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ALERTNESS AND THE
CONTROL OF ATTENTION

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To my Mother and Father

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ABSTRACT

The thesis aims to examine the ways in which alertness influences the relationship between attention and performance in a reaction situation. Alertness is operationally defined as the state induced following the presentation of a warning signal. The relationship of alertness to attention is considered, and research on alertness, both physiological and behavioural, is reviewed. Attempts to incorporate the observed effects of alertness into models of attention, generally based on traditional arousal theory, are examined, and a number of unresolved issues are identified. Empirical work carried out to investigate these issues shows that (a) expectancy does not interact with alertness at foreperiods of less than one second in duration; (b) alertness focusses attention towards more probable stimulus locations, in line with the predictions of arousal theory; (c) simultaneous improvements in both speed and accuracy of responding can be produced by alertness with stimuli of up to at least 800 milliseconds in duration, and this cannot be explained as a shift in speed-accuracy tradeoff; (d) explicit task instructions are more effective when subjects are alert than when they are not, and tentative evidence suggests that this may also be the case with the effects upon behaviour of implicit task context. These results support and extend the proposal by Kahneman (1973) that alertness produces a general facilitation of attention, the behavioural manifestations of which are task dependent. This conclusion contrasts with the more mechanistic role ascribed to alertness by Posner (1974), i.e., that of simply producing earlier sensory input sampling. A simple theory of alertness is presented which embodies these conclusions, and some further research topics of interest and relevance are identified and discussed.

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Section 1. Background to the Research

1.1 General Introduction

1.1.1 The Importance of Attention in Psychological Research

In 1890 William James made the simple statement: "My experience is what I agree to attend to" [page 402]. This immediately suggests that what we attend to has something to do with conscious experience, and that this can be both selective and controllable; indeed James goes on to state that "attention implies withdrawal from some things in order to deal effectively with others" [page 404]. James devoted a chapter of his book, "The Principles of Psychology," to the topic of attention, in which he proposed a three-way classification system to describe what he saw as its various properties. According to this system, attention could be: (1) either active or passive (i.e., voluntary or involuntary), (2) either sensorial or intellectual, and (3) either immediate or derived (i.e., spontaneous, or the result of a train of thought). To the author, this taxonomy of attentional states still makes intuitive sense, but now, some 90 years later, scientific psychology should hopefully have had time to elaborate on some of these ideas, and test them empicically. We seek to explain how we can pay attention to one thing rather than another, how our observable behaviour changes as a result, and what factors can influence the control which we have over our attention. The aim of the present thesis is to make some contribution towards this goal.

With the advent of behaviourism in the 1920s, the word "attention" was dropped from the vocabulary of psychology as being too mentalistic a concept to be of use in scientific research. An example of this view can be seen in the discussion by Telford (1931) of the experiments carried out by

Woodrow (1914) in an attempt to measure attention. Telford wrote:

> To call it attention does not explain it. This is but a process which must itself be explained in terms of neuro-muscular sets and tensions [page 29].

Subsequently Mowrer and his colleagues (Mowrer, 1940a,b, 1941; Mowrer, Rayman and Bliss, 1940) argued from both philosophical and empirical standpoints that expectancy, or attentional set, need not be accompanied by peripheral muscular tensions. Rather, their results suggested that mental set could be a neuronal process or state with a central locus, and therefore unobservable by direct means. That this viewpoint received a critical reception is illustrated by the following comment from Freeman (1940):

> In my opinion Mowrer, Rayman and Bliss's ruling out of motor factors as component determinants of set, by the method of proclamation rather than by adequate control, leaves us with no alternative explanation other than the soul hypothesis masquerading in intra-neural false whiskers [page 624].

A significant landmark in the revival of interest in the study of attention as a respectable discipline was the publication in 1958 of Broadbent's "Perception and Communication." In this book he proposed a viewpoint which was radically different to the traditional stimulus-response approach of behaviourism. The individual was presented as a system capable of processing only a limited amount of information at any one time. Thus it was necessary to postulate an attentional mechanism which could selectively reject unwanted information and admit relevant data in a serial manner to a limited capacity processing channel. Over the subsequent two decades, many changes have been made to this original formulation, and new models have been proposed in the light of experience - Broadbent's own views having moved away from the deterministic methods of information theory towards a more indeterminate statistical approach (Broadbent, 1971) - but in all of these, the importance of attention in directing and controlling behaviour has always remained to the forefront.

This importance is reflected in the fact that several authors have suggested that attention may be synonymous with consciousness, in the sense that we are always conscious of what we are attending to. Posner and Klein (1973) argue that we are only aware of those processes which compete for, and gain control of, a central limited capacity information processor. Posner, Klein, Summers and Buggie (1973) further state that the observation of interference between mental operations provides a means of detecting the operation of the conscious processor. Shallice (1972) similarly states that when there are a number of competing processes, consciousness can be defined as the operation of a selector which permits one process to become dominant, and which also defines the goal of the process. Kahneman's (1973) view of consciousness is that we only need be aware when our expectations are not met (i.e., we must change our behaviour), or when no expectations have yet been formed. Although expressed differently, these statements all reflect the point made by Elithorn and Lawrence (1955) regarding the the classical view of skilled performance, i.e., that reflex activities can co-exist but attention or consciousness is an indivisible attribute of the organism.

More generally, a number of authors (Posner and Snyder, 1975a,b; Carr and Bacharach, 1976; Mandler 1979) consider that attention mechanisms, often facilitated by increased arousal or activation, have a central function in determining which information enters into consciousness for further processing, and they discuss the adaptive value of such mechanisms. Similarly, Hilgard (1980), in reviewing changing attitudes to the notion of consciousness over the years, considers that attention serves as a controller for the operation of a heuristic processor which we call consciousness. In contrast, Neisser (1976) has warned that we should not trivialise consciousness by simply regarding it as a limited capacity stage in the information processing chain between input and output. Going further than this and taking a somewhat philosophical stance, Wilson (1976) considers consciousness and self awareness to be unique, in that they allow us direct knowledge of the physical world in addition to that which enters via our sense organs.

While concepts such as consciousness and awareness are particularly nebulous, and must be regarded with caution, Vaughan and Ritter (1973) point out that from a physiological point of view, the processes collectively labelled "attention" represent the highest order of cerebral organisation, and involve dynamic connections between many brain systems. Thus the central position occupied by attention within psychological research reflects the implicit assumption or belief that attention is, of necessity, intimately associated with those aspects of behaviour which, as Shallice (1972) points out, are traditionally considered to be unobservable, but nevertheless identifiable with brain functioning. As such, all attempts to describe human behaviour must take attention into account, whilst at the same time, the direct study of attention and its determinants will provide an insight into some of the processes which underlie that behaviour.

1.1.2 Alertness as a Component of Attention

So far, no attempt has been made to give any definition of attention, other than to outline the classifications proposed by James (1890). Moray (1969) has identified seven different "types" of attention, and these can be summarised briefly as follows:

1. Mental concentration - involving exclusion of external stimulation;
2. Vigilance - watch keeping;
3. Selective attention - the cocktail party problem (Cherry, 1953);
4. Searching - for a signal amongst a set of signals;
5. Activation - sit up and pay attention;
6. Set - a preparation to respond in a certain way;
7. Analysis by synthesis (Neisser, 1967) - start with an initial wholistic impression and refine this via active hypothesis testing.

Clearly, all of these definitions in some sense involve what James described as the withdrawal from some things in order to deal more effectively with others, and illustrate the diverse aspects of behaviour to which the term "attention" has been applied.

Posner and Boies (1971) have identified three components of attention which overlap Moray's definitions to varying degrees, these components being capacity, selectivity and alertness. Attentional capacity refers to the amount of information which can be processed at any one time by an organism, and selectivity describes the organism's ability to select information from one source or of one kind rather than another. The third component, alertness, refers to the development and maintenance of attention following the presentation of a signal which informs subjects that they should prepare to take in information. This is exactly the same process as is Moray's Activation. Alertness also resembles vigilance (Moray's 2nd definition of attention), both in terms of the need to maintain attention, and also in terms of the brain processes which appear to underlie the two situations (see section 1.2.1 on the physiological correlates of alertness). Alertness, or activation, and vigilance differ in that alertness refers to a short term state of high attention, whereas vigilance involves the maintenance of attention over a prolonged period. Gottsdanker (1975) has observed that it takes considerable effort to sustain high attention for more than about one second, and Naatanen (1970a) has used the expression "short-term exhaustion" to describe the changes which occur under such conditions.

The everyday use of the word "alert" conjures up images of being wide awake, attentive and generally receptive to events in the environment. Often the word is used to describe the behaviour of a cat or dog when it pricks up its ears and becomes tense in response to a sudden noise. Implicit in such usage is the notion of readiness to act, and that an organism will somehow perform better or more efficiently when it is alert than when it is not alert. In Posner's (1978) terms, alertness allows those mechanisms which sub-serve awareness to be brought more readily into contact with sensory information.

Clearly then, as a component of attention, alertness has an important role to play in determining behaviour: in addition to directing attention and selecting among different alternatives, the organism must be capable of developing and maintaining attention in the first instance, and it is this process to which alertness refers. In previous research (e.g., see Bertelson, 1967) the terms readiness and preparation have been used interchangeably with alertness to describe the changes produced by a warning signal. In the present report the term alertness is preferred, because its physiological connotations (described in section 1.2), and its colloquial usage, make it seem to the author to be more appropriate and more descriptive.

An operational definition of alertness may be given as "the state induced by the presentation of a warning signal just prior to the presentation of a task involving information processing, usually a reaction task." The time interval between the onset of the warning signal and the onset of the task stimulus will be referred to either as the warning interval, or as the foreperiod (other terms also having been used in the literature being preparatory period and preparatory interval).

1.1.3 Layout of this report

The remainder of this report is concerned specifically with alertness. The next section (1.2) examines the nature of alertness, in terms of the physiological changes which take place following the presentation of a warning signal. The relationship between alertness and arousal and the locus of alertness effects are also considered. Section 1.3 is a review of various topics in the psychological literature which have a direct bearing on the study of alertness. In section 1.4, a number of theoretical interpretations of alertness are presented, and on the basis of this, section 1.5 outlines the main aims and approaches of the research presented in this thesis.

Section 2 first of all describes the general methodology underlying the empirical work, followed by detailed descriptions of the actual experiments, and discussions of the implications of their results. While these could equally be interpreted as twelve separate experiments, based on four distinct paradigms, they are presented in a logical manner as seven sections, each one united by the nature of the questions being asked, and the hypotheses being tested.

In section 3.1 a brief summary of the main results is given, and the general conclusions and hypotheses are presented. A basic theory of alertness is presented in section 3.2, which can be regarded as an attempt to integrate the current findings into the existing body of knowledge. Work which has been reported since the present research was carried out is also considered, and some limitations of the present approach are discussed in section 3.3. Finally, various areas of behaviour are identified in which the control of attention is relevant, and in which the alertness model could be tested, and these are examined in section 3.4.

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1.2 The Nature of Alertness

1.2.1 Physiological Correlates of Alertness

The presentation of a warning signal has been shown to result in the following physiological changes:

(1) attenuation or blocking of the alpha rhythm (8 to 13 Hertz frequency band) of the electroencephalogram (EEG);
(2) a slow negative drift in EEG (known as the CNV or contingent negative variation);
(3) cardiac deceleration;
(4) inhibition of motor reflexes.

This pattern of responses has been described by Lynn (1966) as being highly similar to the localised orientation response discussed by Sokolov (1963). Kraut (1976) has also found a familiarisation effect with warning signals, analogous to the habituation of the orienting response. These four aspects of alertness are examined separately in the following paragraphs.

Lansing, Schwartz and Lindsley (1959), Leavitt (1969), and Thompson and Botwinick (1966) have all observed that EEG alpha rhythm blocking tends to be time-locked to warning signal onset, with maximum blocking occurring after about 500 milliseconds (ms.). These studies found that reaction time also correlated with warning interval, typically showing a minimum reaction time at an interval of about 500 ms., but that the degree of alpha rhythm blocking and speed of reaction did not actually correlate with each other.

The appearance of the CNV following a warning signal has been found in a number of studies (Naatanen, 1970b; Teece, 1972; Loveless, 1973). It can begin anytime up to 200 ms.

after the onset of the signal, and its termination appears to depend on the duration of the warning interval (Posner, 1974). The CNV has been labelled as an "expectancy wave" by Besrest and Requin (1973), and as a "readiness potential" by Vaughan and Ritter (1973) since a similar wave also appears as part of a conditioned response. Wilkinson and Haines (1970) have found that CNV reflects both expectancy and detection performance in a vigilance situation, illustrating the similarity between alertness and vigilance already noted in section 1.1.2.

At foreperiods greater than about one second in duration, it is possible to identify two components in the CNV, one occurring immediately following the warning signal, and a later component which appears to peak at or around expected stimulus occurrence time (Loveless, 1975; Loveless and Sanford, 1975; Gaillard, 1977,1980). It seems most likely that this later component reflects expectancy and response preparation, since its amplitude is affected by manipulations such as induced muscle tension (Sanders, 1980), speed-accuracy trade-off instructions (Gaillard, 1977; Gaillard and Perdok, 1980), and sensory versus motor attention instructions (Loveless and Sanford, 1974).

The early component of the CNV has been referred to as an orientation wave by Loveless and Sanford, and these authors consider this to reflect an increase in the effective sensitivity of the perceptual system. They found that higher intensity warning signals produced an orientation wave of greater amplitude, along with faster reaction times. Nissen (1977) similarly concluded that the effect of warning signal intensity was mediated via an alerting mechanism. This physiological distinction between orientation and expectancy waves suggests that caution is necessary in interpreting and comparing behavioural results which have been obtained using widely differing foreperiod durations. In particular, at short foreperiods of less than one second, these two waves are confounded, and while the simple alertness or orientation process may be relatively constant and related to the nature of the warning signal, expectancies about the task, and general context effects are also clearly capable of manifesting themselves at the physiological level.

Following the presentation of a warning signal, cardiac deceleration tends to occur, and this correlates moderately with reaction time (Obrist, Webb and Sutterer, 1969; Elliott, Bankart and Flaherty, 1976). There is also evidence of a very brief early accelerative component which may be an orientation response to the warning stimulus (Coles and Duncan-Johnson, 1975), and there may also be a subsequent acceleration, the magnitude of which reflects the difficulty of the task which the subject is performing (Duncan-Johnson and Coles, 1974; Kahneman, Beatty and Pollack, 1967; Kahneman, Tursky, Shapiro and Pollack, 1969).

Inhibition of the spinal reflexes associated with the muscles about to respond has been observed during the warning interval by Requin (1969) and by Semjen, Bonnet and Requin (1973). There is also a reduction in irrelevant movement and in the frequency of eye blinking and eye movements (Obrist et al., 1969; Webb and Obrist, 1970). Kahneman (1973) describes this as a pattern of motor inhibition, which serves to clear the system for anticipated stimuli.

Finally, in addition to these four main physiological measures, there is some evidence that pupil diameter and evoked potential may also be influenced by alertness. Bradshaw (1968) has observed that a warning signal tends to produce an increase in pupil diameter, a measure which is considered by Goldwater (1972) to be a useful index of autonomic activity, and to reflect mental effort and attention. Naatanen (1970b) and Karlin (1970) both examined evoked potentials to stimuli which had been preceded by a warning, and found a tendency towards increased amplitude of the evoked response, but this was by no means a consistent effect. Sabat (1978) has also observed that following a warning signal the variance of auditory evoked responses fell by 50 percent within half a second. However, Posner, Klein, Summers and Buggie (1973) make the cautionary point that since alertness is accompanied by desynchronisation and alpha blocking, it is difficult to interpret changes in evoked potentials when they occur against different backgrounds.

In conclusion, it is important to point out that although the constellation of physiological changes outlined above does relate to alertness (and hence to attention) in some way, correlations between single parameters and behaviour are often small. Buser (1976), in reviewing research on neuro-physiological signs of attention, has identified a variety of problems associated with attempts to apply the principles of reductionism, functional localization and S-R reflexology in this area. In view of the myriad of interacting brain functions which must underlie attention, the absence of strong relationships is not surprising, and Vaughan and Ritter caution that the search for "simple neurophysiological correlates of attention" will inevitably be a fruitless one.

1.2.2 Alertness and Arousal

Arousal is a very broad term, generally used to describe or imply the level of cortical activation resulting from activity in the brainstem reticular formation, and ranging from a state of deep sleep through wakefulness to an extreme state of excitment and motivation. This is usually considered to be correlated with intensity level of the physiological processes of the organism, reflecting a state of sympathetic dominance, and measurable via indices such as heart rate, muscle tension, EEG activity, and metabolic rate (Naatanen, 1973).

The overall pattern of physiological responding associated with alertness, outlined in the previous section, also appears to resemble a state of general arousal, with the notable exception of heart rate, which decelerates rather than accelerates following a warning signal. An explanation for this discrepancy has been provided by Lacey (1967), and Lacey and Lacey (1970), who have demonstrated that there is a reliable deceleration of heart rate accompanying those tasks which involve the reception of simple environmental stimuli. In contrast, cognitive tasks such as mental arithmetic or reversed spelling show a concomitant heart rate acceleration. Lacey has called this phenomenon "direct fractionation," and considers that the traditional unitary concept of arousal may need to be revised, drawing a loose analogy with the way in which intelligence is considered to have a number of factors which correlate with each other to varying degrees. Leavitt (1968) and Naatanen (1973) have also argued that the unitary arousal model is inadequate, and Posner (1974) points out that while we may wish to view arousal as a general drive state, the specific requirements of information input, processing and output may all be different. Lacey argues that heart rate may enable us to identify two different types of attention, and associated with these, two different patterns of arousal indices. One appears to be a state of inward attentiveness, which is to be accompanied by an overall increase in physiological activity, and where external stimulation is rejected. In the other pattern, a state of outward attentiveness to the environment appears to be accompanied by an increase in all physiological indices other than heart rate, which shows a deceleration.

With this "intake-rejection" theory, Lacey claims that cardiovascular activity is instrumental in controlling input from the environment, i.e., it provides a mechanism for shutting out or attenuating new input while cognitive processing takes place. However, Obrist, Webb and Sutterer (1969), Kahneman (1973), Elliott (1976) and Pribram and McGuinness (1976) all propose that heart rate changes merely indicate central inhibitory processes which facilitate input and output, rather than determining how the system functions. Additional related evidence which tends to support the latter view comes from Lansing, Schwartz and Lindsley (1959), concerning alpha blocking following a warning signal. In their control condition Lansing et al. presented stimuli to subjects whenever spontaneous alpha blocking was observed. They found no relationship between reaction time and degree of spontaneous blocking. Thus it can be argued that the alpha blocking observed following presentation of the warning signal may not have been causal in reducing reaction time, but rather that both were the result of another factor, i.e., the presentation of the warning signal itself.

In summary, the physiological correlates of alertness appear to be similar to those which reflect a general state of arousal, along with an enhanced receptiveness towards external stimulation. As such, theoretical predictions about changes in behaviour under arousal should also be testable by manipulating alertness. This possibility is examined further in section 1.4.1.

1.2.3 The Locus of Alertness

Mowrer (1941) showed that expectancy, defined in terms of a bias towards a particular stimulus class or set, need not have any peripheral or muscular concomitants. In his experiments, stimuli were always presented in the same spatial location and in the same modality, and only one response was required regardless of the stimulus presented. In such a paradigm, the effect of stimulus probability upon reaction time which Mowrer found cannot be explained by differential peripheral muscular adjustments. This implies that mental set or selectivity can be developed as a central process, without the need for a peripheral explanation. Alertness is a rather more general and non-specific form of attention than mental set, and as already discussed in section 1.2.1 (physiological correlates), is accompanied by a number of physiological changes. However, there is considerable evidence to indicate that alertness is in fact also a central phenomenon.

