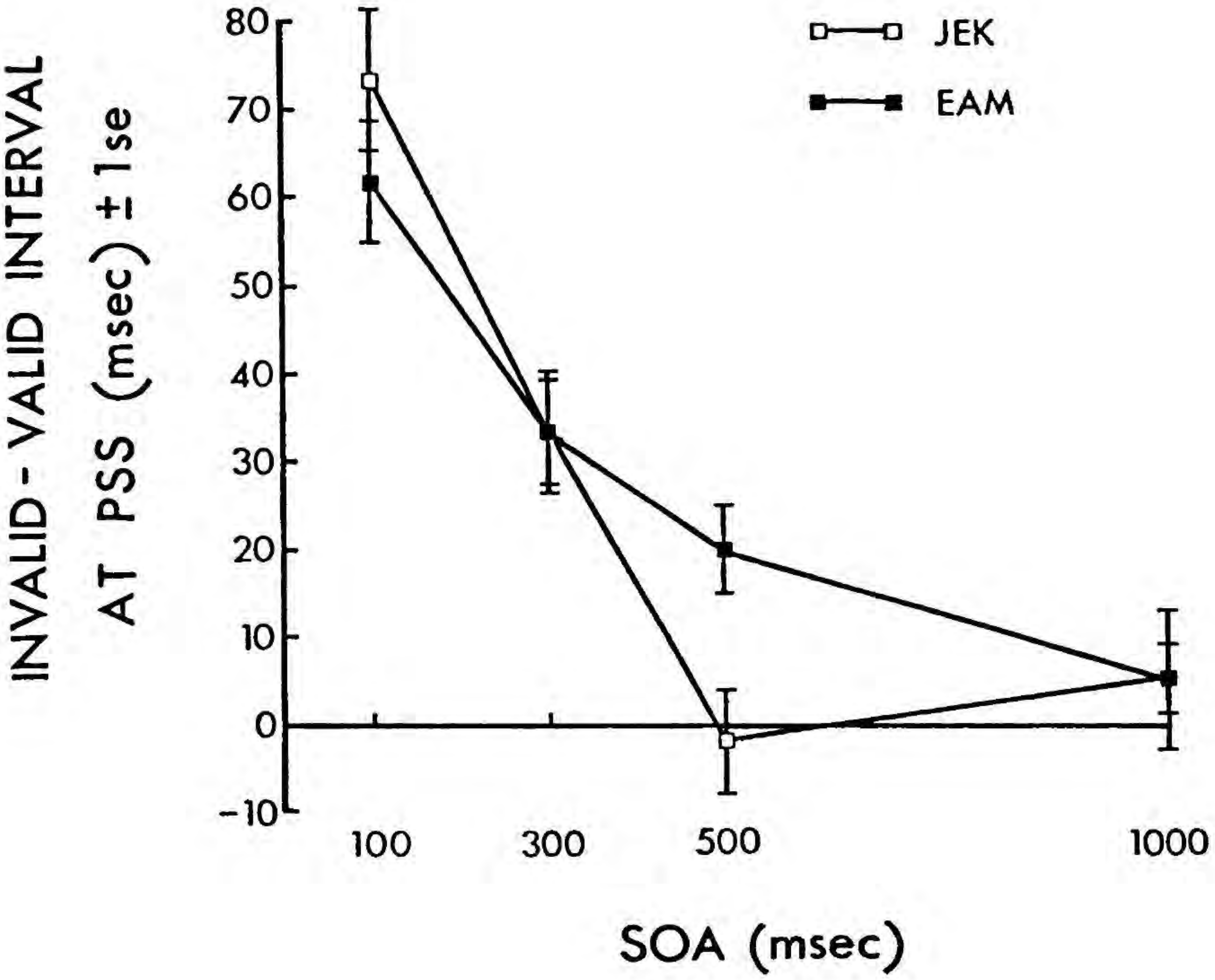

Figure 8.10 Results of experiment 8.2.

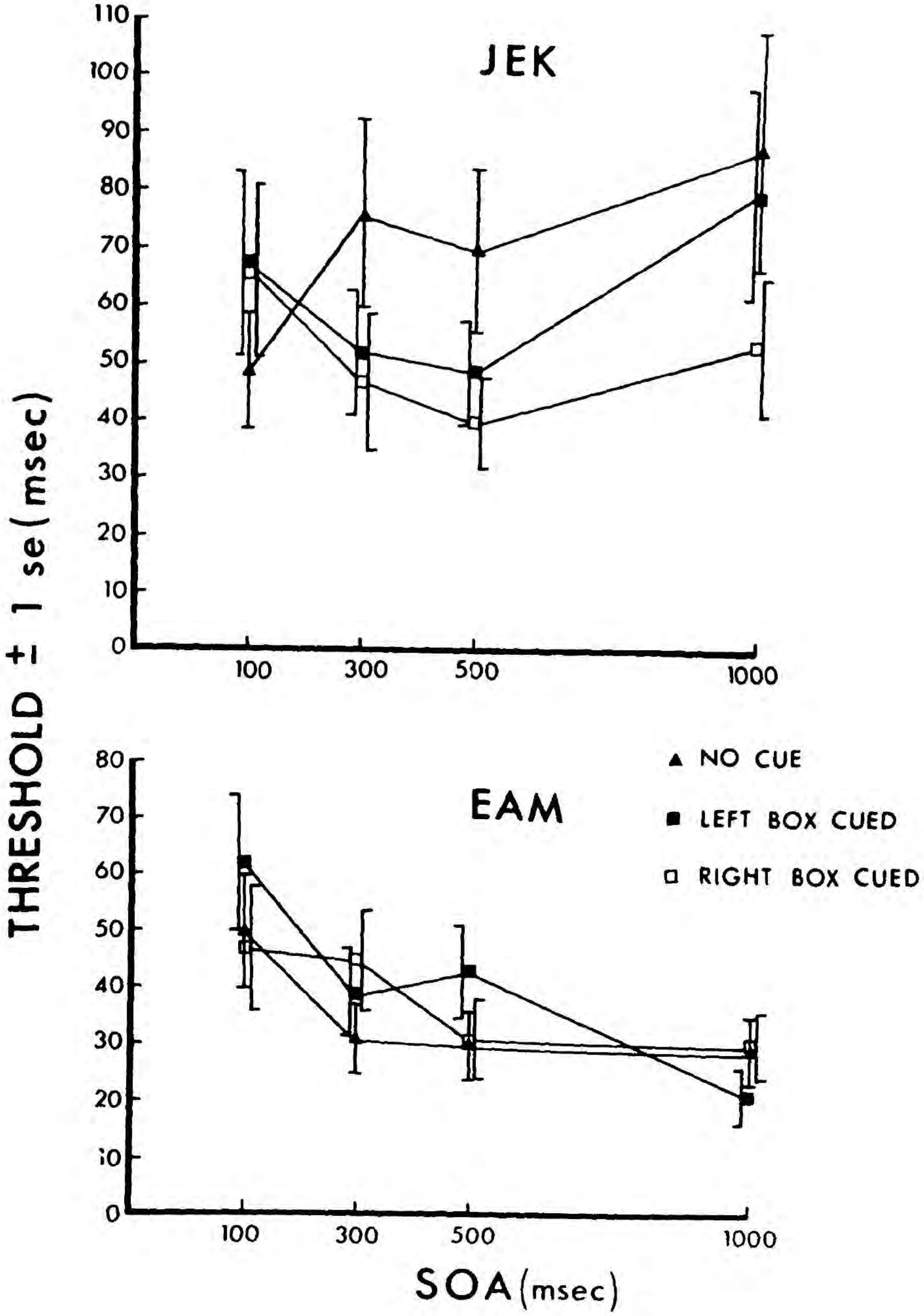

Figure 8.11 Thresholds from experiment 8.2.

subject JEK are larger in the no cue condition than in the cued conditions for the SOAs of 300, 500 and 1000 msec. However, this is not the case at 100 msec where the largest differences in means were observed. [The increased thresholds in the no cue condition compared to the cued conditions for SOAs of over 300 msec may be due to the smaller number of temporal cues available for the subject to prepare for the onset of the targets. It has already been demonstrated that reaction times are influenced by preparatory or alerting effects (for example, experiment 3.1) and it seems likely that temporal order judgments may also be subject to these effects.] There appear to be no differences between the thresholds for the three cueing conditions for subject EAM. These results are in agreement with those of Stone (1926) on the prior entry effect. He demonstrated that the effect was characterised by a horizontal translation of the psychometric function without systematic change in shape. These findings are also consistent with those of Collyer (1976) on the 'induced asynchrony effect' (IAE). He showed that if two stimuli either side of fixation were successively extinguished near to two subsequent 'test' stimuli, the apparent onset order of the test stimuli was influenced by the offset order of the two preceding stimuli in the following way. The onset of the test stimulus on the same side of fixation as the initially extinguished stimulus tended to be judged as occurring earlier than the test stimulus on the opposite side. In addition, the effects were of changes in the mean but not the standard deviation of the psychometric functions. Collyer suggested that the preceding stimulus offset asynchrony 'controls rapid shifts in the distribution of attention over the visual field' (p52), and that the IAE is a prior entry effect. In terms of externally-controlled orienting, the first stimulus offset captures attention leading to judgments that the test stimulus appearing subsequently in that location (after the equivalent of an SOA of 150 msec) occurred earlier than the other test stimulus.

To conclude, experiment 8.2 supports the view that the presentation of a brief peripheral stimulus produces covert orienting. This is reflected in both the facilitation of manual reaction times to subsequent stimuli in the same location and a corresponding bias of temporal order judgments. The consequence of such orienting is a type of response inhibition which affects the speed of responding to a repeated peripheral stimulus, but not judgements about its temporal properties.

8.7 General Conclusions

Further properties of the facilitatory and inhibitory components of externally-controlled covert orienting have been revealed in the present chapter by different methods of investigation. First, experiment 8.1 demonstrated that double-cueing results in reduced inhibition compared to single-cueing. This argues against the suggestion of

Posner and Cohen (1980) that the inhibitory effect is due entirely to the presentation of sensory information in the visual periphery. Rather, the finding that double-cueing reduces the facilitatory and inhibitory components by approximately the same amount (see also the unpredictable tracking conditions of experiment 5.3 where both components were abolished) is further evidence in support of the view that inhibition is dependent upon, and a consequence of prior orienting to a peripheral stimulus. In addition, the analysis of reaction time distributions from experiment 8.1 revealed that responses on double-cued trials are no more variable than those on single-cued trials, which suggests that double-cueing does not result in orienting to one peripheral location only.

From further analyses of reaction time distributions it was concluded that both the facilitatory and inhibitory effects are characterised in general by changes in central tendency but not in variability of reaction times. This unexpected result is difficult to interpret within any current model of information-processing. However, the data were not conclusive as the inhibitory effects of experiments 6.2 and 7.2 were consistent with the prediction that SIQR should increase as median reaction time increases. It is suggested that further experimentation is required in order to explain these conflicting observations.

There is no evidence that either facilitation or inhibition changes as a function of practice, at least for experimental sessions of between 10 and 30 minutes. Thus the effects are not specific to early stages of practice, unlike those from studies employing much longer R-S intervals which allow a greater opportunity for the subject to use active strategies in preparing for each stimulus. These are abandoned when the subject realises that the stimulus probabilities are such that active strategies are inappropriate. The experiments presented on externally-controlled covert orienting have used short SOAs and R-S intervals so that the facilitatory and inhibitory effects are seen as the result of passive orienting. However, chapter 9 includes a discussion of whether or not the effects can be overridden by active control.

The analysis of individual differences indicated that there was a tendency for fast subjects to be characterised by more facilitation and less inhibition than slow subjects at the SOAs of 100 and 500 msec respectively. However, the marginally significant correlations need to be replicated and further data from SOAs of greater than 500 msec are required before any conclusions can be made.