Botwinick and Thompson (1966) recorded electromyogram (EMG) onset times in addition to reaction times, and found that alertness only affected the time between stimulus onset and appearance of the EMG response. Motor times from EMG to response were unrelated to warning interval duration. Frowein and Sanders (1972) have also found that movement time, as distinct from overall response time, is independent of foreperiod duration. The conclusion from these studies is that alertness does not affect motor processes. Further evidence in support of this view comes from Karlin (1970), who found a relationship between alertness and CNV even when overt motor responses were not required, and from Mo and George (1977), who have found an effect of foreperiod duration upon time estimation accuracy, a judgement which would appear to have no motor component. Requin, Bonnet and Semjen (1977) have also observed that spinal reflex responses do not reflect biases in response probabilities, suggesting that preparatory adjustments occur at an earlier stage of information processing. All of this evidence, in conjunction with the distinction already drawn in section 1.2.1 between orientation and expectancy waves, implies that orientation reflects alertness, and expectancy reflects motor preparation.

Warning intervals as short as 100 ms. have been shown to improve both detection performance (Klein and Kerr, 1974) and reaction time (Bertelson, 1967). This 100 ms. interval is too short for either binocular convergence or a visual saccade to influence performance, since the response latencies of these two systems are approximately 160 ms. and 200 ms. respectively (Robinson, 1968). It may however be noted in passing that when used as a response measure, visual saccade latency is reduced when the test stimulus is preceeded by a warning signal (Cohen and Ross, 1977). Attempting to eliminate any possible effects of "receptor inefficiency," Leavitt (1969) employed a visual fixation point and an illuminated background, and still found that a warning signal produced an improvement in number estimation accuracy, for tachistoscopically presented stimuli. Ross and Ross (1977) have also shown that a warning signal can facilitate eye-blink conditioning in both auditory and visual modalities, further ruling out eye movements as an explanation for the effects of alertness. Thus the effects of alertness cannot be ascribed to visual peripheral adjustments.

On a more general level, Lansing, Schwartz and Lindsley (1959) argue that out of a total observed mean reaction time of 280 ms., basic physiology suggests that about 200 ms. of this must be taken up with central integration activity, and the remainder with peripheral processes. They found that alertness produced a reduction in reaction time of 74 ms., and therefore concluded that the alertness effect must be primarily central in nature.

A related area of research, which also suggests that the effects of alertness are mediated centrally, is that in which an additional stimulus (known as the accessory stimulus) is presented at the same time as the test stimulus, but to which a response is not required (see Kantowitz, 1974, for a review). A number of investigators have found that when the accessory stimulus is auditory and the test stimulus is visual, reaction time to the test stimulus is reduced, when compared with reaction times to the test stimulus on its own (Bertelson, 1967; Bertelson and Tisseyre, 1968; Davis and Green, 1969). This phenomenon is known as immediate facilitation, and appears to be asymmetrical in that a visual accessory does not facilitate responses to an auditory stimulus (Nickerson, 1973; Sanders, 1972), ruling out the argument that it might simply be energy integration across the sensory modalities which produces the reduction in reaction time. An alternative explanation proposed by Posner, Nissen and Klein (1976) is that auditory stimuli are more alerting than visual stimuli, and thus the facilitation is most probably due to the alerting effect of the auditory accessory, even though it is presented simultaneously with the test stimulus. Support for this comes from Gaillard (1976), who found that alertness, as indicated by the amplitude

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In conclusion, it would appear that the mechanisms whereby alertness influences behaviour are central in nature, even though there are a number of physiological measures which provide a loose indication of the operation of these mechanisms. Pachella (1974) however argues out that reaction time techniques enable psychological processes to be examined, and deductions to be made about mental processes which need not have any external physiological manifestations whatsoever. Thus, response times, and response accuracy where appropriate, should be suitable measures to employ in attempting to study alertness in general, and in testing specific models of alertness, whether or not these models have a physiological basis.

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1.3 Research Relating to Alertness

1.3.1 Historical Perspective

James (1890) observed that one effect of attention was to reduce reaction time. He also noted that voluntary attention can only be sustained for a few seconds at a time. This fluctuation of attention over time has been labelled the "attention wave," and its effects on simple reaction time were investigated by Breitweiser (1911). Using a range of warning intervals from one to ten seconds, he found that the fastest reactions were obtained following two or three seconds warning. When attention was occupied by performing mental arithmetic both before and after presentation of the warning signal, the effect vanished. This implies that active or voluntary attention is involved in the facilitation of reactions by a warning signal.

Woodrow (1914) endeavoured to "measure attention" by varying the warning interval from one to 24 seconds in a simple reaction task. He found a minimum reaction time at the two second interval, rising greatly to a maximum at the 24 second interval. The magnitude of these differences was much greater than those found by Breitweiser, probably because Breitweiser used a design in which a different warning interval was used on each trial (mixed blocks), whereas in Woodrow's experiments, blocks of trials involving the same warning interval were presented together (constant blocks). When Woodrow tried to replicate Breitweiser's mixed blocks design he found no differences, over a range of intervals from four to 24 seconds. Woodrow concluded that unpredictability of the foreperiod duration in the mixed blocks design caused less "adaptation of attention" to any specific foreperiod, thereby eliminating the relationship between reaction time and foreperiod found in the constant blocks design.

The constant blocks paradigm of Woodrow can be criticised on two points. Firstly, a simple reaction time task using a fixed warning interval over a series of trials is more of a time estimation task than a reaction task, and Woodrow himself (1951) has subsequently shown that estimation of short intervals is more accurate (and hence more predictable) than estimation of long intervals. Secondly, Woodrow always used the same sequence order for presentation of blocks, thereby confounding practice effects with those of his independent variable. The problems associated with constant block designs can be avoided by using appropriately balanced orders of presentation, and by measuring choice reactions instead of just simple reactions. The alternative solution of using mixed blocks of simple reactions is prone to problems relating to the range of warning intervals employed and to stimulus onset predictability. These topics will be examined in greater depth in the next section.

In his investigations into the time taken up by cerebral operations, Cattell (1886) looked at the differences between foreperiod ranges of 0.75 to 1.25 seconds, 0.75 to 2 seconds, and 0.75 to 15 seconds in a simple reaction task. The manner in which these intervals were distributed is unspecified, and appears to have been at the whim of the experimenter. The shortest range of intervals produced the fastest reactions, but this may well have been an effect of range rather than an effect of warning interval per se, and so no firm conclusions can be drawn from these results.

Using a somewhat different paradigm to those discussed so far (and for the period, relatively sophisticated timing apparatus), May (1917) examined the influence of warning intervals, ranging from zero to 0.88 seconds, on a task which he describes as "controlled association." In these experiments, a first stimulus specified the task set or decision rule to be used, e.g., subordinate, opposite, etc., as well as acting as a warning signal. The test stimulus was then presented, and the subject made an appropriate response according to the given rule. In such a paradigm, not only does generalised alertness build up during the warning interval, but selectivity towards the stimulus-response set also develops. A direct parallel can be drawn here with the more recent letter matching experiments of Posner and Boies (1971), in which the first of a serially presented pair of letters serves as both a warning and as a template for comparison with the second letter. In line with Posner and Boies' results, May found that response times were fastest at the 0.5 second interval. May did not distinguish between the development of a task set and the build-up of generalised attention or alertness as did Posner and Boies, but simply concluded that preparatory set (as produced by the task set/warning signal) shortens association time by between 10 and 25 percent.

The point already made in the previous section about the physiological distinction between orientation and expectancy effects probably accounts for the apparent conflict between May's claim that 0.5 seconds is the optimal interval, and Woodrow's conclusion that it takes from two to four seconds to reach "full" attention. This merely serves to highlight the conclusion reached by Teichner (1954), in reviewing research on simple reaction time, that there is probably no single optimal foreperiod as such, in view of the great many factors which can influence simple reactions. More recent research, however, using choice reaction and detection paradigms (e.g. by Poulton, 1950; Davis, 1959; Karlin, 1959; Leavitt, 1968, 1969; Klein and Kerr, 1973; Posner and Boies, 1971; Gottsdanker, 1975) has suggested that a foreperiod of about half a second appears to be consistently optimal, when extraneous factors such as foreperiod distribution and range are appropriately controlled for. It is to an examination of these factors which we now turn.

1.3.2 Range Effects, Expectancy and Preparation

With the advent of behaviourism in the 1920s, research into attention fell out of favour, and there appear to have been few publications relating to alertness and the effects of warning signals for several decades. However, in the 1950s several investigations were carried out into the manner in which simple reaction times were dependent upon the range and variability of the warning intervals used in such experiments. Klemmer (1956) observed that simple reaction time was an increasing function both of the mean warning interval for a given range, and also of the variability or actual size of the range. Since reaction time had been shown by Hyman (1953) to be a function of stimulus uncertainty, Klemmer (1957) plotted his reaction times as a function of time uncertainty (in units of information), and obtained a linear relationship. His information measure of time uncertainty was a combination of stimulus predictability or expectancy, with an allowance for the failure of time estimation at the longer intervals.

Karlin (1959) and Drazin (1961) confirmed Klemmer's finding that simple reaction time was a function of foreperiod variability, and also showed that within a specific block of trials or range of intervals, individual reaction times were fastest at the longer intervals and slowest at the shorter intervals. This latter result is again consistent with the view that reaction times are a function of stimulus uncertainty: in a standard simple reaction experiment, all foreperiods are of equal frequency, and so on any given trial, as time passes, the conditional probability of stimulus occurrence increases. In theory, the conditional probability of stimulus occurrence is unity at the maximum foreperiod.

This expectancy model is based purely upon stimulus predictability as the prime determinant of simple reaction time, expectancy being defined by Thomas (1970) as "the conditional probability of stimulus occurrence," and more simply by Naatanen and Merisalo (1977) as "subjective stimulus probability." It also assumes that the experimental subject is capable of developing a model of the temporal properties of the situation, and can make use of this in judging the immediate probability of stimulus occurrence. Karlin (1966) and Granjon and Reynard (1977) have shown that subjects are in fact capable of doing this, and the ability to estimate probabilities across time has also been confirmed more directly by Robinson (1964) using tracking methods, and in a variety of probability learning situations (reviewed by Jones, 1971). From an extensive series of experiments, Elliott (1973) concluded that for any given central foreperiod value, simple RT was a direct function of foreperiod range, and for a given range, RT was an inverse function of central value. Neisser (1976) elegantly summarises the manner in which expectancy (and set in general) influences behaviour by describing it as a form of "perceptual inertia."

Additional support for the view that expectancy plays a role in determining simple reaction time comes from a variety of sources. Sanders (1965) and also Breitweiser (1911) have found that when secondary tasks such as reading or mental arithmetic are introduced between trials or during the warning interval, the tendency for reaction times to reflect the conditional probability of stimulus occurrence is reduced or eliminated. Sanders interpreted this as evidence that subjects normally use this time for general preparation, which might consist of development of the model of expectancy and prediction of when the next stimulus is due. A complementary finding to this is that the inverse relationship between reaction time and foreperiod duration is enhanced when additional temporal information (e.g., a regular click) is presented during the foreperiod (Granjon, Requin, Durop and Reynard, 1973; Requin, Granjon, Durop and Reynard, 1973). A relationship between simple reaction time and conditional stimulus probability based on the foreperiod distribution has also been observed in monkeys (Beaubaton and Requin, 1973), in cats (Macar, Vitton and Requin, 1973), and in pigeons (Keller and van Der Schoot, 1978).

In an attempt to test this expectancy model to the limit, several investigators have tried to "stabilize psychological expectancy," by constructing presentation schedules such that the probability of stimulus occurrence is independent of time elapsed since presentation of the warning signal. Schedules of this type are known as Bernoulli sequences (Feller, 1957), but are more commonly referred to in the psychological literature as non-aging foreperiod distributions, in the sense that as the foreperiod gets longer, stimulus probability does not increase, or age. These distributions contain more short warning intervals than long ones, and so from the point of view of the subject, elapsed time since the warning signal no longer gives any information as to stimulus probability, a compared to a standard rectangular, or aging, distribution.

With a non-aging distribution of foreperiods ranging from 250 ms. to 32 seconds, Nickerson and Burnham (1969) found that responses at the 250 ms. foreperiod were fastest, and those after 32 seconds were slowest. This represents a reversal of the relationships found by Klemmer, Drazin and Karlin, who all used aging distributions, and suggests that expectancy can indeed be manipulated by altering the distribution of warning intervals. Naatanen (1970a, 1971) was also led to test the expectancy model by using non-aging distributions, after he had observed that the inverse relationship between simple reaction time and foreperiod duration was only present in mixed block designs, and not in constant block designs. His results showed that over a non-aging distribution of warning intervals from 1 to 5 seconds, there was no relationship between warning interval and reaction time, again providing confirmation of the expectancy hypothesis.

Nickerson (1967) and Nickerson and Burnham both measured reaction times using non-aging distributions of foreperiods from 25 to 250 ms., and found a minimum reaction time at the 250 ms. interval. They argued that since they had stabilised expectancy across the range of foreperiods, then the differences in reaction time observed must have another cause. (Additional support for their claim of stabilised expectancy came from the incidental finding that anticipatory responses were constant across the foreperiod range.) Nickerson suggested that reactions were being delayed at foreperiods of less than 250 ms. because of psychological refractoriness (the term coined by Telford (1931) to describe the phenomenon where the first of two successively presented stimuli produces a delay in the response to the second stimulus). However, a more likely explanation is that the minimum reaction time found by Nickerson at the 250 ms. warning interval actually indicates facilitation of simple reaction time, resulting from the build-up of preparation, or alertness, during the foreperiod.

Evidence in favour of this latter explanation comes from the observation that refractoriness does not occur, or is very much reduced, when the first of the two stimuli does not require a response, i.e., when it is effectively just a warning signal (Davis, 1959; Bertelson, 1967; Bertelson and Tisseyre, 1969). Some authors have in fact argued that it may be possible to account completely for psychological refractoriness simply in terms of the time taken to prepare for stimulus input (Poulton, 1950; Rabbitt, 1969,1980; Rabbitt and Vyas, 1980).

Bertelson (1967) was aware of the difficulties outlined above which are inherent in using simple reaction times to examine the time course of preparation (his expression for the build-up of alertness). He advocated the use of choice reaction paradigms and blocks of trials during which the warning interval was kept constant. In this way, there would be little or no uncertainty about when the stimulus would occur, so alertness could develop and its effects be observed without being confounded with expectancy phenomena. An earlier experiment by Bertelson and Boons (1960) had already indicated that preparation need not be specific to a particular stimulus or response. By presenting a choice reaction task under prepared or unprepared conditions (i.e., constant 0.5 second foreperiod or variable foreperiod, mean 2.9 seconds), they found that preparation could reduce choice reaction time. Bertelson obtained similar results over a range of warning intervals from zero to 300 ms., finding the minimum reaction time and maximum error rate at around 100 to 150 ms. The conclusion to be drawn from these results is that some efficient yet non-specific preparation can be done even when the nature of the stimulus and response are not known.

Bertelson and Tisseyre (1968) replicated the above findings and in addition examined choice reaction time using blocks of trials in which different warning intervals were mixed (in a rectangular distribution). They found no differences in the shape of the reaction time/warning interval relationship between this condition and the constant blocks condition. Their results suggest that while expectancy may be involved in a mixed blocks design, it does not contribute significantly towards the choice reaction time. Furthermore, with such a short range of foreperiod durations (zero to 300 ms.), Bertelson and Tisseyre argue that it is always in the subject's interests to begin to prepare immediately upon receipt of the warning signal, and that an expectancy-based strategy would be inappropriate. Support for this view comes from Alegria (1974) and Gottsdanker (1975), who have shown, by embedding catch trials within short foreperiod paradigms, that subjects are unable to maintain a state of preparedness for more than about one second. It seems likely then, that the expectancy hypothesis only becomes appropriate at longer foreperiods and wider ranges, where the subject can make use of the temporal properties of the sequence of intervals to predict when best to prepare to process the stimulus.

In conclusion, these studies have shown that alertness has a preparation effect which is distinct from expectancy, and which can typically be observed as a reduction in choice reaction time at foreperiods of less than one second. However, in mixed block designs with foreperiods greater than one second, subjects are liable to attempt to defer their preparation until expected stimulus occurrence time, resulting in alertness being confounded with expectancy. This appears particularly to be the case in simple reaction paradigms, unless expectancy is explicitly controlled for by means of non-aging warning interval distributions.

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1.4 Theories of Alertness

1.4.1 Arousal Theory and Alertness

In the light of the evidence presented in section 1.2.2 that alertness exhibits a physiological response pattern similar to that found in aroused subjects, it might be expected that theories of arousal should also be applicable to the investigation of alertness. This section presents a general review of arousal theories of behaviour, and the predictions which can be made as a result about the effects of alertness.

An inverted-U function relating performance to arousal has been proposed on the basis of empirical findings by a number of investigators (e.g., Hebb, 1955; Stennett, 1957; Malmo, 1959, Duffy, 1962). The central feature of such a view is that for every behaviour there is an optimal level of arousal at which performance is best, and that performance will be inferior if arousal is either below or above this optimal level. Easterbrook (1959) has provided an explanation for this by stating that increases in arousal act consistently to reduce the ranges of cues used by an organism in performing a task. At first irrelevant cues are dropped out and performance improves. Further increases in arousal however, result in the ignoring of cues relevant to the task, thereby producing a deterioration in performance. Walley and Weiden (1973) extended this notion by describing a neurophysiological model in which cognitive masking of simultaneous inputs is a result of lateral inhibition, and the extent to which this happens is a function of arousal level. These authors however suggest the possibility of a regulatory mechanism whereby the self-defeating process of masking out relevant cues at high arousal levels can be checked.

A number of criticisms of the inverted-U model have been made, and alternative models have been proposed to account for the observed data. Broadbent's (1971) interpretation is more in terms of changes in signal detection. He suggests that as arousal level rises the probability of missing a signal falls, but the probability of making an error rises as a result of less cautious behaviour. Hence there is an optimal level of arousal where these two factors balance and overall performance is best. A logical extension of this view would seem to be that the exact shape of the relationship between performance and arousal level will be a function of the response payoff matrix, and need not necessarily show an inverted-U shape. In a slightly different vein, Naatanen (1973) argues that the inverted-U function is an artifact of experimental procedures which cause a change in the direction of attention, away from the task and towards the stimulation being used to induce arousal. This may, for example, be loud noise, exercise, muscular tension, or some other form of distraction. Naatanen presents evidence which suggests that general behavioural efficiency more probably increases simply as a negatively accelerated function of arousal. A useful analogy for attention in this context is that of a light beam, which can have both direction and breadth (Herdandez-Peon, 1964; Wachtel, 1967). Arousal may produce a highly focussed "beam" of attention, but as Mandler (1979) suggests, the arousing agent itself may be distracting and cause the beam to be directed away from the task at hand.

Loud noise has long been known to raise physiological arousal level (Freeman, 1939; Glass and Singer, 1972), and the results from a number of studies on tracking, monitoring and observing have suggested that this noise-induced arousal has a tendency to focus attention towards the more central aspects of the task (Hamilton and Copeman, 1970; Finkelman and Glass, 1970; Hockey, 1970a,b, 1973). Hockey has also shown that this focussing was in favour of those components of the task which had the highest priority or probability, rather than just those stimuli physically located in the centre of the display. Poulton (1978a,b) however has warned that some of the observed effects of noise may be due to artefacts such as masking of cues by the noise, and order effects due to asymmetric transfer between conditions. In addition, some authors have failed to replicate Hockey's results (Forster and Grierson, 1978; Loeb and Jones, 1978), although this may have been because of differences in the tasks employed or in the type of noise used; Hockey himself has pointed out that task variable is a significant factor in accounting for the discrepancies found relating to noise effects.

This hypothesised inter-relation between attentional selectivity and arousal has been observed in a variety of other paradigms not involving loud noise. Anxiety (Wachtel, 1968), electric shock (Bacon, 1974) and task complexity (Bartz, 1976) have all been used as a means of inducing arousal, and focussing or "funnelling" of attention has been observed as a result. Thus, subject to the caveats given by Naatanen, Poulton and Mandler about the possible side effects of the methods used to induce arousal, it would appear that there is considerable support for the basic claim of arousal theory that level of arousal tends to be correlated with a state of focussed attention.