Finally, the temporal order judgment paradigm (experiment 8.2) provided support for the view that the facilitatory effect is attentional. The absence of inhibition using a non-speeded response is consistent with the proposal made in previous chapters that the inhibitory effect is an inability to make either a manual or an ocular response as quickly to a stimulus appearing in a recently-stimulated peripheral location as to one in a different location.

CHAPTER 9

Discussion

9.1 Introduction

The aims of this chapter are to summarise the experimental findings, relate them to those of Posner and his colleagues and examine the implications for theories of spatial selectivity.

Chapter 3 presented three experiments on internally-controlled covert orienting which were designed to replicate and extend the work of Posner, Nissen and Ogden (1978). It was demonstrated that the allocation of attention to a symbolically-cued location speeds the simple detection response to targets from that location with respect to those from other locations and that such orienting is similar in the horizontal and vertical dimensions (experiment 3.1). If a symbolic cue is presented briefly (in order to avoid visual congruity effects - see experiment 3.2), the combined costs and benefits in terms of manual reaction time are approximately 50 msec for SOAs of 500 and 1000 msec. It was concluded that a searchlight analogy is useful in describing internally-controlled covert orienting, the width of the searchlight's beam being dependent upon the nature of the task (experiment 3.3). Finally, it should be noted that at least for SOAs of between 0 and 1000 msec there was no evidence that an early advantage in terms of simple reaction time to a target from a symbolically-cued location is replaced by a subsequent disadvantage.

The experiments reported in chapter 4 were based on the work of Posner and Cohen (1980) on externally-controlled orienting, and demonstrated the effects of brief non-informative direct cueing on simple and choice manual reaction time and saccade latency to subsequent targets (experiments 4.1, 4.4 and 4.3 respectively). For manual responses, detection of targets is faster from a cued location than from an uncued location 100 msec following the onset of the direct cue in the periphery. For longer SOAs (300 and 500 msec) this facilitation is replaced by inhibition such that detection is then slower from the cued location than from the uncued location. The early facilitatory component is seen as the result of the aligning of attention (but not the eyes) with the cued location (see the first conclusion from chapter 3). However, no facilitation was observed in the saccade latency experiment and this was interpreted as reflecting the need to suppress the relatively automatic eye movement response to the direct cue in the periphery, which then delays saccades to subsequent targets at the same location. Therefore the saccade latency result is probably due to the similarity in the eye movement generation system between the effect of the cue and the response required.

Chapters 5, 6, 7 and 8 further examined the nature of the two components involved in externally-controlled covert orienting, facilitation and inhibition.

9.2 The Facilitatory Component

Chapter 5 considered the attentional nature of facilitation and the question of automaticity. Three divided attention studies were conducted and it was concluded that not every event in the visual periphery results automatically in externally-controlled covert orienting as the facilitatory component can be affected by the requirements of certain secondary tasks. For example, it can be delayed by counting backwards in threes (experiment 5.2), or indeed abolished if the direct cue in the periphery occurs at the same time as a discontinuity in a central tracking task which requires the programming and execution of a small saccadic eye movement (unpredictable eye tracking conditions of experiment 5.3).

The temporal order judgment experiment (8.2) provided strong evidence in support of the view that the facilitatory component is attentional. The results were consistent with the prior-entry hypothesis, that is, attended events are seen as occurring earlier than unattended events. Thus following a direct cue in the periphery, an invalid target (that is, one in a different location to that of the cue) must be presented approximately 70 and 30 msec before a valid target at SOAs of 100 and 300 msec respectively for subjective simultaneity.

It could be argued that the requirement to fixate on a central point throughout an experiment results in an unnatural viewing condition which reduces the ecological validity of the studies presented. When the subject was not required to maintain fixation but was encouraged to make saccades (random eye movements condition of experiment 5.3), increased facilitation was observed at the SOA of 100 msec. It was suggested that following a direct cue in the periphery a saccade is made towards it (externally-controlled overt orienting) so that an early valid target receives the additional benefit of foveal processing. This conclusion was supported by the observation from the saccade latency experiment (4.3) that all the early anticipations were saccades to the cue. Thus it appears that overt orienting occurs to a direct cue in the periphery at least under two conditions; namely when eye movements are actively encouraged, and when the speeded response required is a saccade to the target. However, it was noted in section 5.4.1.3 that subjects preferred not to move their eyes around the visual display, and after completing one block of trials in the random eye movements condition most reported that they would rather fixate in the centre (see also section 2.8). Thus the fixation requirement should not be regarded as an unnatural viewing restriction as it may be considered appropriate in some situations; for example, where there is a high rate of signals distributed randomly over a specific area of visual space.

Further support for the importance of the facilitatory component of externally-controlled covert orienting comes from the work of Remington (1980), described in section 1.5, which demonstrated that covert orienting precedes overt orienting if both are externally-controlled. This study is also significant in that a detection-threshold paradigm was used. In the discussion of internally-controlled covert orienting (section 1.4) it was noted that selective attention not only speeds simple detection responses (Posner, Nissen and Ogden, 1978) but also enhances perceptual sensitivity (Bashinski and Bacharach, 1980). The results of Remington indicate that the same is true of attention under external control. Thus a target appearing immediately after, and in the same location as a direct cue in the periphery is responded to more quickly, judged to be occurring earlier and perceived more readily than a target in a different location.

Recent experiments by Krumhansl (1982) have extended this conclusion by establishing effects of externally-controlled covert orienting on figural and positional judgments. Her work was based on that of Todd and Van Gelder (1979) who investigated the effect of abrupt stimulus changes on the processing of visual information. They compared performance on two types of trial : 'onset' and 'no-onset'. On onset trials the target appeared in an otherwise empty field, whereas on no-onset trials stimuli were present in all possible target positions until the beginning of a trial when all the stimuli except the target disappeared. The subject was required to make a saccade to the target as quickly as possible. Saccade latencies were found to be shorter on onset trials than on no-onset trials, which was attributed to the greater involvement of transient visual channels (as described by Breitmeyer and Ganz, 1976) in the onset condition. Yantis and Jonides (1982) also noted that 'stimuli with abrupt onsets were found to produce shorter latencies in visual search than stimuli without sharp temporal boundaries'.