A number of authors (e.g. Kahneman, 1973; Keele, 1973; Posner, Klein, Summers and Buggie, 1973; Walley and Weiden, 1973) appear to regard the presentation of a warning signal simply as a convenient way of producing a short term, phasic increase in arousal level, and the physiological evidence reviewed in section 1.2.2 supports such a view. This generally results in an improvement in performance, either in terms of speed (Bertelson and Tisseyre, 1969; Leavitt, 1968), or accuracy (Klein and Kerr, 1974; Leavitt, 1969). In cases where speed and accuracy have both been reported, a reduction in reaction time usually appears to be accompanied by an increase in errors (Keele, 1973; Posner et al., 1973), in line with Broadbent's view of arousal as producing fast but risky responding. The prediction of arousal theory that alertness should increase attentional selectivity by focussing attention onto more salient task features and away from irrelevant ones, possibly manifesting itself in an inverted-U relationship with performance, does not appear to have been tested directly. Bertelson and Barzeele (1965) provide some indirect evidence in support of this view, but the results of Holender and Bertelson (1975) do not show any indication of selective attention being caused by alertness. In both of these experiments however, the use of long foreperiods leads to problems of interpretation due to the expectancy effects discussed in section 1.3.2.

1.4.2 The Early-Sampling Model of Alertness

It is relevant that in both of the studies cited in the previous section in which accuracy was improved by alertness, the stimuli were only presented for very short durations. Leavitt (1969) used a number estimation task in which stimuli were presented tachistoscopically for 20 ms., and Klein and Kerr (1974) used a signal detection paradigm in which the signal was displayed for 2 ms. and then masked after another 36 ms. Posner, Klein, Summers, and Buggie (1973) have pointed out that if alertness causes subjects to respond faster to the decaying information from a briefly presented stimulus, then they may be able to base their decisions on better quality information, and so not only respond faster, but also be more accurate. Neither Leavitt nor Klein and Kerr measured reaction times along with accuracy, but tentative support for Posner's view comes from Fuster (1958), who found that when arousal level in monkeys was increased by direct reticular stimulation, the monkeys were both faster and more accurate when responding to briefly presented stimuli.

Posner and Boies (1971) found that when one of a pair of letters in a letter-matching task was presented 500 ms. before the other one, it reduced matching reaction time. Furthermore, this reduction appeared to be independent of whether or not subjects were alerted when the first letter was presented, and the combined effect of alertness and of presenting the first letter in advance was equal to the sum of their separate effects. By regarding the development of selectivity to the first letter as synonymous with its degree of encoding, Posner and Boies concluded that alertness neither facilitated nor interfered with encoding.

Taking this in conjunction with the conclusions of Posner et al. about the effects of alertness on performance with brief stimuli, Posner (1974) proposed a model of alertness in which the only effect of alertness was to cause the information building up in a sensory/memory system to be sampled and acted upon earlier by the decision-making processes. This provides a parsimonious mechanism, in accordance with Broadbent's (1971) idea of fast but risky responses which in some instances may be more accurate than slow responses. In particular, Posner's model predicts that accuracy scores should show an interaction between alertness and stimulus duration, in which responses to long duration stimuli should be less accurate when subjects are alert, whereas at short durations, alerted subjects' responses should be both faster and more accurate. Posner et al. (1973) attempted to test this model by looking at responses to stimuli of 40 and 400 ms. in duration under alerted and non-alerted conditions. The error data showed significant main effects of both alertness and duration, but no interaction, although sign tests suggested that there was a reduction in errors due to alertness at the 40 ms. duration. While this provides tentative evidence in support of Posner's hypothesis, it is by no means conclusive. The studies of Klein and Kerr, Leavitt and Fuster already mentioned only examined short duration stimuli, without comparing these against longer duration controls, and therefore there does not appear to have been any satisfactory test of Posner's proposed alertness/duration interaction.

1.4.3 Effort Theory of Alertness

An alternative account of how alertness might affect the accuracy of responses to brief stimuli has been proposed by Kahneman (1973). His view is that alertness produces a surge of effort which is directed towards the task, and this is reflected by concomitant changes in physiological arousal indices. This does not necessarily just improve the overall effectiveness with which the task is performed, but it also alters some aspects of the subject's strategy in dealing with the task. Kahneman argues that alertness will improve the encoding process if there is room for improvement, i.e., where a stimulus is subject to perceptual error. Thus, if a stimulus is brief or weak, and errors are likely to occur, alertness may improve encoding and thereby improve overall performance.

This is consistent with the stance taken by Norman and Bobrow (1975) that speed-accuracy tradeoffs occur when a system is limited by its available resources, whereas genuine improvements in performance may be observed when the operation of the system is limited by the available data, and additional resources can be brought to bear on the task. Specifically, Kahneman states that given the appropriate conditions, alertness may improve encoding of sensory input, and thereby improve performance. This derives from his view that perceptual processes require, and must compete for, effort, which can be allocated flexibly from a limited capacity pool according to particular needs.

A prediction of such a model is that alertness should be capable of producing genuine improvements in performance in situations other than those where brief stimuli are used; it just so happens that paradigms which use brief stimuli, because they are data-limited, are highly suitable for observing perceptual errors. No attempts appear to have been made to examine the effects of alertness on tasks where the stimuli are not of very brief duration but are nevertheless still data-limited and thus prone to perceptual errors.

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1.5 Research Aims and Plan

From the foregoing examination of the literature, it would appear that over and above the readily observable effect of alertness upon reaction time, there are a number of testable predictions concerning alertness, and attempts to investigate these were carried out in the following manner.

The first experiment to be described was an attempt to control for expectancy in a simple reaction time paradigm by using a non-aging foreperiod distribution, in order to determine the validity of Bertelson and Tisseyre's (1968) claim that the role of expectancy should be negligible at foreperiods of less that one second. This technique should also produce a "pure" alertness/simple reaction time function.

Arousal theory predicts that alertness should be capable of altering attentional selectivity in a manner analogous to the focussing effects of other arousers such as loud noise, as discussed in section 1.4.1. The problems of distraction and direction of behaviour which were pointed out should be absent in the alertness paradigm. Experiment 2 was designed to look at the focussing hypothesis by examining the inter-relationship between alertness and stimulus probability and their effects upon choice reaction time.

Experiment 3 was designed as a replication of the attempt by Posner, Klein, Summer and Buggie (1973) to produce enhanced performance with alertness at short duration stimuli, compared with impairment or no change at longer durations. In addition, an analysis of reaction time distributions was carried out as part of this experiment in order to establish a baseline relationship between speed and accuracy (at both short and long durations), independent of alertness manipulations, which could then be compared with the alertness effect.

Kahneman's (1973) prediction that alertness should not be restricted to those tasks which only use very brief duration stimuli was tested in experiments 4 and 5. Here, stimulus discriminability was manipulated such that, even at relatively long durations the task remained difficult, and so was data-limited and error prone. Observation of improvements in performance due to alertness in this situation would be evidence in favour of Kahneman's view of alertness. Experiment 5 also included an attempt to reproduce the basic alertness-reaction time function within this discrimination paradigm.

The most general interpretation of Kahneman's effort theory is that alertness facilitates the allocation of limited resources in a manner which is most appropriate for the task to be carried out. A post-hoc analysis of the results from experiment 4 suggested that this facilitation might extend beyond the task itself and make subjects more responsive to the context within which the task is presented, and that this might be reflected in an increased shift in speed-accuracy tradeoff due to alertness. Experiment 6 attempted to test this notion by presenting the same task in different settings or contexts, and examining the interaction between alertness and context.

In experiment 7, speed-accuracy tradeoff was manipulated directly by means of instructions to the subjects. The prediction here was that alertness should enable subjects to conform more closely to the instructions given by the experimenter, in the sense of increased efficiency of resource allocation to particular task attributes.

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ALERTNESS AND THE
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Section 2. The Experiments.

2.0 General Methodology

2.0.1 Laboratory Equipment

All the experiments described in this thesis were run using a Digital Equipment Corporation PDP-11/45 computer, running under the manufacturer's DOS operating system, to control stimulus presentations and to record subjects' responses. In addition the computer was used to generate and randomize presentation schedules, and to calculate summary statistics such as reaction time and percentage correct for each subject. The actual stimuli were presented to subjects on the screen of a Digital Equipment Corporation GT40 graphics display computer which was controlled by the PDP-11/45. Subjects used the keyboard of the GT40 to make their responses, which were transmitted back to the PDP-11/45 for processing. All the display details for a particular experiment were stored in the GT40 prior to the actual experimental run, so that very little information needed to be passed between the two computers during the experiment, thus allowing for accurate timing to the nearest millisecond.

The computer programs which controlled the sequence of events during an experiment were written by the author in the standard Fortran IV programming language. Measurement of timings from the computer's real-time clock, and control of the GT40 graphics display were done via a set of special purpose routines which could be called from a Fortran control program, and which were written in machine language by Mr. Charlie Foster, a computer programmer in the Department of Psychology at the University of Stirling. The general structure of these programs was similar for all experiments and consisted of four main phases as follows.

Phase 1: Description of experimental procedure.

Here basic parameters such as duration of stimuli, number of trials per block and per condition , stimulus codes and data storage arrays were defined by the experimenter. Randomly ordered presentation schedules appropriate to the experiment were generated and stored.

Phase 2: Stimulus display description.

Each individual display or picture to be used in the experiment was described in terms of lines and characters, etc. These consisted of: fixation point, stimulus markers, mask, stimuli, feedback messages, start and end of block messages, etc., depending on the particular experiment. The picture descriptions were then transmitted to the GT40 where they were stored ready for use in Phase 3, at which time they could be called up simply by number.

Phase 3: Actual data collection.

Here the various pictures generated in Phase 2 were presented to the subject in accordance with the parameters set up in Phase 1. Responses and their times were recorded and stored for subsequent analysis. During this phase the program checked for various errors such as the subject failing to respond within a given time (usually 1 or 1.5 seconds), or any other violation of the timing schedule of the experiment, which might indicate equipment failure. Warning messages were printed on the experimenter's console so that appropriate action could be taken where necessary.

Phase 4: Data analysis and summary.

In most of the experiments, a partial results summary was printed on the console of the computer at the end of each block of trials, allowing the progress of the experiment to be monitored. When data collection was complete, a full results summary was printed. This process was generally made simpler by storing the data in a multi-dimensional array structure which reflected as closely as possible the factorial design of the experiment. The raw data were recorded on magnetic tape for subsequent analysis where required.

Writing these programs, ensuring that they were error-free and that they could detect any odd conditions or subject errors, took up a significant proportion of available laboratory and computer time. However, once they had been written, the actual experimental sessions could be run quickly and easily with a minimum of experimenter intervention, and minor modifications suggested by pilot runs could readily be added. An example of one of the computer programs used is shown in the appendix.

2.0.2 Subjects and the Test Environment

The subjects who participated in these experiments (apart from Experiment 3c, for which the author acted as subject) were undergraduate Psychology students at the University of Stirling. This was a course requirement for these students. Apart from Experiment 4a, which lasted for about an hour, all sessions were about 30 minutes in duration, including instructions and explanations. Subjects were tested individually in a small cubicle adjacent to the computer room with the GT40 display screen and response keyboard on a table in front of them. Distance from the screen to the subject's eyes varied from about 50 to 100 cm., depending upon individual seating posture. The widest display used was 6 cm. across (Experiments 2 and 3), so this subtended a maximum visual angle of about 3 to 6 degrees. As visual acuity was not a relevant issue in these experiments, this variation was not considered important, but for consistency, subjects were always asked to maintain the same posture throughout the experiment.

Once seated, the subject was given a sheet of instructions describing the task, and was then shown a few practice trials to ensure that he/she fully understood the procedure. Before starting the actual experiment the cubicle door was closed, and the subject was not disturbed for the duration of the session. At relevant times, messages appeared on the screen informing the subject of the progress of the experiment. For example, at the end of each condition the message "Press any key to continue" would be presented and the computer would wait for a response before proceeding, thus allowing the subject to rest for as long as desired. Within conditions, blocks of trials lasted only for a few minutes, with fixed rest periods of about

30 seconds between them. This was done because it was found during pilot tests that continual attending and responding to the display soon became quite tiring. During these intervals the message "End of block" was displayed. The onset of a new block or condition was heralded by presentation of a warning tone and the fixation point or markers for the experiment. Feedback was presented for 500 ms. as soon as a response had been made, both to keep the subject informed, and also because it tends to reduce variability in reaction time (Snodgrass, 1969). Using these techniques it was hoped that fatigue and boredom might be avoided and motivation sustained throughout the session.

The only way in which the experimenter could observe the subject's behaviour during the experiment was through the computer console, where partial results were printed at the end of each block, and any unusual conditions (possibly due to hardware or software problems, etc.) were logged. At the end of the session, the subject was shown his or her results and given a description of the aims of the experiment.

2.0.3 Common Design Features

In addition to the points discussed in the preceding sections, there were certain methodological details which were adopted in all of the experiments, and these merit some discussion.

The inter-trial-interval (ITI) used in these experiments refers to the time period from the end of the feedback for the previous trial up to the presentation of the warning signal for the current trial. In order that this latter event be unpredictable, the ITI must either be of fairly long duration such that the subject cannot estimate the interval accurately, or else it must vary from trial to trial. Bertelson (1967) has compared a constant (5 second) ITI condition with a variable (1.5 to 5 second) condition, and found no effect of type of ITI on the relationship between foreperiod (zero to 300 ms.) and choice reaction time. In variable inter-stimulus-interval (ISI) simple reaction time paradigms, Possamai, Granjon, Requin and Reynard (1973), Alegria (1975a,b) and Alegria and Delhaye-Rembaux (1975) have found that repeated intervals tend to produce a reduction in reaction time. However, in these experiments the ISI also acted as the foreperiod for the simple reaction task, and so was highly subject to expectancy effects, and not directly comparable with the present experiments, in which the ITI was distinct from, and preceded, the foreperiod. Thus, following Bertelson's method, and because it allowed more efficient data collection (higher average trial presentation rate), it was decided to use the variable ITI technique throughout, employing a uniform distribution of ITIs ranging from 1.5 to 5 seconds for all experiments.

Stimulus presentation schedules were generated according to the stimulus frequencies required for the experiment (usually equi-probable) and then randomly ordered. It was not considered necessary to control explicitly for stimulus repetition effects since these only tend to appear at response-stimulus intervals of shorter duration than the 2 second minimum used in the present experiments (Hale, 1967; Rabbitt, 1968; Smith, 1968).

The warning signal used in all of the experiments was a clearly audible 1000 Hertz tone of 50 ms. in duration. It has been found by many researchers that an auditory signal is more alerting than a visual signal (Bertelson and Tisseyre, 1969; Sanders and Wertheim, 1973; Sanders, 1975; Gaillard, 1976; Ponser, Nissen and Klein, 1976). In addition, presentation of the warning signal in one modality (auditory) and the test stimulus in the other (visual) reduces the likelihood of problems caused by psychological refractoriness (Davis, 1959; Davis and Green, 1969; Sanders, 1972). Approximate measurement of the sound level of the tone indicated that it was at about 60 to 65 decibels in contrast to the ambient sound level in the experimental cubicle of about 50 to 55 decibels (constant noise produced by air conditioning equipment).

The warning interval was considered to commence with the onset of the warning tone. Foley (1959) has shown that it is the warning signal onset rather than its duration or termination which determines the effective foreperiod duration. The tone was presented in all conditions, even those in which there was no warning. This means that the tone and stimulus were presented simultaneously in the zero warning interval (or non-alerted) conditions. This was done simply for consistency, and to ensure that any effect of warning interval found was genuinely due to the variation in the duration of the interval, rather than due to any potential tone/no-tone effect. The fact that the tone acted as an accessory stimulus in the non-alerted conditions, thereby possibly giving rise to a reduction in reaction time (Kantowitz, 1974), merely serves to reinforce the significance of any oberved reduction produced by manipulation of the warning interval duration.

Within-subject designs (Winer, 1962) were used in all experiments, as they were generally well suited to the types of manipulations being performed, and were also more efficient in terms of numbers of subjects and testing time required. One between-subjects comparison (Experiments 4a and 4b) suggested an interesting hypothesis, so this was re-tested as a within-subjects design. Treatment combinations were generally presented separately except where the design dictated otherwise, as in Experiments 1 and 2 which used probability schedules, or where the number of conditions was prohibitive, as in Experiment 7, where 3 stimulus durations and two warning intervals were mixed within blocks. Comparisons of mixed versus blocked designs in foreperiod research by Bertelson and Tisseyre (1968) and by Sanders (1972) have suggested that the overall pattern of results is unaffected by the design used.

Throughout the empirical work, performance accuracy is analysed in terms of percentage correct scores, and response bias in terms of percentage different scores (i.e., the discrimination response "different" rather "same"). These were chosen in preference to measures of sensitivity and bias such as the d' and ß parameters of Signal Detection Theory (Green and Swets, 1966), since there was no a priori reason for using such measures. In addition, Macdonald (1976) has found that these and similar parameters are highly susceptible to statistical artifacts at sample sizes such as those employed in the present experiments.

Computations and statistical analyses were in the main performed by digital computer, using the SPSS program package (Nie, Bent, and Hull, 1970), the BMDP program series (Dixon and Brown, 1979), and a variety of other programs written by the author and by members of the Department of Psychology at Stirling University.

- 0 -

2.1 Experiment 1

Alertness, Expectancy and Simple Reaction Time

2.1.1 Introduction

This experiment was a direct attempt to examine the effects of alertness upon simple reaction time, while trying to avoid the interference of expectancy. By using short warning intervals of less than one second in duration it should, as argued by Bertelson and Tisseyre (1968), always be to the subject's own advantage to prepare for the stimulus immediately, rather than to try and defer alertness until expected stimulus occurrence time. However, in order to ensure that expectancy has been eliminated as a contributory factor, it is necessary to use a non-aging distribution of foreperiods in which the conditional or subjective probability of stimulus occurrence is independent of foreperiod duration. Naatanen (1970a, 1971) adopted this technique but only examined foreperiods greater than one second. Nickerson and Burnham (1969) investigated non-aging ranges from zero to 250 ms. and from 250 ms. to 32 seconds, finding a minimum reaction time at 250 ms. in both cases. the present experiment covered a range from zero to 750 ms., straddling both Nickerson and Burnham's 250 ms. duration and also the 500 ms. duration already noted as being optimal in many choice reaction paradigms (see section 1.3). Two control conditions which used non-aging distributions were also presented for comparison purposes. The rationale and method of generating these distributions follows Sanders (1966,1967) and Naatanen (1970b), and is described as follows.

By manipulating the frequencies of warning intervals it is possible to produce a distribution such that from a Bayesian viewpoint, the stimulus probabilities are the same at each warning interval. To explain this consider the line labelled CONTROL in Table 1. Here the objective or actual probabilities for each warning interval are 0.25. However, because this is a sequence in time, a Bayesian model would state that if the stimulus did not occur at time 0, then it must occur at one of the other 3 times, and the probability becomes one third for these remaining intervals. If the stimulus does not occur at time 250, then it will occur at time 500 or 750, with a probability of 0.5 for each interval. Finally if it does not occur at time 500 then it must occur at time 750 with a probability of 1. Thus if a practiced subject availed himself of all the information available, his reaction times ought to drop (or age) as a function of warning interval (in theory to zero at an interval of 750). Following this logic, a non-aging distribution can be constructed such that the Bayesian probability remains constant across warning intervals (SUBJECTIVELY EQUAL condition, Table 1). Note that in order that the longest interval remains unpredictable, it is necessary to introduce some no-stimulus catch trials into the sequence.

For the purposes of this experiment, a third condition (OBJECTIVELY EQUAL condition, Table 1) was introduced, as a form of control for the possible effects of these catch trials. Thus if subjects' reaction times reflect actual objective probabilities then the Control and Objectively Equal conditions should produce "pure" alertness functions, and the Subjectively Equal condition should show reaction time as a rising function of warning interval. On the other hand, if expectancy is having an effect, then the Subjectively Equal condition should show a "pure" alertness function, the Objectively Equal condition should be a decreasing function and the Control condition should drop off to zero reaction time at the 750 ms. warning interval. In summary, unless one of these three functions is flat, alertness can be said to have an effect independent of stimulus predictability or expectancy, regardless of the model which best describes the subjects' behaviour.