However, Krumhansl (1982) argued that the results could be due to a greater difficulty in distinguishing the target position from the non-target positions on no-onset compared to onset trials because of visual persistence following the offset of the non-target stimuli. In order to investigate this possible explanation, Krumhansl's procedure involved equating the pretarget fields (in terms of overall luminance) for the two conditions. The pretarget field consisted of an array of characters to the left and right of fixation. These were alternating 'x's and '+'s, the order being varied from trial to trial. This pretarget field was presented for 500 msec and its offset was immediately followed by the target which was one of the two characters in any one of the stimulus positions. Thus the target was either the same as the character in that location in the pretarget field ('no-form-change' trials) or different ('form-change' trials). The target field was then masked after between 60 and 120 msec, the subject's task being to identify the target character and to indicate its location. The results revealed that both judgments were more accurate in the form-change condition, even though the pretarget fields were identical in the two conditions. If it is assumed that a form-change (having similar characteristics to a direct cue in the periphery) results in externally-controlled covert orienting, then it can be concluded that the facilitatory component includes enhanced figural and positional judgments in addition to the effects described above. Indeed Krumhansl suggested that 'the stimulus onset or change may direct attentional capacities to the appropriate target position, thereby enhancing the processing of its position and form'.(p522)

Events in the visual periphery, including motion and abrupt luminance changes produced by motion have been considered important in directing eye movements (Finlay, 1982). Vernon (1962) noted that 'we very quickly become aware of movement at the margin of the field of vision, the image of which falls on the periphery of the retina' and that 'as soon as we become aware of such movement, we immediately turn the head and the eyes until its image falls on the centre of the retina'.(p139) From the experiments described above it is suggested that after a salient event in the visual periphery (for example, a luminance change), but before overt orienting takes place, externally-controlled covert orienting occurs which results in enhanced responding to and processing of further stimuli from that location for approximately 100 msec.

9.3 The Inhibitory Component

If a target appears more than 100 msec after a direct cue in the periphery and in the same or nearby location, there is an inability to respond to it as quickly either manually (experiments 4.1 and 4.4) or ocularly (experiment 4.3) as to a target in a different location. This inhibitory effect is regarded as a consequence of externally-controlled covert orienting to the cue. It is important to note that inhibition is also observed as a result of externally-controlled overt orienting, that is, following an eye movement towards and then away from an event in the periphery, both manual responses (Cohen, 1981) and saccades (Vaughan, 1982) are slower to a target appearing in the previously-fixated location than to one appearing elsewhere.

The experiments presented in chapters 4-8 were mainly concerned with inhibition resulting from externally-controlled covert orienting. Several possible explanations were investigated. First, a comparison between cue-target and target-target procedures eliminated 'response inhibition' as proposed by Harvey (1980). At least for manual responses inhibition does not result from the need to prevent responding to the cue (see, for example, experiment 6.1). Secondly, in agreement with Posner and Cohen (1980), the results of experiment 6.2 demonstrated that the inhibitory effect is not due to the alignment of attention with an alternative location. Several characteristics of the inhibitory component argued against both masking and sensory habituation as explanations for the effect. For example, it lasts over a second (experiments 6.3 and 6.4), affects a larger area of visual space than was originally stimulated (experiment 6.3), shows complete interocular transfer (experiment 7.1) and is determined by environmental rather than retinal co-ordinates (experiment 7.2). In addition, experiment 7.3 provided support for the view that inhibition is a consequence of externally-controlled orienting rather than a general bias towards responding to stimulus change. Inhibition occurs when target location is repeated, but not when the colour of targets at different locations is repeated. Finally, the complete absence of an inhibitory component using a temporal order judgment paradigm (experiment 8.2) was taken as evidence that inhibition is a response-related process, that is, it reflects a reluctance to respond rapidly to a stimulus appearing in the same peripheral location as a previous one that produced covert orienting.

9.4 Is Externally-Controlled Orienting Necessary to Produce Inhibition?

Posner and Cohen (1980) argued from the results of their double-cueing experiment (described in section 1.6) that the inhibitory effect does not arise from attentional orienting but from the sensory information presented at the cued location. In their study, double-cueing resulted in reduced facilitation but the usual amount of inhibition, in comparison with the effects of single-cueing. They concluded that externally-controlled covert orienting was not a necessary condition to produce inhibition. Attempts to replicate their findings (see section 8.2 and experiment 8.1) demonstrated that double-cueing results in reduced facilitation and inhibition, both effects being approximately halved in magnitude. It should be noted that the results of experiment 6.1 demonstrated that two locations (left and right of fixation) can be inhibited at the same time, but only if externally-controlled covert orienting is directed successively to each location. When two locations are simultaneously cued as in the double-cueing experiments, facilitation is reduced because of an inability to orient to two locations either side of fixation as effectively as to a single location [see Podgorny and Shepard's (1983) conclusion that subjects are 'more successful in confining their attention to sets of mutually proximal items'(p360), in addition to Posner, Snyder and Davidson, 1980]. [Analysis of reaction time distributions in section 8.2

revealed that the intermediate amount of facilitation on double-cued trials is not due to covert orienting to one location only.] The corresponding reduction in inhibition on double-cued trials in experiment 8.1 (also not attributable to averaging of invalid and valid trials) is thus taken as evidence that externally-controlled orienting (indicated by facilitation at 100 msec) is indeed necessary to produce subsequent inhibition.

Several other experiments provided evidence to support this view. The results of the divided attention studies reported in chapter 5 were consistent with the proposal that inhibition is a consequence of externally-controlled orienting, so that when facilitation is delayed or abolished by the addition of a demanding secondary task inhibition is similarly delayed or abolished. There was no evidence that the time course and amount of inhibition are purely dependent upon the presentation of sensory information in the periphery. For example, in the unpredictable eye tracking conditions of experiment 5.3 facilitation was abolished by the requirement to make a small saccadic eye movement when the direct cue occurred. In this case there was no evidence of an inhibitory effect, which argues against the view of Cohen (1981) that only facilitation is an active process and that under dual-task conditions the facilitatory component would be attenuated while the inhibitory component would continue to exert its full influence.