Catch trials are known to increase reaction time (Drazin, 1961; Naatanen, 1972), so it might be expected that the overall fastest reaction times should be in the Control condition. The catch trial frequencies in the other two conditions are identical, so any observed differences between these two conditions can only be ascribed to stimulus probability effects.

2.1.2 Design and Method

The three frequency distributions outlined in the introduction and shown in Table 1 were generated by computer and given different random orderings for nine subjects, each of whom participated in all three conditions in a counterbalanced design. Each condition consisted of three blocks of trials, the first of which counted as practice. On average there were 44 trials per block, the variability being due to the different frequency schedules used. Each trial consisted of the following sequence:

* During the inter-trial-interval a fixation point (a plus sign, +) was visible in the centre of the screen;
* At the end of the inter-trial-interval, the warning tone was presented;
* After the appropriate warning interval had elapsed, the stimulus (a cross, x) replaced the fixation point;
* As soon as the subject responded, reaction time feedback was given for 500 ms., and the sequence was started again for the next trial.

On trials where no response was required, the message "NO RESPONSE" appeared one second after the presentation of the warning tone, and remained for 500 ms. If the subject did not respond to the stimulus within one second, or responded prematurely (i.e., before the stimulus appeared), the messages "TOO LATE" or "TOO SOON" respectively were displayed for 500 ms. These trials were logged and later discarded from the analysis. There were very few (less than 5 percent) of these errors, and an inspection of premature responses suggested that they were probably responses to the warning signal.

Design Summary:

4 x 3 within-subjects design = 12 conditions;

Warning Interval (mixed: 0/250/500/750 ms.) x

Probability Schedule (blocked);

9 subjects, average 22 trials per condition =

198 observations per data point;

Measures: Simple Reaction Time.

2.1.3 Results and Discussion

The results are summarised in Table 2 and Figure 1. Statistical analysis showed that the effect of warning interval on reaction time was significant ($F=59.69$, $df=3,24$, $p<0.001$), as was the effect of probability schedule ($F=19.73$, $df=2,16$, $p<0.01$). The interaction between these two main effects was also significant ($F=3.87$, $df=6,48$, $p<0.01$). As none of the functions is flat, as might be expected if subjects' responses simply reflected either the objective or the subjective probability schedules, this suggests that warning interval duration is having an effect distinct from that of stimulus predictability or expectancy. Naatanen and Merisalo (1977) have shown that estimates of subjective stimulus probability (i.e., of expectancy) peak near the mid-point of the foreperiod distribution. This persists to some extent even when non-aging distributions are employed, and so it might be argued that this could account for some of the present results. However, the experiment described by Naatanen and Merisalo used longer foreperiods of around 2 seconds in duration, which are not directly comparable with the zero to 750 ms. foreperiod range used in the present experiment. In addition, the present results for the Subjectively Equal and Objectively Equal conditions are almost identical, suggesting in fact that stimulus predictability did not play a major part in this experiment, and supporting Bertelson and Tisseyre's view that expectancy is not a viable strategy at short foreperiods. Furthermore, the general bowed shape of the curves, with minima around the 250 to 500 ms. warning intervals, essentially confirms the findings of Nickerson and Burnham. Overall it appears that the warning interval or alertness effect is superimposed upon an objective rather than upon a subjective probability effect, as the control condition shows by far the greatest reductions in reaction time at the longer warning intervals.

The main difference between conditions appears to be due to the introduction of the catch trials, and this is more evident at the longer warning intervals, as indicated by the significant interaction term in the analysis. To examine this more closely, an alternative way of looking at the data was used. Figure 2 shows reaction time plotted against stimulus probability (objective) at each of the four warning intervals. This suggests that the relationship between reaction time and stimulus probability may differ as a function of warning interval.

To test this idea, linear regression of reaction time against ln(1/probability) was performed, the logarithmic transformation being used to give an information measure, as suggested by Hyman (1953). This produces slope and intercept parameters at each warning interval, and these are presented in Table 3 and Figure 3. The lower panel of Figure 3 shows that the reduction in reaction time produced by alertness, independent of stimulus probability, is greatest at the 500 ms. warning interval (F=9.89, df=3,24, p<0.001). More interestingly, the upper panel of Figure 3 suggests that the effect of stimulus probability upon reaction time is greatest at the same point at which alertness is having its greatest effect. This main effect of warning interval did not reach significance (F=2.16, df=3,24, p=0.117), but a t-test on the difference between the slope values for warning intervals 0 and 500 indicated that there was in fact a difference (t=1.915, df=8, p<0.05, one-tailed). In other words, this post-hoc analysis suggests that alertness is not only causing a reduction in simple reaction time, but may be doing so to a greater extent for high probability stimuli than for low probability stimuli. This could be interpreted as providng support for the prediction of arousal theory, given in section 1.4.1, that alertness should increase attentional selectivity by focussing attention onto more salient task features.

The overall conclusion from this experiment is that alertness produces a reduction in simple reaction time which is consistent with previous findings, and is independent of the effects of expectancy. Furthermore, attempts to control for expectancy had no effect upon the overall pattern of results, suggesting that in this paradigm which involved foreperiods of less than one second in duration, expectancy is not a significant factor. Finally, alertness appears to enhance the improvements in reaction time which subjects show to high probability signals, perhaps suggesting, in line with arousal theory, that being alert or prepared enables the individual to attend more closely to the dominant features of the task.

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Table 1 Experiment 1 (design)

Objective and subjective stimulus probabilities as functions of warning interval, under different presentation schedules.

	WARNING INTERVAL 0	250	500	750	NO SIGNAL
CONTROL:					
OBJECTIVE	.25	.25	.25	.25	
SUBJECTIVE	.25	.333	.5	1.0	
OBJECTIVELY EQUAL:					
OBJECTIVE	.171	.171	.171	.171	.316
SUBJECTIVE	.171	.206	.260	.351	1.0
SUBJECTIVELY EQUAL:					
OBJECTIVE	.25	.187	.141	.105	.316
SUBJECTIVE	.25	.25	.25	.25	1.0

Table 2 Experiment 1

Simple reaction time as a function of warning interval and probability schedule.

Warning Interval		0	250	500	750
CONTROL	Mean RT	398	313	284	289
	sd(RT)	46	29	22	35
OBJECTIVE	Mean RT	422	341	339	354
	sd(RT)	59	40	45	32
SUBJECTIVE	Mean RT	416	329	337	366
	sd(RT)	45	49	42	42

Table 3 Experiment 1

Regression of RT on ln(1/probability).

Warning Interval	0	250	500	750
Correlation, rho	.204	.650	.831	.865
Slope	40	71	99	87
Intercept	351	214	151	180

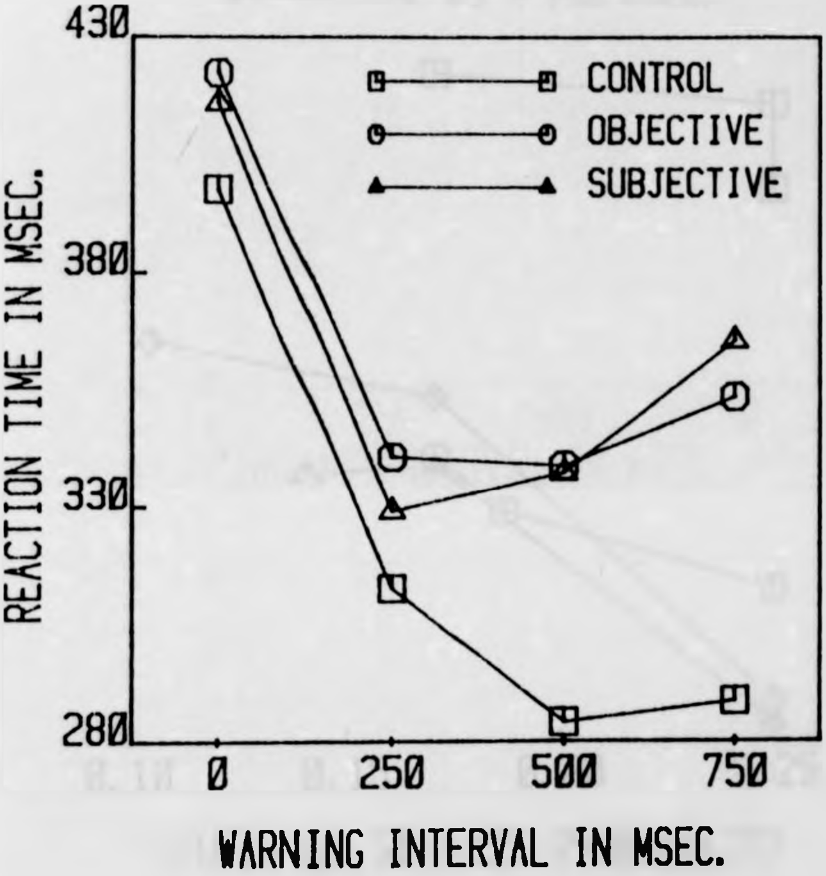


Figure 1 Experiment 1

Simple reaction time as a function of warning interval for different presentation schedules.

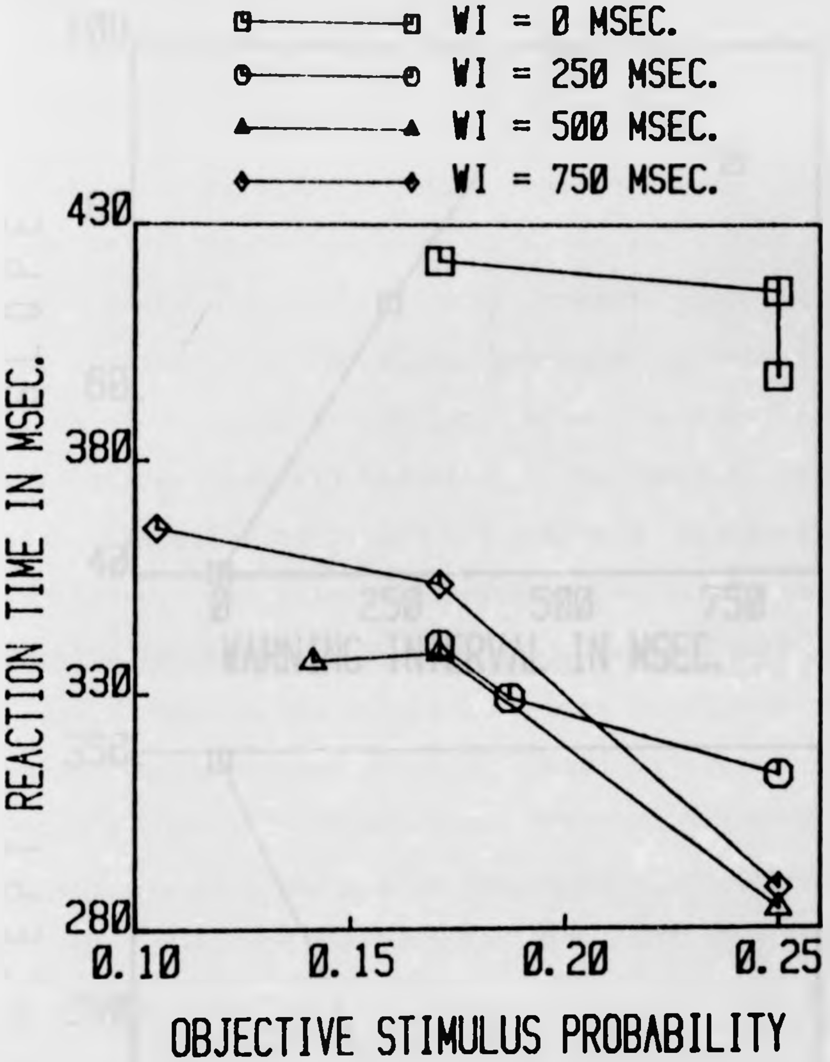


Figure 2 Experiment 1

Simple reaction time as a function of objective stimulus probability at different warning intervals.

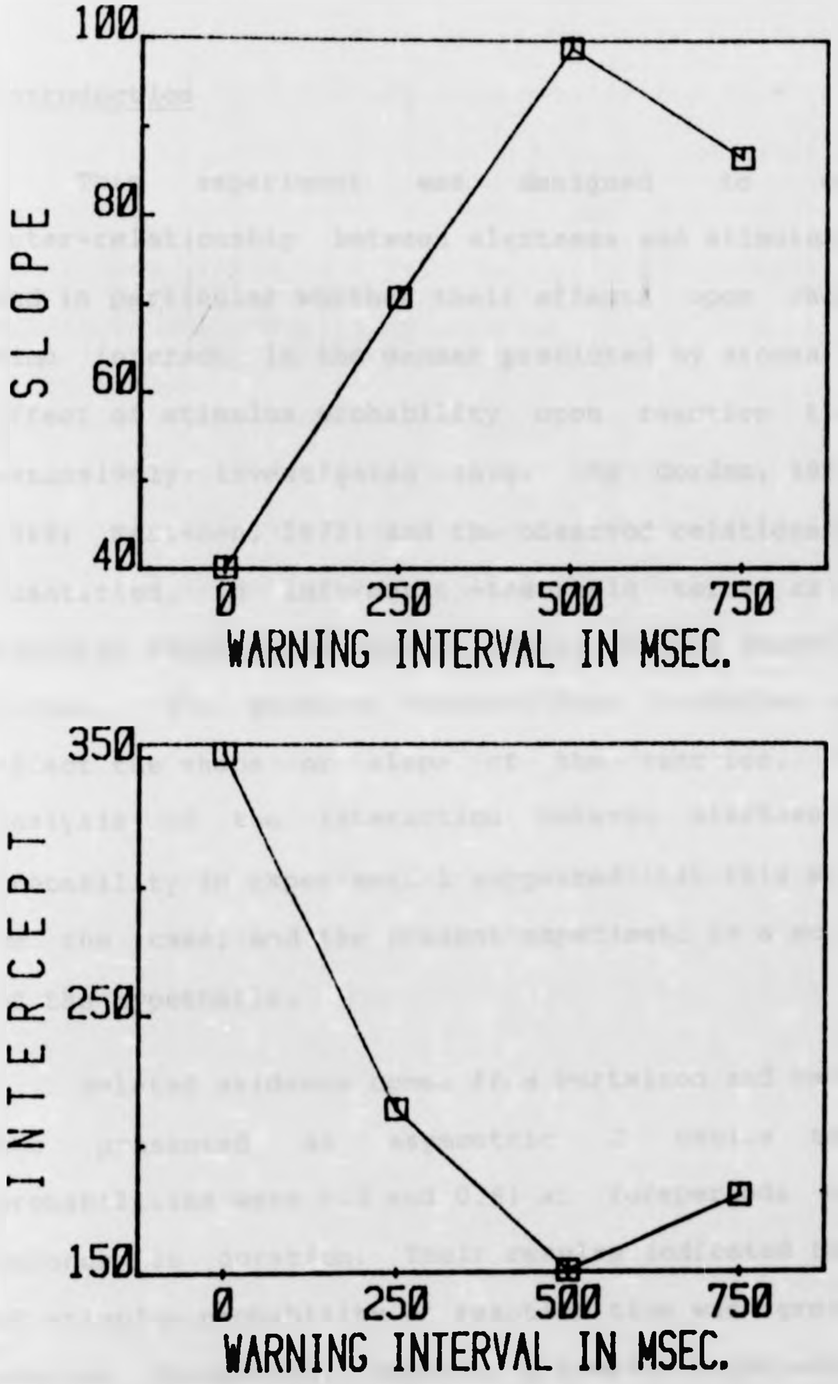


Figure 3 Experiment 1

Slope (upper panel) and intercept (lower panel) from the regression of reaction time on stimulus probability, as functions of warning interval.

2.2 Experiment 2

Alertness, Spatial Probability and Choice Reaction Time

2.2.1 Introduction

This experiment was designed to examine the inter-relationship between alertness and stimulus probability, and in particular whether their effects upon choice reaction time interact in the manner predicted by arousal theory. The effect of stimulus probability upon reaction time has been extensively investigated (e.g. by Gordon, 1967; Krinchik, 1969; Naatanen, 1972) and the observed relationship has been quantified, in information-theoretic terms as a logarithmic function (Hick, 1952, Hyman, 1953), or as a power function by Gordon. The point of interest here is whether alertness will affect the shape or slope of the function. The post-hoc analysis of the interaction between alertness and stimulus probability in experiment 1 suggested that this might in fact be the case, and the present experiment is a more formal test of the hypothesis.

Related evidence comes from Bertelson and Barzeele (1965), who presented an asymmetric 2 choice task (stimulus probabilities were 0.2 and 0.8) at foreperiods of 0.5 or 5 seconds in duration. Their results indicated that the effect of stimulus probability on reaction time was greatest at the shorter foreperiod. However, a similar experiment by Holender and Bertelson (1975) failed to show any interaction between foreperiod and probability. A problem with both of these studies is the interpretation of the long 5 second foreperiod as a non-alert condition. As already discussed in the introduction (section 1.3.2), long foreperiods are liable to be affected by expectancy, possibly giving inconsistent and therefore inconclusive results. Naatanen (1972) found no interaction between stimulus probability and foreperiod over a range from 1 to 8 seconds in duration, but this range is again too long to provide a positive test of the arousal hypothesis. By using foreperiods of zero and 500 ms., the present experiment avoids this problem, particularly since experiment 1 has shown that expectancy does not play a role at such short foreperiods.

A four-choice paradigm was chosen for this experiment since it allowed a wide range of probabilities (from 0.05 to 0.6) to be investigated simultaneously within a single sequence of trials. Alegria and Bertelson (1970) have found that the number of alternatives in a choice reaction task does not appear to influence the nature of the relationship between foreperiod and reaction time. A four-choice equi-probable control condition was also employed, since evidence has been found of finger and hand effects on reaction times in multi-choice paradigms (Kornblum, 1969, Rabbitt and Vyas, 1970).

2.2.2 Design and Method

A 2 by 2 experimental design was employed, consisting of two alerted (ie., 500 ms. warning interval) conditions, and two non-alerted (zero warning interval) conditions. One alerted and one non-alerted condition used a uniform probability distribution across the four possible stimulus locations, so the probabilities were all 0.25. The other two conditions had an unequal distribution consisting of the probabilities 0.05, 0.1, 0.25 and 0.6. In these unequal probability conditions, the actual physical positions on the screen of the various probabilities were varied across the eight subjects in a counterbalanced manner, to minimise possible key-pressing effects relating to finger position. The equal probability conditions also gave an independent means of examining any potential finger position effects which might need to be corrected for. The probability schedules were randomly ordered within blocks of 60 trials, and each subject did 3 blocks of trials in all four treatment combinations, balanced for possible order effects. The first block in each condition counted as practice.

The stimulus display consisted of a horizontal line of four marker crosses, 2 cm. apart at the centre of the screen. The stimulus was another cross which could appear above any one of these marker crosses. The first and second fingers of both hands were used by the subjects for response selection, in a straightforward one-to-one manner. The sequence of eacn trial was as follows. During the inter-trial-interval, the 4 marker crosses were displayed on the screen. The warning tone was then sounded either 500 ms. prior to, or simultaneously with, the stimulus cross (alerted and non-alerted conditions, respectively). As soon as the subject made a response, the crosses were replaced with a feedback message which was either "CORRECT" or "WRONG" for 500 ms., and the sequence for the next trial then began. If the subject failed to respond within 1.5 seconds, the warning tone was sounded, the trial was logged as a non-response, and the next trial commenced.

Design Summary:

2 x (2 x 4 within-subjects design = 8 conditions);

Alert/Non-alert(blocked) x

Probability(mixed: .05/.1/.25/.6), or

Finger Position(mixed: 1/2/3/4);

8 subjects, average 30 trials per condition =

240 observations per data point;

Measures: Choice Reaction Time, Percentage Correct.

2.2.3 Results and Discussion

Table 4 and Figures 4 and 5 show all the results of the experiment. Figure 4 shows that the finger used in response selection had no consistent effect on reaction time or on percentage correct. The only significant result from this part of the experiment was that of alertness on reaction time ($F=46.02$, $df=1,7$, $p<0.001$), as was to be expected. Alertness did not interact with finger position. These findings, along with the counterbalancing of position-probability assignments in the unequal probability conditions, ensure that this potential artefact can safely be disregarded when analysing the main results of the experiment. The overall mean reaction times and percentage correct figures from the equal probability control conditions are also plotted on Figure 5, for contrast with the unequal probability results. There were no significant differences between these and the scores for the 0.25 probability level within the unequal probability condition.