It is therefore concluded from these results that inhibition is dependent upon externally-controlled orienting. Without further methodological and statistical details of Posner and Cohen's (1980) double-cueing experiment, it is difficult to explain the discrepancy between their data and those presented here.

9.5 Is Externally-Controlled Orienting Sufficient to Produce Inhibition?

An important question concerns whether or not inhibition is an inevitable consequence of externally-controlled covert orienting. First, it should be noted that the results from the random eye movements condition of experiment 5.3 demonstrated that inhibition is much reduced if overt orienting to the cue is allowed to take place. This was interpreted as the result of the benefit of foveal processing for a valid target following an eye movement to the cued location.

Secondly, it is necessary to examine evidence relating to the possibility that the inhibitory effect can be overcome by the active allocation of attention to the previously-stimulated location. Posner, Cohen, Choate, Hockey and Maylor (1982) described two experiments involving the presentation of a symbolic cue to fixation at the beginning of a block of trials. The cue was either a cross or an arrow pointing to the left or right. There were equal numbers of blocks using each of the three cues.

Following brief presentation of the cue, the first of 10 targets (experiment 1) or 12-20 targets (experiment 2) occurred 5 degrees to the left or 5 degrees to the right of a central fixation point. Essentially a target-target procedure was employed, the R-S intervals being approximately 2000 msec in experiment 1 and between 200 and 1000 msec in experiment 2. The subject's task was to press a single key as quickly as possible following the onset of each target. When the cue was an arrow, 80% of the targets occurred in the direction indicated and 20% in the other direction. When the cross acted as the cue, the targets were equally likely to occur on either side. The trials were coded (valid, neutral and invalid) as in the experiments described in chapter 3. The results from both experiments indicated that although for the early trials in a block there were effects of attention in the expected direction (that is, valid RT < neutral RT < invalid RT), these effects quickly disappeared so that there was no difference between reaction time for the three types of trial by the end of the block. These results are consistent with those of Posner, Snyder and Davidson (1980) on blocked trials, described in section 1.4, that is, subjects seem unable to maintain spatial selectivity (under internal control) for an extended period. In addition, Posner et al (1982) noted that in experiment 2 (which used R-S intervals ranging from 200 to 1000 msec) there was a 'negative sequential dependency effect' whereby reaction time to a target appearing at the same location as the previous target was slower than to a target on the opposite side. This effect has been described as inhibition in the present studies (see, for example, experiment 6.2). Posner et al (1982) attributed the failure to demonstrate spatial selectivity in their experiments (1 and 2) and in the Posner et al (1980) study to the inhibitory effect, as repeated targets occurred more often on the valid side than on the invalid side, because of the probabilities involved. They concluded that sustained attention with blocks of trials involves the inhibitory component described by Posner and Cohen (1980). Whatever benefit might be obtained by the allocation of attention to a cued location is counteracted by inhibition that occurs when targets appear in the same location on successive trials. The implication is that, at least for the later trials in a block, inhibition is indeed an inevitable consequence of externally-controlled covert orienting.

However, there are several reasons to question this conclusion. First, no negative sequential dependency effect was found in the first experiment reported by Posner et al (1982) using R-S intervals of 2000 msec. [This is consistent with the results of the present studies in which the inhibitory effect was found to decrease with increasing R-S interval. For example, inhibition was only approximately 15 msec for R-S intervals of 900 and 1000 msec in experiments 6.2 and 6.4 respectively. Although it was larger (nearly 30 msec) in experiment 7.1 at an R-S interval of 900 msec, it is reasonable to assume from the interactions observed between trial-type and R-S interval that the inhibitory effect would be absent by 2000 msec.] However, there were no differences between the overall results of the two experiments reported by Posner et al (1982), that is, reaction times on valid, neutral and invalid trials were similar. Secondly, it is unlikely that the inhibitory effect can account for the results of Posner et al (1980). Although details of their procedure were not given, the time between the offset of one target and the onset of the next was probably at least 2000 msec. Before the appearance of a target there was a warning signal presented at the fovea for 1000 msec. The target was then displayed until the subject made a simple detection response. Feedback was given immediately in the form of the reaction time in milliseconds or 'ERROR' presented on the screen. The next trial began after an unspecified intertrial interval. Therefore the R-S interval would have been at least 2000 msec. In addition, as catch trials were included, some R-S intervals would have been over 4000 msec. These estimates were confirmed by an analysis of the number of trials completed in each experimental session. After allowing for possible rest periods, each trial probably lasted at least 3000 msec. It is therefore difficult to attribute the results of Posner et al (1980) to the inhibitory effect, as the stimulus timing was such that there would be no effect on reaction time of the location of the target on the previous trial. Therefore the inability of subjects to maintain a constant expectancy over a block of trials must be attributed to some other factor.

Further support for this conclusion comes from the results of a recent experiment by Sanders and Reitsma (1982). The subject was required to press a single key following a visual target which occurred either at fixation or 50 degrees to the left of fixation. The R-S interval varied between 6 and 24 seconds. At the beginning of each of five 20-minute sessions the subject was informed of the target probabilities for that session. Thus the target appeared at fixation with a probability of 1.0, 0.8, 0.5, 0.2 or 0.0, corresponding to probabilities of appearing in the peripheral location of 0.0, 0.2, 0.5, 0.8 and 1.0 respectively. For example, in one session the target always occurred at fixation (1.0, 0.0) while in another it was equally likely to appear in the two possible locations (0.5, 0.5). The results revealed the expected cost-benefit function for targets appearing at fixation (that is, increasing reaction time for decreasing probability from 1.0 to 0.2), but no effect of target probability on reaction time to targets presented to the peripheral location. Sanders and Reitsma suggested that covert orienting to the periphery under internal control may be 'so demanding that it can only be maintained for a short period of time'.(p144) This does not entirely explain the asymmetry observed between the fovea and the periphery. However, it is clear that because very long R-S intervals were used, the absence of costs and benefits in the periphery cannot be attributed to the inhibitory effect.

The possibility that the inhibitory effect can be overcome by attention was investigated more directly by Posner, Cohen and Rafal (1981). Their experiment was based on that of Posner and Cohen (1980) which was described in detail in section 1.6 and replicated by experiment 4.1. There were two conditions. In the first condition the target appeared inside the cued peripheral box on 80% of the trials and inside the uncued box on 20% of the trials. The second condition was the reverse, that is, the target was more likely to appear inside the uncued box (80%) than inside the cued box (20%). The results indicated that the direct cue summoned attention in both conditions leading to an initial advantage (-facilitation) for targets appearing inside the cued box. [From this it might be argued that externally-controlled covert orienting is 'automatic', that is, the cue seems to attract attention towards a peripheral location even if there is a low probability of finding a target there. However, in these two conditions the subject must orient to the cue in order to discover the probable target location.] In the first condition, this early facilitation was not followed by the usual inhibition observed when the target is equally likely to appear in the two locations. However, in the second condition there was evidence of increased inhibition compared to the control where the target probabilities were equal (Posner and Cohen, 1980).

The results from the longer SOAs therefore demonstrate the powerful effect on reaction time of the subject's expectations of target location. Thus the inhibitory effect can be overcome by the allocation of attention towards the cued location. Experiment 6.4 also provided evidence in favour of this view that inhibition can be influenced by higher-order control.

Taken together, these findings lead to the conclusion that externally-controlled orienting is not a sufficient condition to produce inhibition. The alignment of either the eyes or the attention with the cued location (both active measures) can overcome the inhibitory effect.

9.6 Implications for Spatial Selectivity

The present studies must be considered in relation to two important findings of Cohen (1981). The first was described briefly in chapter 5 (see section 5.4.2). His subjects fixated the central box of the three-box display (see Figure 2.3) and were instructed to move their eyes to the brightening of a peripheral box (direct cue). After 500 msec the central box brightened and the subjects were then required to move their eyes back to the centre. Targets were presented at either 100 or 650 msec following the onset of the direct cue in the periphery. There was evidence of facilitation of reaction time on valid trials for the early targets. This was followed by inhibition for the later targets appearing at the previously-cued peripheral location. This suggests that both externally-controlled covert and overt orienting can produce inhibition, that is, manual responses to targets appearing at previously attended (for example, experiment 4.1) or fixated (Cohen, 1981) locations are delayed if orienting is externally-controlled. In addition, saccadic responses to targets appearing at previously attended (experiment 4.3) or fixated (Vaughan, 1982) locations are similarly inhibited.

The second important experiment conducted by Cohen investigated the co-ordinates of facilitation, using a similar technique to that of experiment 7.2. Subjects were presented with an array of six boxes in two horizontal lines. They were required to fixate on the central box of the top row until a signal was given to indicate that they were to move their eyes to the central box of the bottom row. Immediately before the saccade, one of the two peripheral boxes of the top row was brightened. Targets could then occur in any one of the four boxes forming the corners of the rectangular display. The results for the SOA of 100 msec indicated that the facilitatory component is determined by retinotopic co-ordinates, that is, the fastest responses were made to targets appearing in the box directly below the cue. At the longer SOA (550 msec) no evidence of inhibition was found, although from the results of experiment 7.2 it is clear that the inhibitory effect is determined by environmental co-ordinates.

Thus, the facilitatory and inhibitory components appear to act at different levels to achieve a balance between attending to locations in space and maintaining spatial selectivity. The present studies, combined with Cohen's finding that the inhibitory effect is present even when eye movements are made (that is, reaction time to stimuli appearing at a previously fixated location is slower than to stimuli at other locations) provide support for Posner et al's (1982) recent conclusions concerning externally-controlled orienting. First, the facilitatory component operates within a single fixation. It seems to be a preparatory process, marking out a peripheral location as being of potential interest. Facilitation occurs rapidly and precedes overt movements towards the stimulated location. If a saccade is made, attention should also move, since facilitation follows retinotopic co-ordinates. However, it is likely that in normal viewing attention would rapidly move back to the fovea. Following a second eye movement, the location of the previous stimulus is then reduced in its ability to produce a response, either manual or ocular (the inhibitory effect). Detection of targets from the previously-stimulated location is influenced by both the facilitatory and inhibitory components even if no overt movement was made towards the initial stimulus.

From the co-ordinates and time courses of the two effects, it can be inferred that facilitation is associated with attention and target acquisition within a fixation and is therefore likely to be involved in the direction of the eye movement system. Inhibition, however, seems to operate between successive fixations, acting to delay orienting to a location that was sampled (either covertly or overtly) within the last second (equivalent to the time for two or three saccades). These conclusions are consistent with the recent work of Mack (1981) and Jonides, Irwin and Yantis (1982). Both studies suggested that retinotopic co-ordinates indicate an early stage of processing, whereas environmental co-ordinates indicate a later stage. Mack concluded that a saccade to a briefly flashed target is programmed in terms of retinal co-ordinates if the saccade occurs within 500 msec of its disappearance. With longer saccadic delays, target location is specified in terms of 'perceptual' co-ordinates, supporting a model of eye movement control in which either immediate retinal co-ordinates or stored perceptual co-ordinates are used to program saccades. The experiment by Jonides et al (1982) on the integration of visual information from successive fixations led them to conclude that

> '..early in the visual system, there is a storage site in which information is coded retinotopically and in which this information is subject to integration and erasure effects by new entries that arrive within the same window. Later in the system, there may be another storage site that codes information by environmental co-ordinates, one that has a different set of time variables governing integration and erasure.' (p194)

Their procedure involved the successive presentation of two 12-dot displays which, if superimposed, would fill all but one of the 25 locations of a 5 x 5 matrix. The subject was required to identify the location of the 'missing' dot. Two viewing conditions were used. In the first condition the subject was asked to make a saccade to the first set of dots which was briefly presented 4 degrees to the right of fixation. As soon as the eye movement occurred, the second set of dots appeared in the same (environmental) location. In the second condition the subject was required to fixate centrally throughout, the first set of dots appearing 4 degrees to the right of fixation and the second set at fixation. Thus in the first condition the two sets of dots shared environmental but not retinal location, whereas they did not share either in the second condition. Performance was found to be far superior in the first condition, a result which has been taken by many as evidence of a storage mechanism that holds the contents of more than one fixation in a code that is tied to environmental rather than retinal co-ordinates (see, for example, the peer review commentaries by Allik and Bachmann, Banks, Breitmeyer, Goldberg, Jonides, Navon and Rayner on the paper by Haber, 1983).