From Figure 5 it can be seen that alertness reduces reaction time at all stimulus probabilities ($F=7.33$, $df=1,7$, $p<0.05$), and that higher probability stimuli are also responded to more rapidly in both alerted and non-alerted conditions ($F=19.29$, $df=3,21$, $p<0.001$). There were no effects of alertness or probability on percentage correct. Although Figure 5 suggests an interaction between alertness and probability for reaction times, this was not statistically significant. However, the analysis of variance does not take the ordering information present in the stimulus probability variable into account, and so to perform a stronger test, regressions of reaction time on $\ln(1/\text{probability})$ were performed for both the alert and non-alert conditions, the logarithmic transformation being used as in Experiment 1 to give a measure of information (Hyman, 1953).

Mean values for the slopes, intercepts and fits of these functions are given at the bottom of Table 4. T-tests between these mean values show that there are significant differences in both intercept (t=4.151, df=7, p<0.01) and slope (t=2.759, df=7, p<0.05). The difference in intercepts reflects the main effect of alertness upon reaction time, but the difference in slopes implies that alertness does indeed have a greater effect on high probability stimuli, as hypothesised in the introduction.

The small drop in reaction time at the 0.05 probability position is consistent in 6 out of the 8 subjects who participated in the experiment, which is not quite significant on a sign test (p=0.11), so it may simply be a spurious result. Alternatively, it may be that due to the very low frequency of occurrence of this stimulus, its appearance on the screen may have had some sort of novelty effect, or it may be related to Attneave's (1953) observation that subjects tend to be conservative in their estimates of extreme frequencies. As this question is not of direct relevance to the hypothesis being tested in the present experiment, it has not been pursued further.

In conclusion, the results of this experiment show that alertness produces a greater reduction in reaction time to high probability stimuli than to low probability stimuli. In conjunction with the observed interaction between alertness and temporal probability in Experiment 1, this confirms the prediction of arousal theory that alertness should exhibit a focussing effect upon attentional selectivity.

- 0 -

Table 4 Experiment 2

RT and percentage correct - Equal probabilities

	ALERT				NON-ALERT			
Finger Position	1	2	3	4	1	2	3	4
Mean RT	485	511	491	502	546	594	565	561
sd(RT)	67	120	126	100	85	118	96	115
Mean %C	99	96	95	99	99	95	95	98
sd(%C)	2	7	4	1	2	7	6	3

RT and percentage correct - Unequal probabilities

	ALERT				NON-ALERT			
Probability	.05	.1	.25	.6	.05	.1	.25	.6
Mean RT	545	582	491	432	582	601	544	497
sd(RT)	101	123	94	108	116	111	92	89
Mean %C	89	90	95	98	95	94	98	98
sd(%C)	18	5	4	1	9	6	2	3

Regression of RT on ln(1/probability)

	ALERT	NON-ALERT
Correlation, r	.842	.757
Slope	53	39
Intercept	417	487

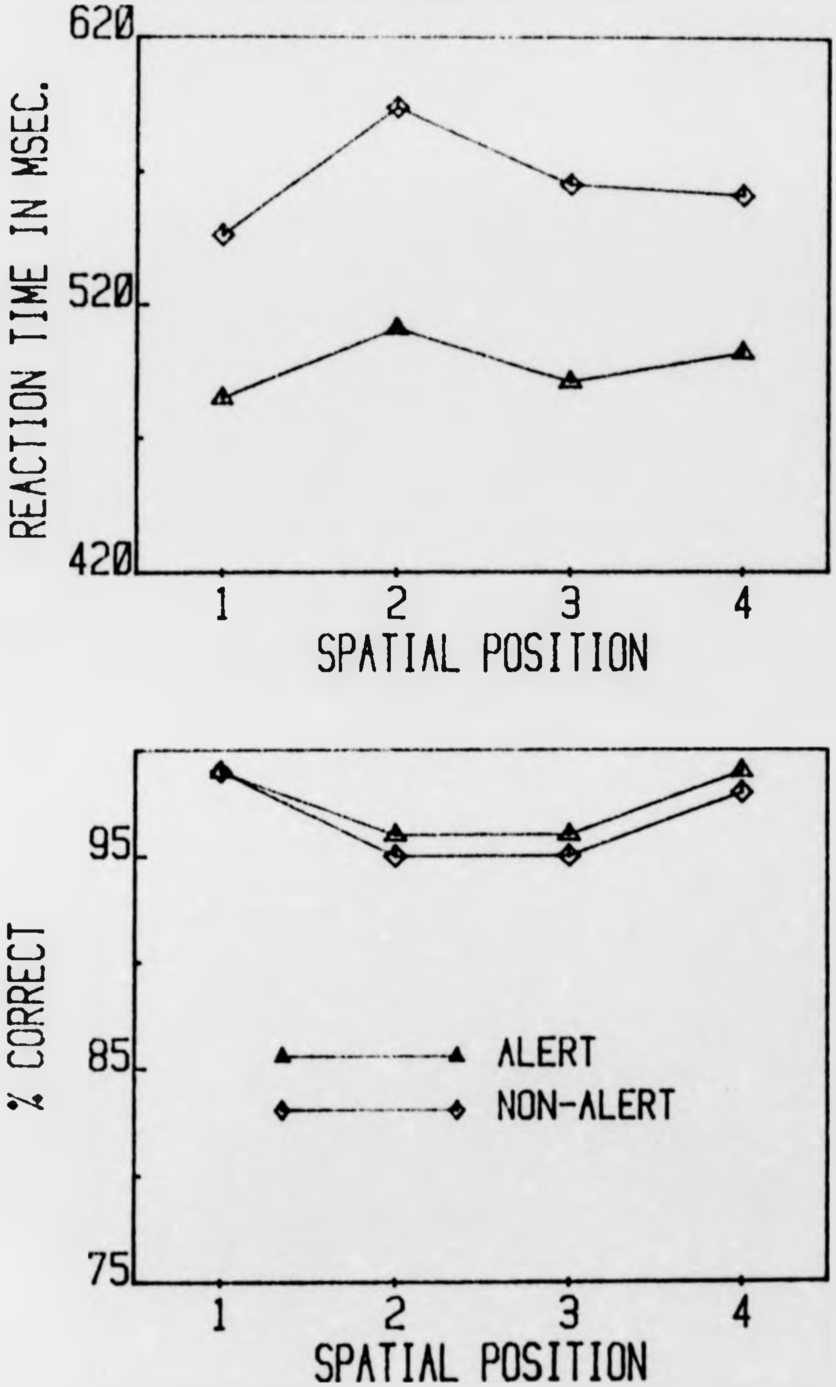


Figure 4 Experiment 2

Reaction time (upper panel) and accuracy (lower panel) as functions of finger position and alertness.

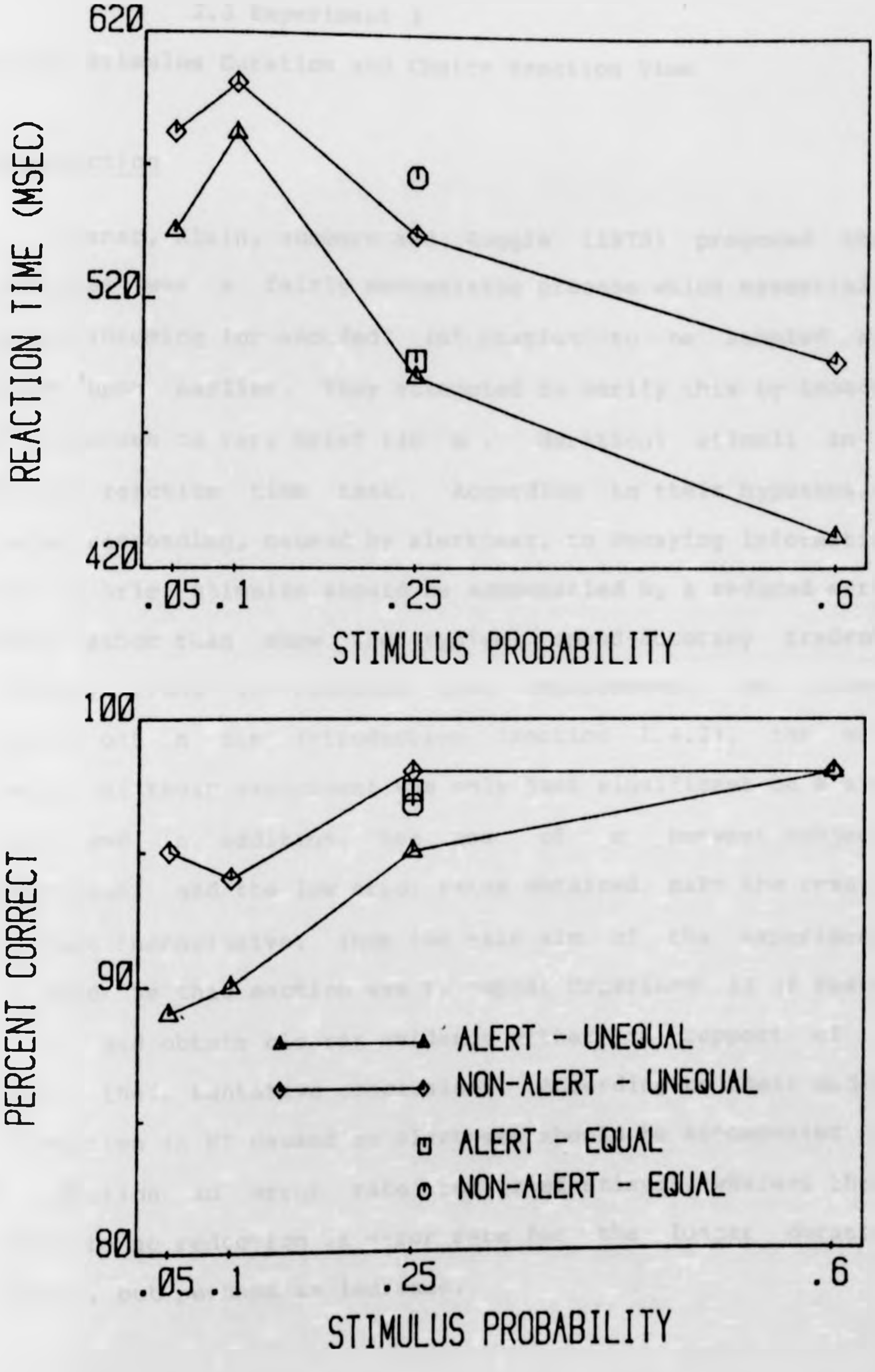


Figure 5 Experiment 2

Reaction time (upper panel) and accuracy (lower panel) as functions of stimulus probability and alertness. Mean values for the equal probability (p=0.25) conditions are also shown.

2.3 Experiment 3

Alertness, Stimulus Duration and Choice Reaction Time

2.3.1 Introduction

Posner, Klein, Summers and Buggie (1973) proposed that alertness was a fairly mechanistic process which essentially caused incoming (or encoded) information to be sampled and acted upon earlier. They attempted to verify this by looking at responses to very brief (40 ms. duration) stimuli in a choice reaction time task. According to their hypothesis, faster responding, caused by alertness, to decaying information from a brief stimulus should be accompanied by a reduced error rate, rather than show the typical speed-accuracy tradeoff normally found in reaction time experiments. As already pointed out in the introduction (section 1.4.2), the main result of their experiment was only just significant on a sign test, and in addition, the use of a between-subjects comparison, and the low error rates obtained, make the results somewhat inconclusive. Thus the main aim of the experiments reported in this section was to repeat Experiment II of Posner et al. and obtain clearer evidence either in support of or against their tentative conclusions. According to their model, a reduction in RT caused by alertness should be accompanied by a reduction in error rate for brief stimuli, whereas there should be no reduction in error rate for the longer duration stimuli, but perhaps an increase.

2.3.2 Design and Method

There were in fact three experiments: in Experiment 3b, stimulus duration was terminated with a visual mask which obliterated any stimulus-specific information, whereas in Experiment 3a stimuli were un-masked; Experiment 3c was a detailed examination of reaction time frequency distributions taken from one subject over a large series of trials, again using masked stimuli. Masks were introduced in Experiments 3b and 3c in order to make the task more difficult and thereby increase error rates to a level meaningful enough to be analysed.

The four-choice reaction time paradigm which was described in Experiment 2 was used again in this series of experiments. Stimuli were either 50 ms. or 500 ms. in duration and were presented under alerted (500 ms. warning interval) or non-alerted conditions (zero warning interval) conditions. This 2 by 2 design was run as 4 separate conditions with 3 blocks of 32 trials per condition, the first block counting as practice in each condition. Order of presentation of conditions was balanced across the eight subjects who performed the task. Each data point was thus based upon 512 observations. The timing and event sequence of a trial was exactly as described in Experiment 2: inter-trial-interval, warning tone, warning interval (0 or 500 ms.), stimulus cross (duration 50 or 500 ms.), subject's response, and finally, feedback. In Experiment 3a, when the stimulus went off, all that remained on the screen were the 4 marker crosses. In Experiment 3b, on the other hand, at the end of the stimulus duration time, the solitary stimulus cross was replaced by 4 crosses, one in each of the 4 possible locations. This acted as an effective mask, eliminating possible after-image or screen decay effects. Experiment 3c used exactly the same paradigm as Experiment 3b, but with only one subject (the author) over a series of 12 sessions, performing 2700 trials in total.

Design Summary:

2 x 2 within-subjects design = 4 conditions;

Alert/Non-alert(blocked) x

Stimulus Duration (blocked: 50/500 ms.);

Expt. 3a (un-masked stimuli):

8 subjects, 64 trials per condition =

512 observations per data point;

Expt. 3b (masked stimuli):

8 subjects, 64 trials per condition =

512 observations per data point;

Expt. 3c (masked stimuli):

1 subject, average 675 trials per condition =

average 675 observations per data point;

Measures: Choice Reaction Time, Percentage Correct.

2.3.3 Results and Discussion: Experiments 3a and 3b

The results of both experiments are presented in Table 5 and in Figures 6 and 7. Considering Experiment 3a first, it can be seen that as expected, alertness produced a significant reduction in reaction time ($F=56.39$, $df=1,7$, $p<0.001$). Stimulus duration, however, had no effect on response time, and nor was the interaction significant. There was no effect of alertness or of stimulus duration on percentage correct. It was because of this lack of effect of stimulus duration, and because of the relatively low overall error rate (7 percent), that Experiment 3b was run using masked stimuli.

The introduction of the mask has clearly made responding to the brief 50 ms. stimuli slower than to the 500 ms. duration stimuli ($F=44.46$, $df=1,7$, $p<0.001$), while the alertness main effect is still present at both durations ($F=13.17$, $df=1,7$, $p<0.01$). There was no interaction between these two main effects. Accuracy at the shorter duration was significantly lower ($F=51.12$, $df=1,7$, $p<0.001$), while alertness had the effect of improving the overall level of accuracy ($F=11.02$, $df=1,7$, $p<0.05$). The interaction was also significant ($F=9.17$, $df=1,7$, $p<0.05$), indicating that the effect of alertness on accuracy was greater at the 50 ms. duration than at the 500 ms. duration. Thus the doubt concerning the results of Posner et al. (1973) is resolved, as it appears that alertness can indeed improve overall performance in terms of both speed and accuracy when stimuli of brief duration are involved.

However, the results of this experiment do not rule out the possibility that alertness may improve performance on longer duration stimuli under certain circumstances. In Experiment 3b, accuracy on the 500 ms. stimuli was around 94 percent, and any potential differences may not have been detected due to a ceiling effect, in the same way that Experiment 3a was found to be inappropriate for examining either the 50 ms. or the 500 ms. stimuli because of low error rates. The point of interest here is that if alertness could produce an improvement for longer duration stimuli as proposed by Kahneman (1973), then Posner's earlier-sampling hypothesis would be unable to account for such data. This possiblity will be examined further in Experiment 4.

2.3.4 Frequency Distribution Analysis: Experiment 3c

If fast responses to brief stimuli result in better accuracy, then this should be observable even in cases where alertness is not being manipulated. This can be tested by looking at accuracy across the distribution of reaction times present within an individual subject's data: faster responding should be accompanied by lower error rates. Furthermore, if alertness merely serves to make responses faster by reducing the mean of the reaction time distribution, without influencing the quality of the information available to the decision mechanism (as Posner proposes), then the speed-accuracy functions under alertness and non-alertness should be identical, at least in the region where they overlap. If, on the other hand, the two functions differ, then alertness must be having an effect on either the encoding process, the decision-making process, or both.

The overall results of this experiment are given in Table 6 and plotted in Figure 8, and they are in complete accord with the findings of Experiment 3b. In order to construct reaction time distributions, the raw data were divided into 10 ms. windows in the range 100 to 1000 ms., and the frequencies of correct and wrong responses were computed for each of the four experimental conditions. These distributions are plotted in Figure 9, and are typical of those found in the psychological literature (e.g., Snodgrass, 1969; Ninio and Kahneman, 1974). (The black or dark curves represent correct reaction times and the blue or light curves represent error reaction times).

This partitioning technique (Pachella, 1974, Wickelgren, 1977) can be extended to give a more informative view of the data by calculating the percentage of correct responses in each window and plotting these against the corresponding reaction times, to give a speed-accuracy tradeoff diagram for each experimental condition. Figure 10 shows the data represented in this manner. Reaction time windows in which the total number of observations (i.e. N correct + N errors) was less than 10 were excluded from the analysis as these were considered to be unreliable. The straight lines on Figure 10 show the first-order regression lines through the points, and the statistics for these regressions are presented in Table 6. It can clearly be seen from Figure 10 that for the 50 ms. duration stimuli, faster responses produce better accuracy, in both the alerted and non-alerted conditions. In contrast, there is no relationship between reaction time and accuracy for the 500 ms. stimuli.

Considering the results in detail for the 50 ms. stimuli only, it may be noted that the regression slopes in the alert and non-alert conditions are very similar (-0.13 and -0.14 respectively). This implies that the advantage in accuracy gained through faster responding is roughly the same, whether alerted or not. This gain can crudely be quantified as about 13.5 percent per 100 ms. However, when the advantage gained in going from non-alert to alert is expressed in the same terms, the gain is only 4.2 percent per 100 ms., based on mean reaction time and percentage correct in these conditions. Why should the relative advantage of a faster response within a condition be so much greater that that between conditions? The within-conditions gain of 13.5 percent per 100 ms. suggests that the difference in accuracy of 4.5 percent between the non-alert and alert conditions could have been produced by a reduction in reaction time of only 35 ms. according to an early-sampling model of alertness, compared with the actual observed difference of 120 ms., leaving an improvement of 85 ms. due to alertness unaccounted for. Expressed in a different way, the reduction of 120 ms. between conditions ought to have resulted in an improvement of 13.5*(120/100) = 16.2 percent per 100 ms. according to the early-sampling model (based on the within-conditions figures), rather than the 4.2 percent found.

The implication of this is that not all of the reduction in reaction time produced by alertness can be accounted for by an earlier-sampling model such as that proposed by Posner and his colleagues. If it were, then in this experiment at least, the improvement in accuracy should have been of the same order as that suggested by the within-condition analyses. This conclusion, while not contradicting Posner's model, suggests that it needs to be extented somewhat in order to account for the observation that alertness does not simply produce a speed-accuracy tradeoff. This relationship between speed and accuracy under alertness will be examined more closely in the following experiments.

Table 5 Experiments 3a and 3b

RT and percentage correct as functions of alertness and stimulus duration, using masked and unmasked stimuli.

		ALERT		NON-ALERT	
STIMULUS DURATION		50	500	50	500
Expt 3a: UNMASKED	Mean RT	499	520	556	558
	sd(RT)	69	82	88	86
	Mean %C	93	94	92	92
	sd(%C)	6	5	6	5
Expt 3b: MASKED	Mean RT	594	483	668	521
	sd(RT)	134	86	101	77
	Mean %C	77	95	68	93
	sd(%C)	9	2	12	4

Table 6 Experiment 3c

RT and percentage correct as functions of alertness and stimulus duration.