The results of studies by Ritter (1976), Wolf, Hauske and Lupp (1980), and Breitmeyer, Kropfl and Julesz (1982) are also consistent with this conclusion. For example, Breitmeyer et al distinguished between two forms of visual pattern persistence, one peripheral and the other central, determined by retinal and environmental co-ordinates respectively. The latter form is 'generated and enhanced by the extraretinal signals which accompany saccades and map the successive, uncorrelated retinotopic representations onto a nonvarying spatiotopic representation'.(p193) The exact nature of the extraretinal signals is unknown. It is clear that the brain must do more than process the world in terms of retinal co-ordinates. It needs to take eye movements into account in order to equate a retinal signal with a real stimulus in visual space. Thus the question remains of how information in retinal co-ordinates is converted into environmental co-ordinates - somehow, knowledge of current eye position and retinal information must be combined. However, the importance of these studies with respect to the present findings lies in their emphasis on 'an early visual memory that codes information by spatial co-ordinates, and perhaps also an earlier memory that makes use of a retinotopic code' (Jonides, in his commentary on Haber, 1983, p25). This conclusion is consistent with the possible functions of the facilitatory and inhibitory components of externally-controlled orienting as outlined above. Thus there is no need for facilitation to be determined by anything more than retinal co-ordinates as it is short-lived, lasting no more than the average time between saccades. However, inhibition lasts at least a second (during which time two or three saccades can be made) and therefore must be coded in terms of environmental co-ordinates.

To conclude, the consequences of externally-controlled orienting are usually a brief facilitation followed by a longer-lasting inhibition, which act together to direct the eye movement system and to maintain selectivity in visual space. From the evidence presented in the thesis, combined with that of Posner and his colleagues, it appears that the inhibitory component is associated with externally- but not internally-controlled orienting. However, although externally-controlled orienting is a necessary condition to produce inhibition, it is not a sufficient condition. The active alignment of either the attention or the eyes with a previously-stimulated location can compensate for inhibition.

9.7 Suggestions for Future Investigation

This section outlines some possible areas for further research aimed at investigating the conclusions drawn from the present studies. First, an assumption was made in chapter 5 in order to account for the results of the divided attention studies, namely that faciliatation is maximal at an SOA of less than 100 msec. It is therefore necessary to repeat experiment 4.1 with the addition of targets occurring at SOAs of between 0 and 100 msec. [However, the cue duration would have to be decreased so that the target does not occur while the direct cue is being presented, in order to avoid possible sensory summation effects.]

It would be of interest to know whether or not the effects described are specific to visual stimuli. For example, can externally-controlled orienting and its consequences occur as the result of a brief, non-informative auditory cue? The possibility may be limited by the ability to localise auditory stimuli in space as it may be considerably more difficult to discriminate between two direct cues separated by 8.4 degrees (as in experiment 4.1) in the auditory modality than in the visual modality.

The spatial extent of the 'facilitated' region produced by direct cueing requires investigation. In relation to section 9.4 it is important to compare the results with those of experiment 6.3 which demonstrated the extent of the inhibitory effect.

It was noted in section 1.6 that inhibition does not occur as the result of internally-controlled covert orienting (Posner and Cohen, 1980). This was taken by Posner as further evidence in support of his view that inhibition is a consequence of peripheral stimulation and not of the previous directing of attention towards the periphery. A brief description of their experiment is necessary. Each trial began with an arrow at fixation (symbolic cue) which indicated that the target would appear on the cued side on 80% of the trials and on the uncued side on 20% of the trials. After 600 msec attention was attracted back to the centre by the brightening of the central box (direct cue), which also indicated that targets would now be more likely to occur at the centre (p=0.6) than in either of the peripheral boxes (p=0.2 each side). Targets occurred at three SOAs following the symbolic cue : 450, 950 or 1250 msec. The results demonstrated clear facilitation for targets on the expected side at the earliest SOA (450 msec), but this was not followed by inhibition at the longer SOAs when attention should have returned to the centre. However, their data are far from conclusive for the following reasons. First, it would be expected from the results of the present studies that inhibition would be negligible at 1250 msec. Indeed there was no difference between valid and invalid trials at that SOA, although responses to targets appearing at the centre were slightly faster due to the benefit of both foveal processing and high probability. Secondly, there was some evidence of inhibition at the SOA of 950 msec, the large facilitation of 31 msec at 450 msec being replaced at 950 msec by inhibition of approximately 5 msec. Stronger support for the existence of an inhibitory effect comes from an analysis of the differences in reaction time between the SOAs of 950 and 1250 msec for the three types of trial. Reaction time increased by 26, 20 and 5 msec for central, invalid and valid trials respectively. The much reduced increase for valid trials could be attributed to inhibition at 950 msec which disappeared by 1250 msec. Clearly a more detailed study is required. In addition, the following experiment should be conducted in order to investigate whether or not internally-controlled overt orienting results in inhibition. It does not rely on the ability of the subject to alter target expectancies rapidly during a trial (which may have been a problem in the Posner and Cohen study). A trial would begin with an arrow at fixation to indicate the eye movement required (either to the left or right box of the three-box display). After 500 msec, the central box would brighten to indicate that the eyes were to move back to the centre. The target would occur at an SOA of 400, 700 or 1000 msec and it would be equally likely to appear inside the left or right box. It would be expected that for the first SOA (400 mesc) manual reaction time to targets inside the fixated peripheral box would be faster than to targets inside the opposite box because of the benefit of foveal processing. However, the comparison of interest would be between reaction time to targets at the previously fixated and unfixated peripheral locations at SOAs of 700 and 1000 msec. Evidence of an inhibitory effect would indicate that both internally- and externally-controlled overt orienting produce inhibition. The results of these proposed studies would distinguish between two views of inhibition. The first is that it reflects a bias against responding to a stimulus from a location that was recently examined, either covertly or overtly, even though the search may have been unsuccessful (as under internal control). This would imply that the inhibitory component involves memory for the recent scan path (both attentional and saccadic). The second view regards inhibition as a reluctance to respond to a stimulus from a recently-stimulated and therefore recently-sampled location, the sampling (both covert and overt) being under external control. This view of inhibition is dependent only upon memory for recent visual events. It should be noted that the evidence so far (Posner and Cohen, 1980), although not conclusive for the reasons indicated above, favours the second view.