	ALERT		NON-ALERT	
STIMULUS DURATION	50	500	50	500
Mean correct RT	450	389	569	441
sd(correct RT)	89	55	126	59
Mean error RT	511	374	684	427
sd(error RT)	134	76	195	84
Mean % correct	76	95	71	93
Total N	635	675	658	732

Regression of percentage correct on RT

Correlation, r	-.786	-.024	-.895	-.033
Slope	-.130	-.000	-.140	-.000
Intercept	104	96	121	93
N of 10 ms. windows used	19	12	23	12

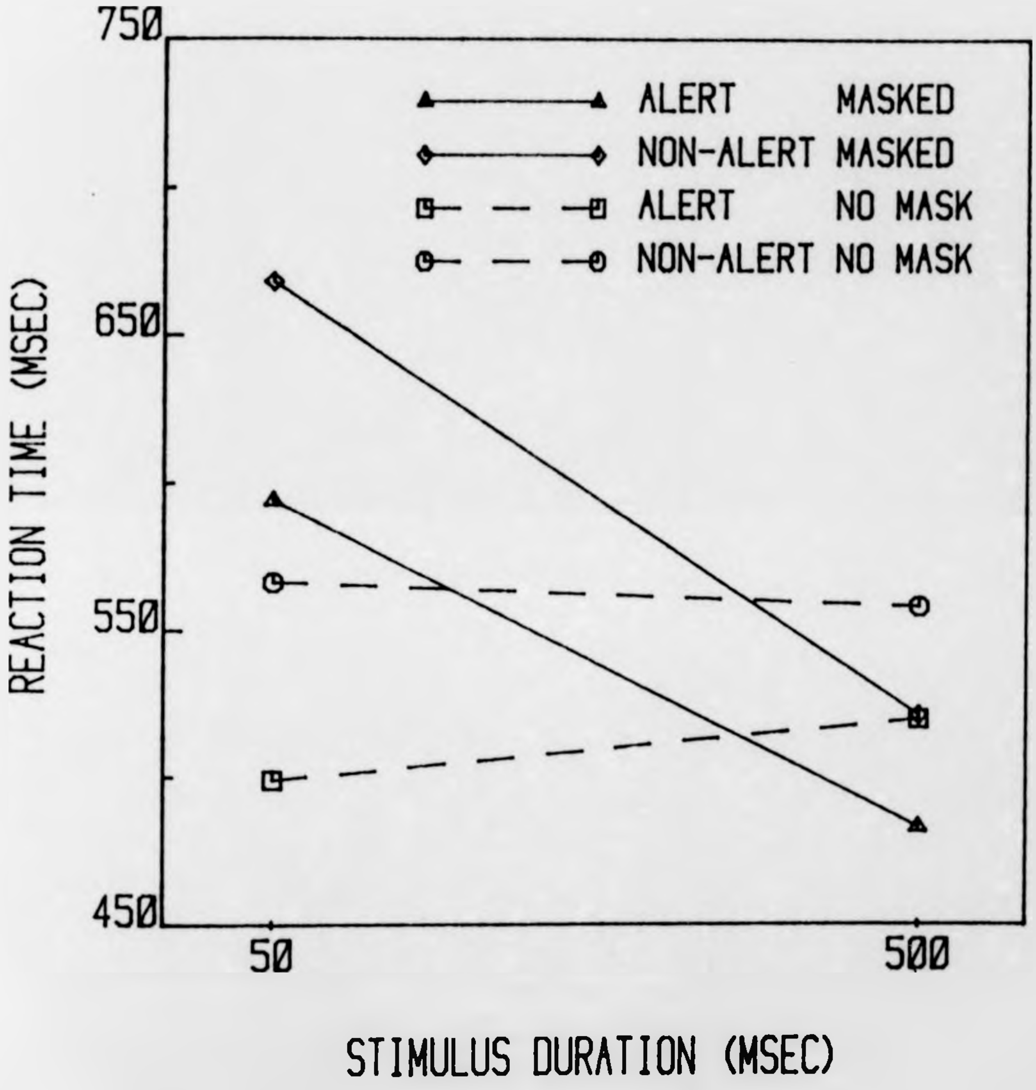


Figure 6 Experiments 3a and 3b

Reaction time as a function of stimulus duration and alertness, with masked and un-masked stimuli.

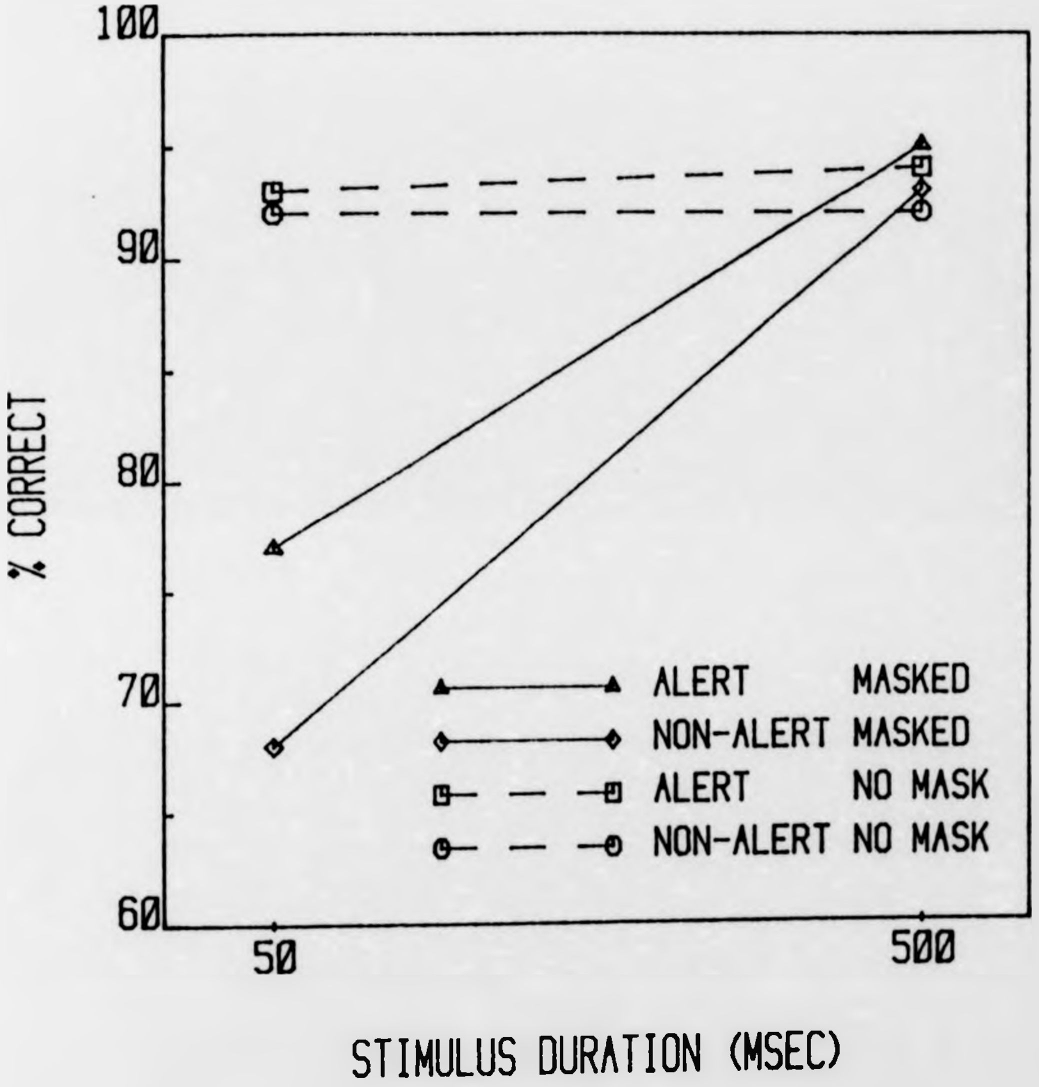


Figure 7 Experiments 3a and 3b

Accuracy as a function of stimulus duration and alertness, with masked and un-masked stimuli.

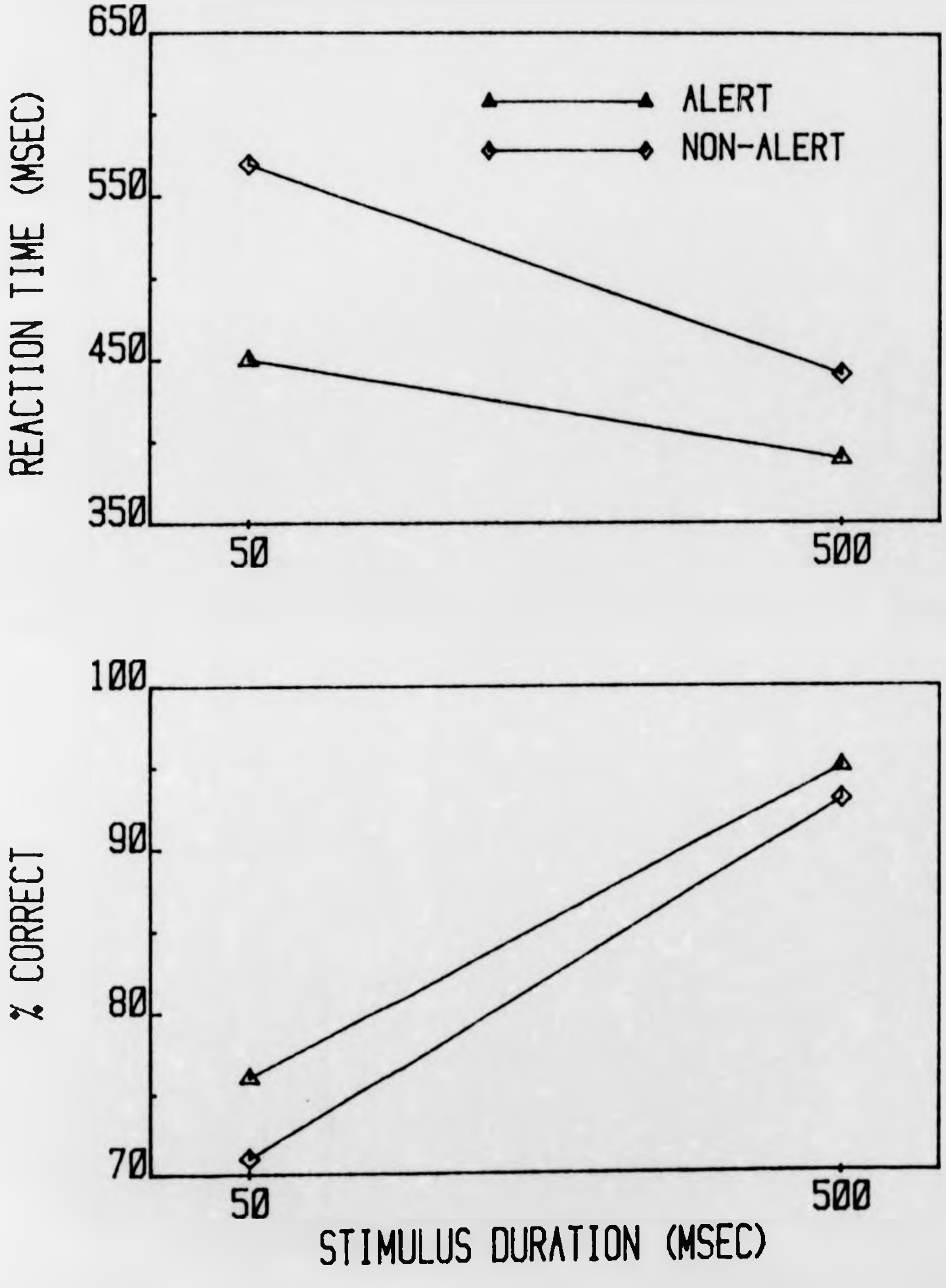


Figure 8 Experiment 3c

Reaction time (upper panel) and accuracy (lower panel) as functions of stimulus duration and alertness.

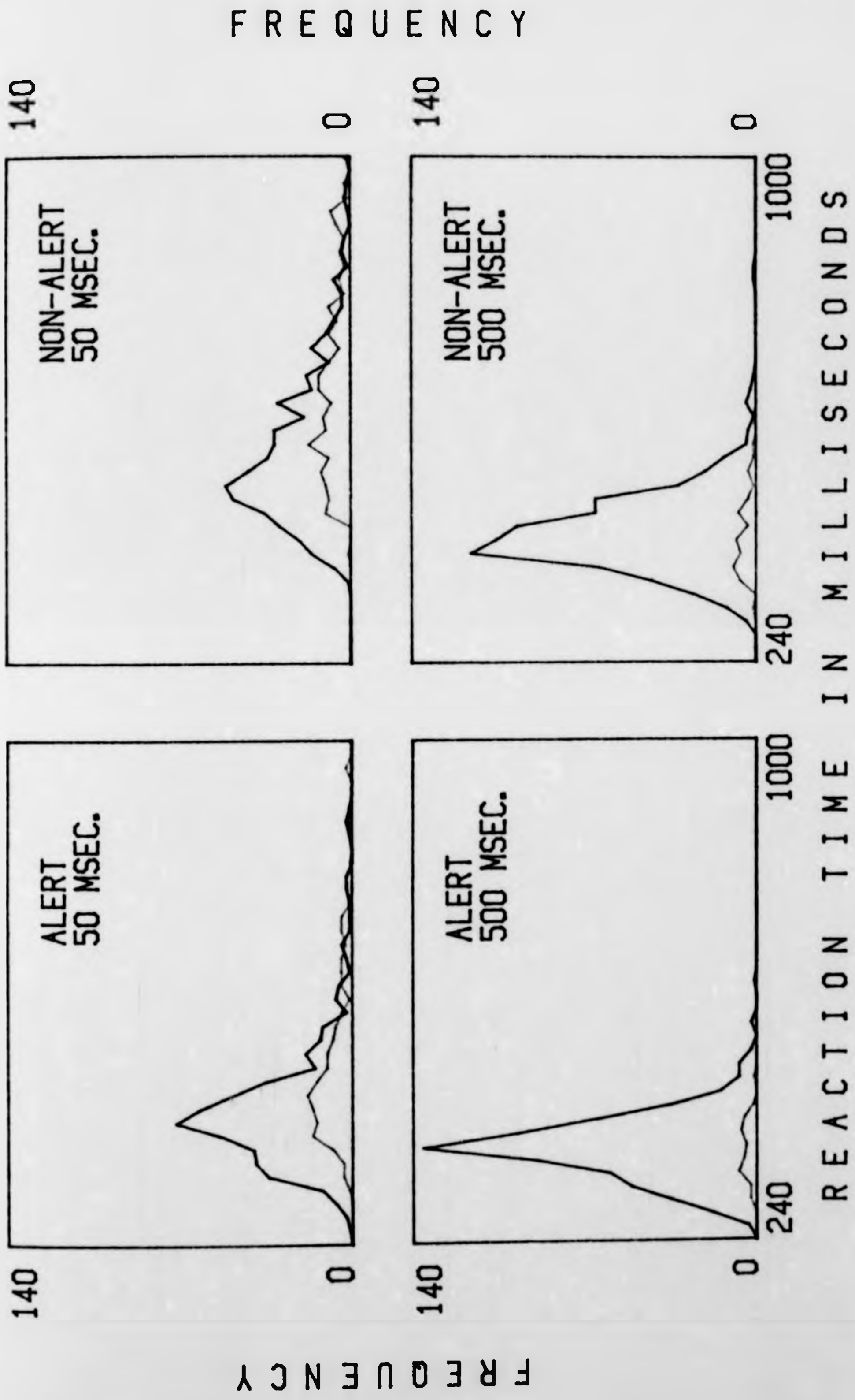
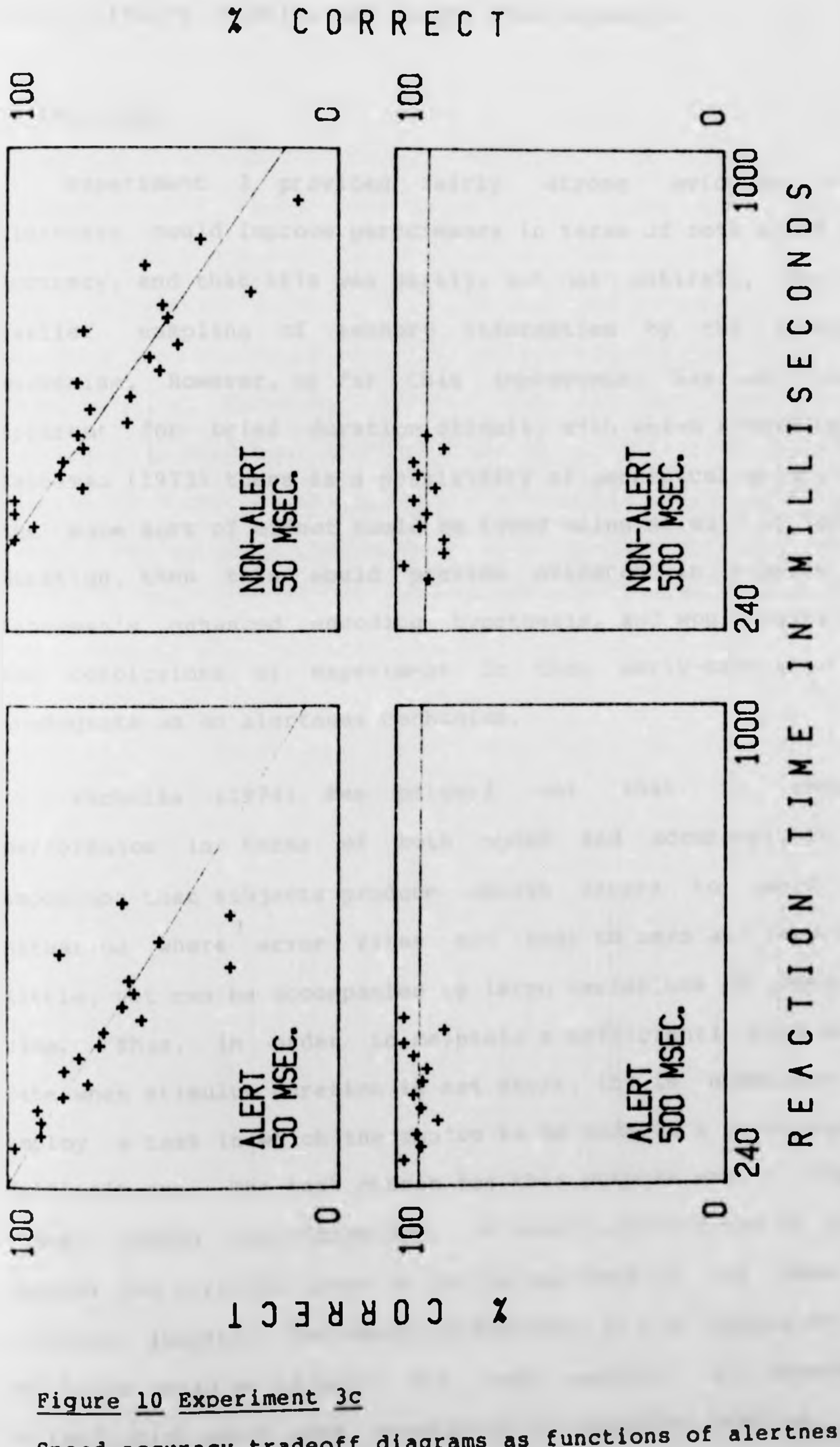


Figure 9 Experiment 3c

Reaction time frequency distributions as functions of alertness and stimulus duration.



<u>Figure</u> <u>10</u> <u>Experiment</u> <u>3c</u>

Speed-accuracy tradeoff diagrams as functions of alertness and stimulus duration.

2.4 Experiment 4

Alertness, Stimulus Duration and Length Discrimination

2.4.1 Introduction

Experiment 3 provided fairly strong evidence that alertness could improve performance in terms of both speed and accuracy, and that this was partly, but not entirely, due to earlier sampling of sensory information by the decision mechanism. However, so far this improvement has only been apparent for brief duration stimuli, with which according to Kahneman (1973) there is a possibility of perceptual error. If the same sort of effect could be found using stimuli of longer duration, then this would provide evidence in support of Kahneman's enhanced encoding hypothesis, and would reinforce the conclusions of Experiment 3c that early-sampling is inadequate as an alertness mechanism.

Pachella (1974) has pointed out that to examine performance in terms of both speed and accuracy, it is important that subjects produce enough errors to avoid the situation where error rates are near to zero and vary very little, yet can be accompanied by large variations in reaction time. Thus, in order to maintain a sufficiently high error rate when stimulus duration is not short, it is necessary to employ a task in which the choice to be made is a perceptually difficult one. The task chosen for this purpose was a simple visual length discrimination, in which subjects had to judge whether two vertical lines on the screen were of the same or different lengths. The actual difference in the lengths of the two lines could be adjusted for each subject, to ensure a suitably high error rate, regardless of stimulus duration.

2.4 Experiment 4

2.4.1 Introduction

The first experiment (4a) in this section was designed to examine the effects of alertness on reaction time and percentage correct over a range of durations from 50 to 250 ms., since pilot tests had suggested that performance would asymptote at around the 250 ms. duration. In addition, the experiments of Posner and Boies (1971), using probe reaction signals, had suggested that stimulus encoding is virtually complete within about 100 to 150 ms., and so improvements in accuracy due to earlier sampling under alertness should not be observable at durations longer than 150 ms. However, the results indicated that alertness was still affecting accuracy at the 250 ms. duration, so the second and third experiments (4b and 4c) extended the range up to a stimulus duration of 1 second. The aim of the experiments was to determine whether the effect of alertness on accuracy was restricted to very brief duration stimuli, or whether improvements in performance could also be observed at longer durations, as predicted by Kahneman's enhanced encoding model.

2.4.2 Design and Method

The stimuli used in these experiments consisted of two vertical lines, both approximately 1 cm. in length, side by side approximately 1 cm. apart, at the centre of the display screen. The length of the left-hand line could be adjusted by the experimenter in steps of approximately 1/5 mm. (one graphic screen unit), and this was the means whereby the difficulty of the discrimination could be varied. The lines were presented to the subject for the appropriate duration, and then masked by a display of 5 vertical lines covering the area occupied by the stimulus. The Subject's task was to decide whether the two stimulus lines were of the same or different lengths. It was decided to terminate the stimulus with the mask for all presentations to ensure that the task would be sufficiently difficult. The findings of Experiment 3 concerning masked and un-masked stimuli had already suggested that this was a useful technique.

As already mentioned, this paradigm allowed the difficulty of the task to be to be manipulated to ensure a reasonably high error rate. This was done for each subject prior to running the actual experiment, using short blocks of 10 trials at various levels of discriminability, until an accuracy of about 75 percent (7 or 8 correct out of 10) was achieved. An intermediate warning interval of 250 ms. was used for these blocks of calibration trials. Intermediate stimulus durations were also used, appropriate to the range of durations involved in the experiment (150 ms. in Experiment 4a, 500 ms. in Experiments 4b and 4c). Once the level of difficulty was set for an individual subject, it was not changed throughout the actual experiment. In practice the length of the shorter line varied across subjects from 86 percent to 98 percent of the length of the longer line.

The sequence of events during each trial was as follows. A fixation cross was displayed at the centre of the screen throughout the inter-trial-interval. The warning tone was then presented, and either immediately or after 500 ms. (non-alerted or alerted respectively), the fixation cross was replaced by the test stimulus, which in turn was replaced by the mask as described above. The subject was required to respond as soon as possible by pressing either the key labelled "SAME" or the key labelled "DIFFERENT," which the index fingers of each hand were resting on. Following this, feedback was immediately given by displaying one of the messages "CORRECT" OR "WRONG" on the screen for 500 ms. If the subject did not respond within 1.5 seconds, the warning tone was sounded, and a new trial commenced. Presentation schedules were such that within each block of trials, "SAME" and "DIFFERENT" stimuli were presented with equal frequency in randomly generated sequences.

Experiment 4a consisted of 5 stimulus durations of 50, 100, 150, 200 and 250 ms., presented under alerted and non-alerted conditions. This gave 10 treatment combinations in a 2 x 5 design, with each of 8 subjects performing all combinations. Each condition consisted of a block of 20 practice trials, followed by two blocks of 30 experimental trials. Presentation order of conditions was balanced across subjects to allow for practice and fatigue effects.

Experiment 4b used a similar design except that there were 3 stimulus durations of 250, 500 and 1000 ms., and 6 subjects participated in the experiment.

Experiment 4c involved 4 stimulus durations of 100, 200, 400 and 800 ms. There were 12 subjects, each of whom performed only one block of 30 experimental trials, rather than two, as in Experiments 4a and 4b. (This change was a purely practical one, and simply related to more efficient use of available laboratory time).

Design Summary:

Expt. 4a: 2 x 5 within-subjects design = 10 conditions;
Alert/Non-alert(blocked) x
Stim. Dur.(blocked:50/100/150/200/250 ms.);
8 subjects, 60 trials per condition =
480 observations per data point;

Expt. 4b: 2 x 3 within-subjects design = 6 conditions;
Alert/Non-alert(blocked) x
Stimulus Duration(blocked:250/500/1000 ms.);
6 subjects, 60 trials per condition =
360 observations per data point;

Expt. 4c: 2 x 4 within-subjects design = 8 conditions;
Alert/Non-alert(blocked) x
Stim. Duration(blocked:100/200/400/800 ms.);
12 subjects, 30 trials per condition =
360 observations per data point;

Measures: Reaction Time, Percentage Correct,
Percentage Different.

2.4.3 Results and Discussion

The results for Experiment 4a are presented in Table 7 and Figures 11 and 12. The main effects of alertness and duration on reaction time were both significant ($F=28.58$, $df=1,7$, $p<0.01$ and $F=6.14$, $df=4,28$, $p<0.01$ respectively), but their interaction was not. The effects of alertness and duration on accuracy (percentage correct) showed a similar pattern ($F=53.27$, $df=1,7$, $p<0.01$ and $F=48.40$, $df=4,28$, $p<0.01$ respectively), again with no significant interaction. The experimental manipulations had no significant effects on response bias, as measured by percentage different responses. These findings suggest that alertness can genuinely improve performance in terms of both speed and accuracy at least up to stimulus durations of 250 ms. This absence of an interaction was somewhat unexpected, since pilot runs had suggested that with an appropriate choice of difficulty level (i.e., stimulus discriminability) which would allow an above chance level of performance at the 50 ms. duration, performance at the 250 ms. duration would be near asymptotic. This however was not a feature of the task which could be controlled easily, as the calibration of difficulty level for each subject was done using only an intermediate stimulus duration of 150 ms. Thus while the experiment shows that alertness-induced improvements are not strictly limited to very brief stimuli, in line with Kahneman's predictions, it does not fully test the upper limit of this result.

Experiment 4b was designed to examine longer stimulus durations, using a range of 250 to 1000 ms. The results are shown in Table 8 and in Figures 13 and 14. The only significant effect on reaction time was that of alertness

(F=7.43, df=1,5, p<0.05), although there was a trend towards slower reaction times at the longer durations (F=3.82, df=2,10, p=0.058). The effect of alertness on percentage correct was significant (F=10.179, df=1,5 p<0.05), as was that of duration (F=13.125, df=2,10, p<0.01). The interaction between alertness and duration on percentage correct was also significant (F=12.902, df=2,10, p<0.01). As in Experiment 4a, analysis of response bias showed no significant differences. The important result from this experiment is that the improvement in accuracy produced by alertness is a function of stimulus duration: it would appear from this that this effect of alertness on accuracy gradually disappears as the longer duration stimuli eventually become less prone to the occurrence of perceptual errors.

The final experiment in this series was run in order to obtain an overall picture of the interaction between alertness and stimulus duration over a wide range of durations from 100 to 800 ms., which overlapped the ranges examined in Experiments 4a and 4b. This was considered preferable to comparing the experiments directly, in view of the different groups of subjects used. The comparison will in fact be made, and its implications considered, in the introduction to Experiment 6 (section 2.6.1). Table 9 and Figures 15 and 16 show the results from Experiment 4c. In general they confirm the findings of the two previous experiments, in that alertness and increasing stimulus duration both significantly reduced reaction time (F=6.07, df=1,11, p<0.05 and F=4.88 df=3,33, p<0.01 respectively), with no interaction. Similarly, accuracy is improved by both alertness and increasing stimulus duration (F=13.07, df=1,11, p<0.01 and F=50.95, df=3,33, p<0.01

respectively). These results suggest that accuracy was increased by alertness at all stimulus durations, since the interaction was not significanct, although there did appear to be a trend (F=2.66, df=3,33, p=0.064). This is quite in keeping with the enhanced encoding hypothesis, since the essential point being made is that alertness may improve performance wherever there is imperfect encoding of the stimulus and there is a chance of perceptual error; as stimulus duration increases, the likelihood of perceptual errror will fall until, with a long enough stimulus, performance will be completely error free. The point at which this occurs will depend on factors such as the nature of the task and its difficulty; the present results suggest that in this particular experiment, perceptual errors were still being made after 800 ms. Finally, as in Experiments 4a and 4b, analysis of response bias produced no significant differences.

Taken as a whole, Experiment 4 indicates that when a task is sufficiently difficult, alertness can improve performance in terms of both speed and accuracy, even for stimuli of relatively long duration. This is evidence in favour of Kahneman's enhanced encoding model, either as an alternative to, or in the light of the results of Experiment 3, more probably as an addition to, Posner's earlier-sampling model.

- 0 -

Table 7 Experiment 4a

Reaction times, accuracy and bias, as functions of alertness and stimulus duration (range 50 to 250 ms).

			ALERT		
STIM. DURATION	50	100	150	200	250
Mean Correct RT	1246	1140	1023	955	952
sd(RT)	313	185	189	209	190
Mean % Correct	52	63	78	86	89
sd(% Correct)	7	16	14	10	11
Mean % Diff.	51	50	51	47	48
sd(% Diff.)	12	12	11	8	8

			NON-ALERT		
STIM. DURATION	50	100	150	200	250
Mean Correct RT	1324	1294	1265	1095	1057
sd(RT)	368	253	307	252	229
Mean % Correct	47	51	69	78	84
sd(% Correct)	8	13	13	14	14
Mean % Diff.	52	49	49	49	48
sd(% Diff.)	22	13	12	9	8

Table 8 Experiment 4b

Reaction times, accuracy and bias, as functions of alertness and stimulus duration (range 250 to 1000 ms).

	ALERT			NON-ALERT		
STIM. DURATION	250	500	1000	250	500	1000
Mean Correct RT	704	714	734	763	767	812
sd(RT)	96	66	97	77	30	35
Mean % Correct	88	94	94	76	91	95
sd(% Correct)	7	4	4	3	5	2
Mean % Diff.	48	46	47	50	47	46
sd(% Diff.)	6	3	3	9	4	4

Table 9 Experiment 4c

Reaction times, accuracy and bias, as functions of alertness and stimulus duration (range 100 to 800 ms).

ALERT

STIM. DURATION	100	200	400	800
Mean Correct RT	1098	867	800	844
sd(RT)	624	404	428	300
Mean % Correct	60	77	87	92
sd(% Correct)	12	13	8	7
Mean % Diff.	48	45	48	48
sd(% Diff.)	10	13	10	3

NON-ALERT

STIM. DURATION	100	200	400	800
Mean Correct RT	1188	1013	906	846
sd(RT)	695	575	411	287
Mean % Correct	51	69	85	92
sd(% Correct)	13	16	10	6
Mean % Diff.	49	48	51	51
sd(% Diff.)	15	9	7	7

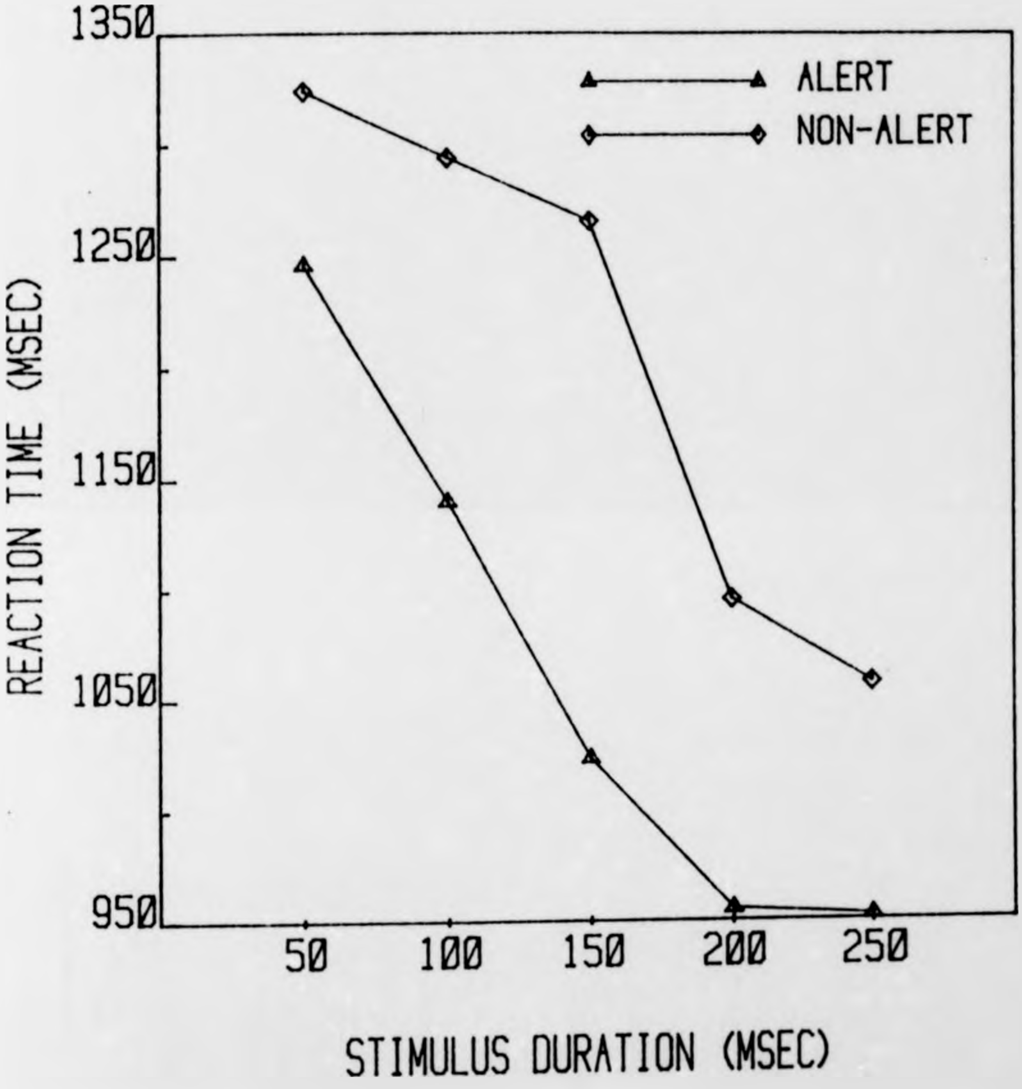


Figure 11 Experiment 4a

Reaction time as a function of stimulus duration and alertness.

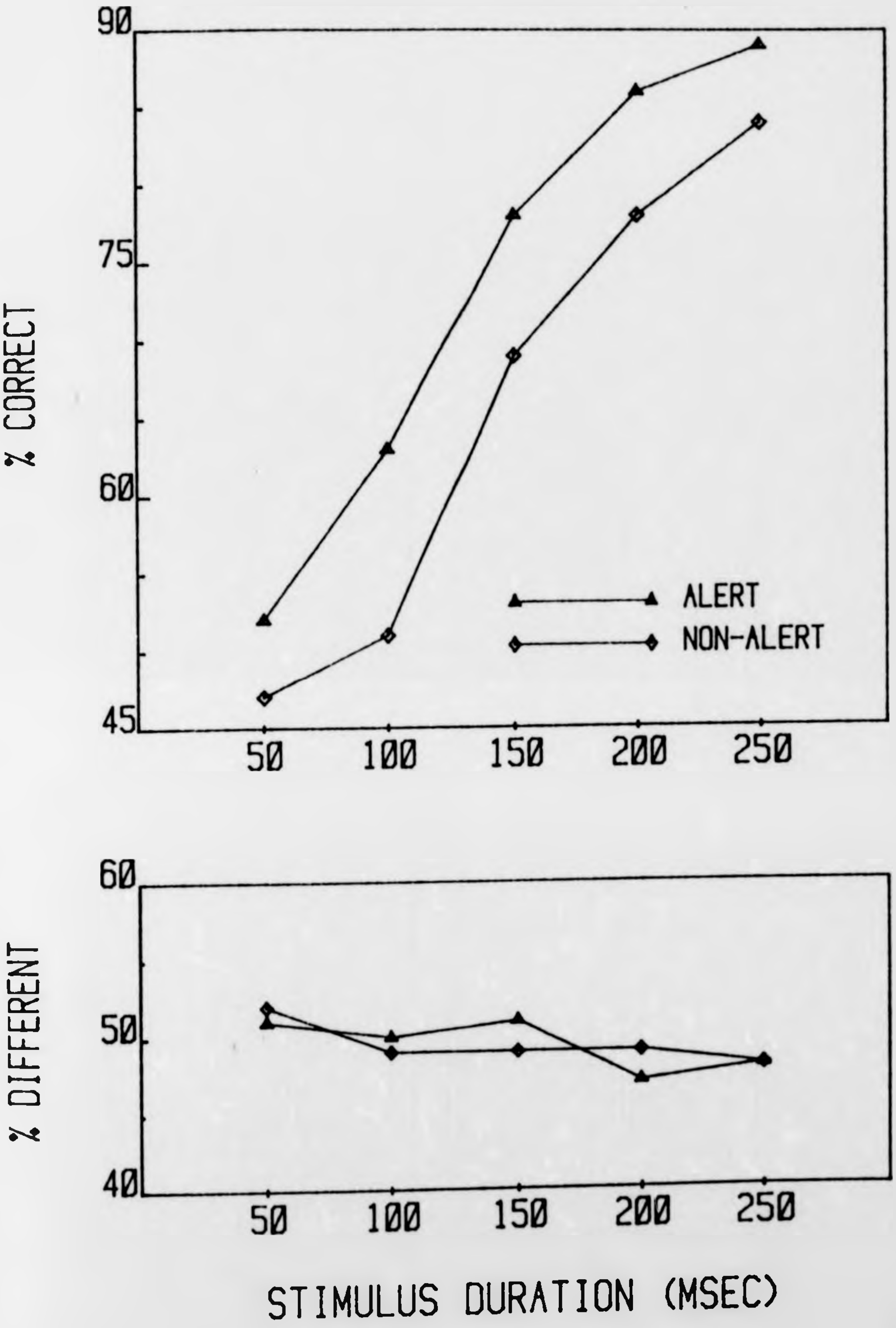


Figure 12 Experiment 4a

Accuracy (upper panel) and bias (lower panel) as functions of stimulus duration and alertness.