Further investigation is required into the failures to obtain costs and benefits when symbolic cueing occurs only at the beginning of a block of trials (Posner, Snyder and Davidson, 1980; Posner, Cohen, Choate, Hockey and Maylor, 1982; Sanders and Reitsma, 1982). It was concluded in section 9.5 that the results could not be attributed to the inhibitory effect. Therefore an alternative explanation is required for the inability to maintain concentration on a peripheral location (internally-controlled covert orienting) for an extended period of time.

Finally, chapter 8 introduced some additional methods of investigation which could be employed to answer some interesting questions concerning externally-controlled orienting. It was suggested in sections 8.3 and 8.5 that further study of reaction time distributions and individual differences might be fruitful. Also the temporal order judgment paradigm could be extended in several ways by altering the timing or display parameters.

For example, the amount of brightening used to produce the direct cue could be reduced in order to determine whether or not externally-controlled orienting occurs to sub-threshold stimuli. If externally-controlled orienting depends on the distance from fixation to the direct cue in the periphery, the time course of the facilitation effect (that is, the bias of perceiving the valid target as occurring first) may be affected by changing the visual angles.

Combined with the present findings, the results of these studies should increase our understanding of the mechanisms by which we prepare for, select and respond to information in visual space.

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APPENDIX A

Instructions to subjects - Experiment 3.1

This is an experiment to investigate the time it takes to react to simple stimuli presented on this screen.

Please place your chin on the rest and alter the height until you are comfortable. You will be required to fixate on the central fixation point throughout the experiment. There will be five blocks of trials, each lasting about four minutes and you may rest between blocks. There are about 50 trials in a block.

Each trial begins with a cue which appears at the fixation point. This may or may not be followed by a target, but if a target is presented, your task is to press the key as quickly as possible with your dominant hand.

There are three types of cue. The first is a simple cross which indicates that the target has an equal chance of appearing either to the right or to the left (or above or below) the cue. The other two cues are arrows, one pointing to the right (or up) and the other pointing to the left (or down). These indicate that the target is four times more likely to appear in the direction of the arrow than in the opposite direction.

Before each block of trials the information on the screen will give you the delay in milliseconds for the next block. The delay is the time between the cue and the target and can be 0 (when they occur simultaneously), 100, 250, 500 and 1000 msec, the five blocks being presented in a random order.

When you have read the delay information and are ready to continue, press the key once. The instructions will disappear to be replaced by three practice trials, one for each type of cue. To start the actual trials you will need to press the key again.

Try to respond to the onset of the target as quickly as possible but without making any errors, that is, both pressing the key when no target is presented, or during the delay period.

Do you have any questions?

APPENDIX B

Instructions to subjects - Experiment 3.3A

This is an experiment to investigate the time it takes to react to simple stimuli presented on this screen.

Please place your chin on the rest and alter the height until you are comfortable. You will be required to fixate on the central fixation point throughout the experiment. There will be five blocks of trials, each lasting about four minutes and you may rest between blocks. There are about 50 trials in a block.

Each trial begins with a cue which appears at the fixation point. This may or may not be followed by a target, but if a target is presented, your task is to press the key as quickly as possible with your dominant hand.

There are two cues. One is an arrow pointing to the left, the other to the right. These indicate that the target is nine times more likely to appear in the direction of the arrow than in the opposite direction. Also the target will appear eight times more often in the near position in the expected direction (about 1 cm from the fixation point) than in the far position (about 3 cms from the fixation point). When the cue is presented you should try to concentrate your attention to receive a stimulus from the expected location, that is, the near position in the direction of the arrow, without moving your eyes.

Before each block of trials the information on the screen will give you the delay in milliseconds for the next block. The delay is the time between the cue and the target and will be 200 (or 500, or 1000) msec. There will also be a reminder to keep your eyes on the fixation point throughout the block.

When you have read the delay information and are ready to proceed, press the key once. The instructions will disappear to be replaced by two practice trials, one for each type of cue. To start the actual trials you will need to press the key again.

Try to respond to the onset of the target as quickly as possible but without making any errors, that is, both pressing the key when no target is presented, or during the delay period.

Do you have any questions?

APPENDIX C

Instructions to subjects - Experiment 4.1

This is an experiment to investigate the time it takes to react to simple stimuli presented on this screen.

Please place your chin on the rest and alter the height until you are comfortable. There will be two blocks of trials, each lasting about two minutes and you may rest between blocks.

When you press the key, the instructions on the screen (that is, the reminder to keep the eyes on the fixation point throughout the block) will disappear and be replaced by three small boxes, one on the left, one in the centre and one on the right of the screen. The fixation point is a small spot in the middle of the central box. After five seconds the experimental block will begin.

The task is very simple. You must press the key (with your dominant hand) as quickly as possible following the appearance of a target. This is a small square of four dots appearing inside either the left box or the right box (but never inside the central box). Targets occur approximately once a second. Try to respond to the onset of the target as quickly as possible but without making any errors, that is, pressing the key before a target appears. Your response will end the current trial and the target will disappear.

The three boxes on the screen will tend to flicker throughout the block. Try to ignore this - it will not give you any information about either the timing or the location of the next target.

The screen will go blank at the end of the first block of trials. The instructions will then return ready for the next block. Press the key once when you are ready to proceed.

Do you have any questions?