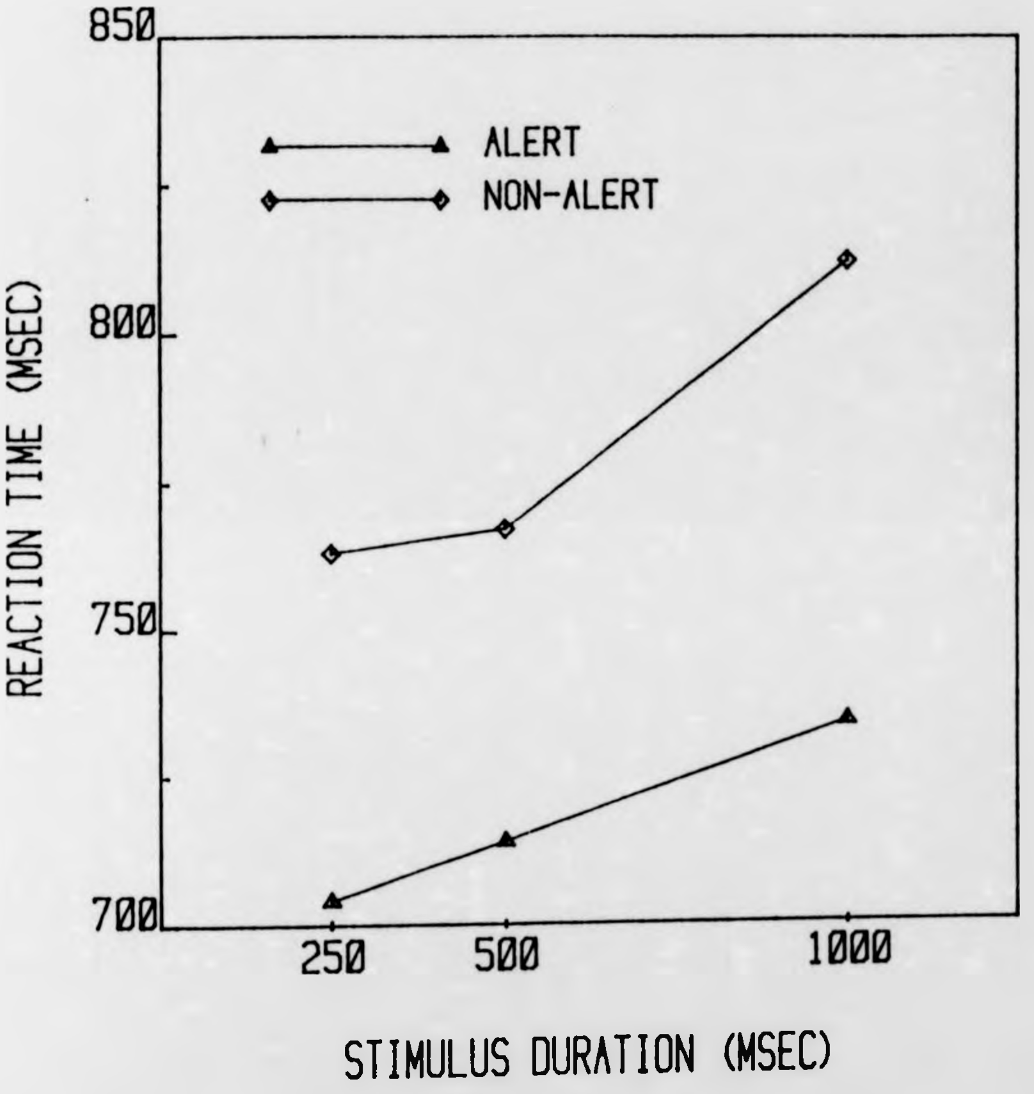


Figure 13 Experiment 4b

Reaction time as a function of stimulus duration and alertness.

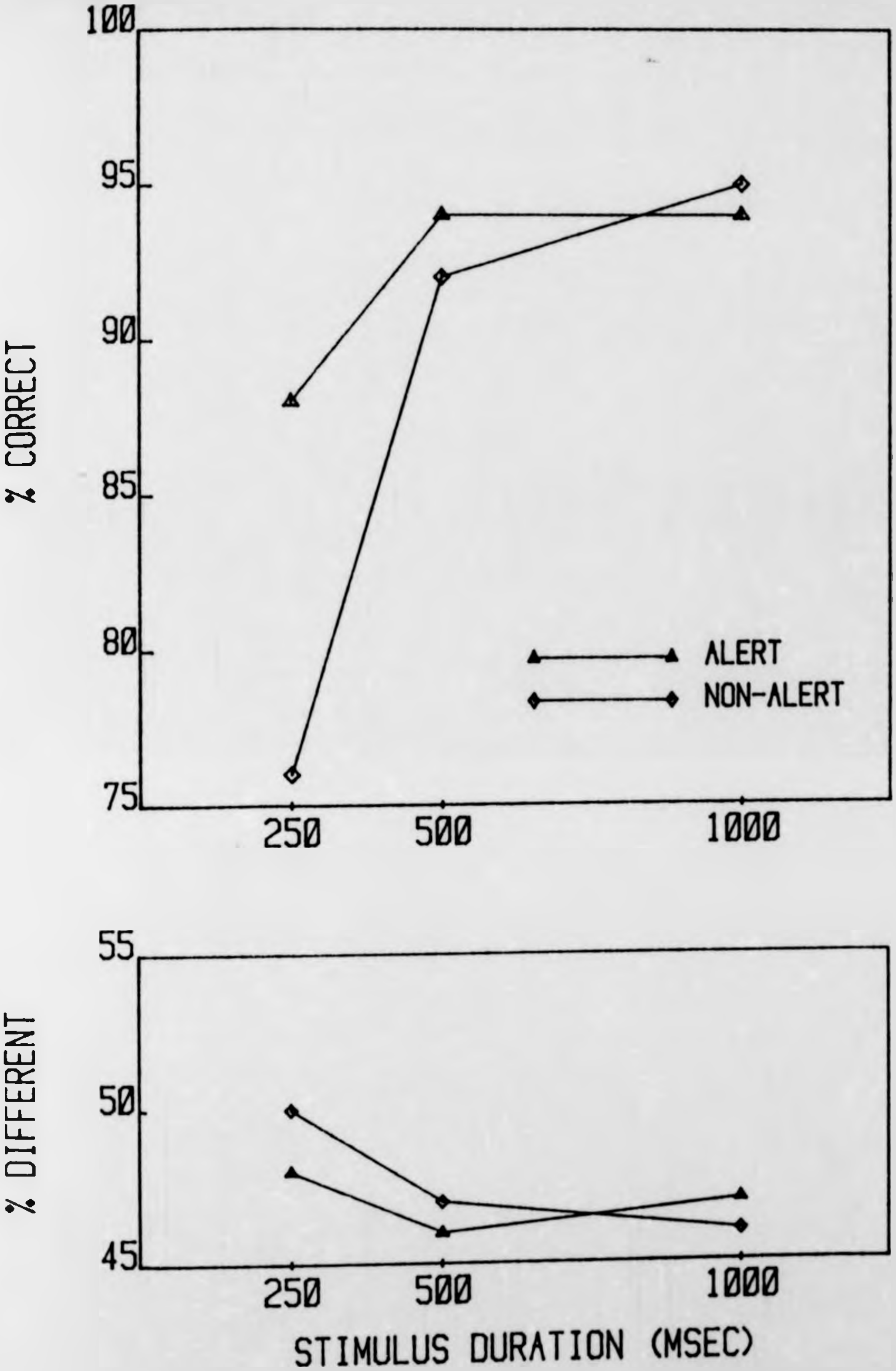


Figure 14 Experiment 4b

Accuracy (upper panel) and bias (lower panel) as functions of stimulus duration and alertness.

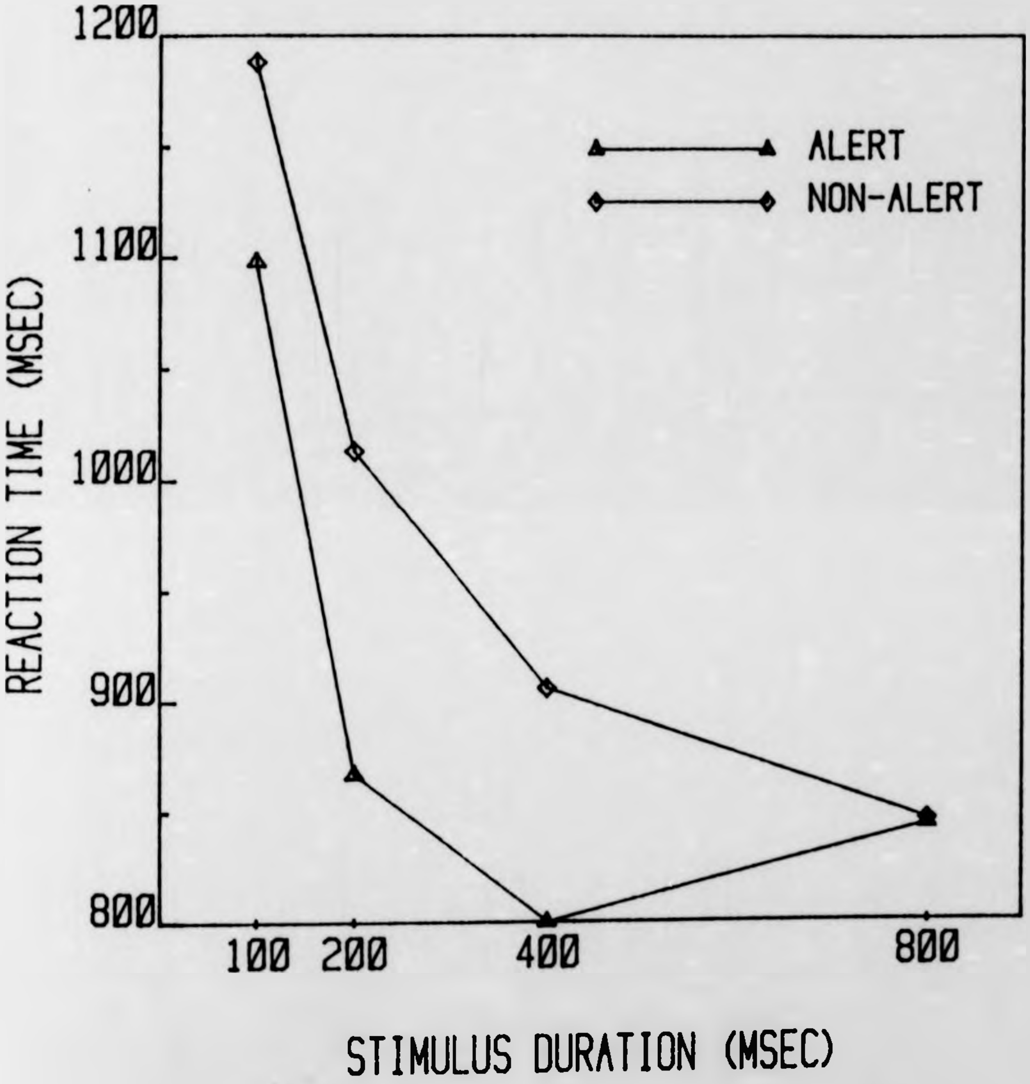


Figure 15 Experiment 4c

Reaction time as a function of stimulus duration and alertness.

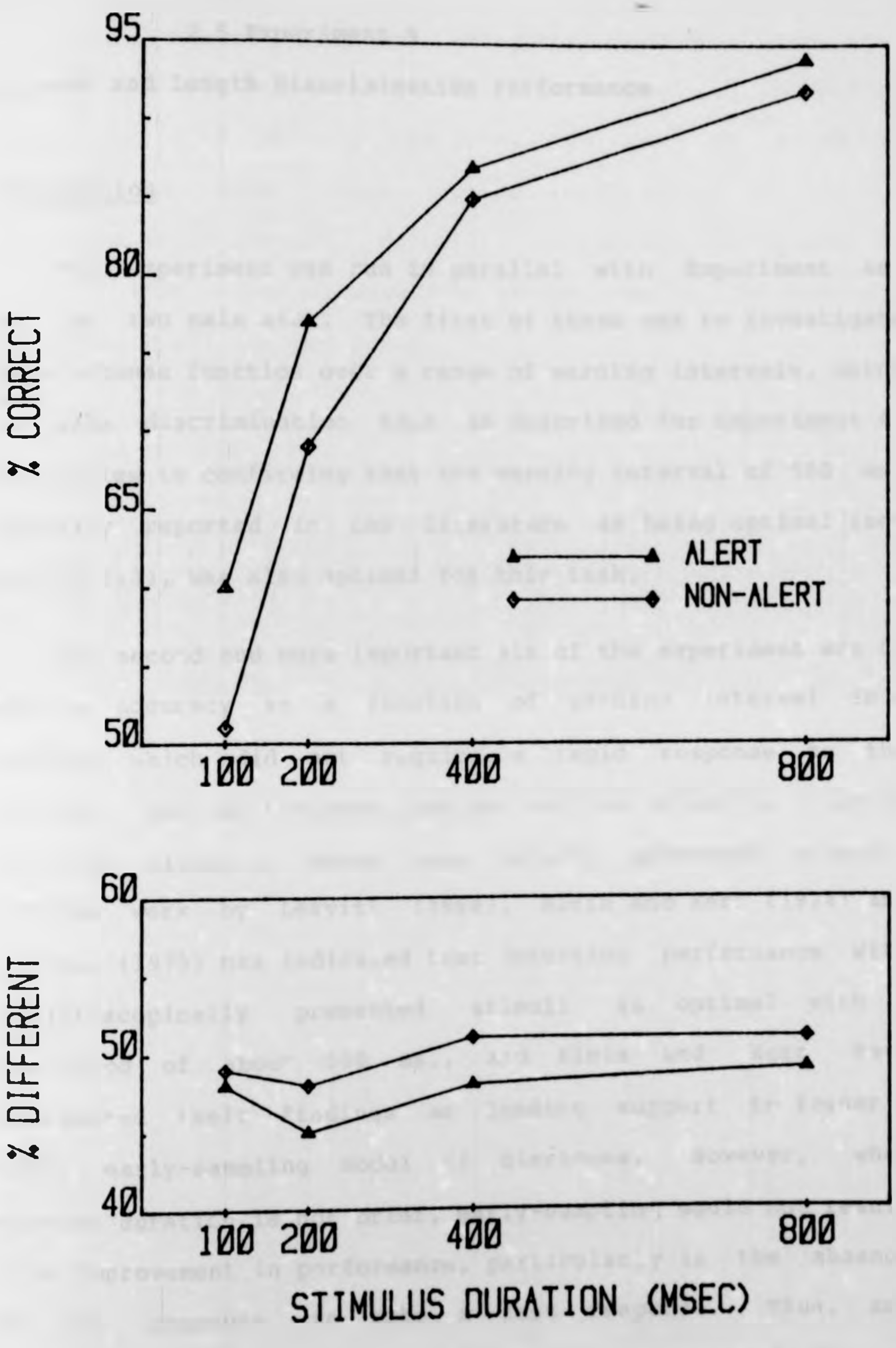


Figure 16 Experiment 4c

Accuracy (upper panel) and bias (lower panel) as functions of stimulus duration and alertness.

2.5 Experiment 5

Alertness and Length Discrimination Performance

2.5.1 Introduction

This experiment was run in parallel with Experiment 4a, and had two main aims. The first of these was to investigate the alertness function over a range of warning intervals, using the same discrimination task as described for Experiment 4, with a view to confirming that the warning interval of 500 ms. generally reported in the literature as being optimal (see section 1.3), was also optimal for this task.

The second and more important aim of the experiment was to examine accuracy as a function of warning interval in a paradigm which did not require a rapid response to the stimulus, but at the same time was not restricted to a simple detection situation using very briefly presented stimuli. Previous work by Leavitt (1968), Klein and Kerr (1974) and Loveless (1975) has indicated that detection performance with tachistoscopically presented stimuli is optimal with a foreperiod of about 500 ms., and Klein and Kerr have interpreted their findings as lending support to Posner's (1974) early-sampling model of alertness. However, when stimulus duration is not brief, early-sampling would not result in an improvement in performance, particularly in the absence of any pressure to make a fast response. Thus, any alertness-induced improvement in accuracy observed in an un-timed discrimination task using stimuli of relatively long duration should provide evidence in favour of an enhanced encoding model rather than an early-sampling one.

2.5 Experiment 5

2.5.1 Introduction

In the present experiment, subjects performed the task both in this un-timed discrimination paradigm, hereafter referred to as the Non-RT condition, and also as a normal reaction time task. This allowed performance in the two situations to be compared directly. A priori it might be expected that accuracy should be better when it does not have to be traded off against speed.

2.5.2 Design and Method

The experiment involved the same visual length discrimination task described for Experiment 4, with a constant stimulus duration of 250 ms. throughout. A slight variation was introduced for the Non-RT condition whereby instead of responding as soon as they were ready, subjects had to wait for 1.5 seconds after the stimulus, until the message "RESPOND" appeared on the screen. At this point they could make their choice and receive "CORRECT" or "WRONG" feedback for 500 ms. as under normal conditions. With this procedure it was found during pilot runs that subjects' natural reactions were to respond as soon as possible to the stimulus. However if they did this nothing happened, i.e., the response was not registered unless it was made after the instruction to respond had appeared on the screen. With a small amount of practice, subjects learned to "relax" and wait for the "RESPOND" prompt before making their response. This delayed-response paradigm is similar to the technique employed by Eriksen, Pollack and Montague (1970) to separate encoding from response-initiation effects.

Calibration of difficulty level for each individual was carried out prior to the experiment, in the same manner as described for Experiment 4, using a warning interval of 250 ms. and a stimulus duration of 250 ms. (the same duration used throughout the experiment).

There were 4 warning intervals in the experiment, zero, 250, 500 and 1000 ms., and each of these was presented in both reaction time and Non-RT conditions, giving a 4 x 2 design. Twelve subjects performed all 8 treatment combinations, order of presentation being balanced across subjects. Each condition consisted of 3 blocks of 20 trials, the first of which was a practice block. All other aspects of the experimental set-up were as described for Experiment 4.

Design Summary:

4 x 2 within-subjects design = 8 conditions;

Warning interval (blocked:0/250/500/1000 ms.) x

RT/Non-RT (blocked);

12 subjects, 40 trials per condition =

480 observations per point;

Measures: Reaction Time, Percentage Correct,
Percentage Different.

2.5.3 Results and Discussion

Table 10 and Figure 17 show correct reaction times as a function of warning interval, and analysis showed that this effect was significant (F=5.68, df=3,33, p<0.01). The shape of this curve confirms that the build up of alertness in this task follows the classic pattern, with a minimum reaction time at around 250 to 500 ms., and provides further support for the apparent robustness of this phenomenon across different paradigms.

The effects of warning interval on accuracy and bias are shown in Table 10 and in Figure 18 for both reaction time and Non-RT conditions. There was no effect on bias in either condition and there was no difference between conditions. However, increasing the warning interval did have an effect upon accuracy (F=5.21, df=3,33, p<0.01), the best performance being at the 500 ms. foreperiod. In the case of the Non-RT condition, where no immediate response was required, this finding confirms the numerous findings (see section 1.2.3) that the effects of alertness cannot be accounted for by an explanation based on a motor preparation hypothesis. There was no difference in percentage correct between reaction time and Non-RT conditions, although there was a trend towards more accurate responding when rapid responses were not required (F=3.29, df=1,11, p=0.097). The possible implication of this finding will be examined further in the discussion of Experiment 7 (section 2.7.3).

These results provide further confirmation of the conclusions of Experiment 3 that alertness can improve accuracy of responding. They also agree with the findings of Experiment

4 by showing that this improvement is not restricted to very brief stimuli, and in addition can occur equally whether or not fast responses are required. Early sampling theory cannot account for these results, and so this is further evidence in favour of the hypothesis that alertness enhances perceptual encoding in addition to producing faster processing.

A related point of interest here concerns the basis of the primacy effect in memory recall, a topic which has been examined by Hockey and Hamilton (1977). Primacy refers to the observation that the initial few items presented in a list of to-be-remembered items are generally recalled better than those occurring later in the list. By using running memory span techniques in their experiments, Hockey and Hamilton eliminated the possibility of subjects adopting a selective rehearsal strategy. However, primacy still persisted, so they postulated an alternative explanation for the phenomenon in terms of alertness.

In this explanation they suggest that subjects are more alert at the beginning of the presentation of a list of items, and that this results in improved perceptual processing and consequently in a higher acquisition strength for the initial items. Subjects are less well prepared for subsequent items because of secondary processing demands such as rehearsal and memory storage as the list proceeds, and so these later items are less well recalled. This interpretation of primacy, and the possible role of alertness therein, is consistent with both the results and the conclusions of the present experiment.

Table 10 Experiment 5

Reaction time, accuracy and bias, as functions of warning interval duration.

	RT TASK			
WARNING INTERVAL	0	250	500	1000
Mean Correct RT	752	629	633	653
sd(RT)	204	102	94	92
Mean % Correct	80	81	87	84
sd(% Correct)	9	10	8	9
Mean % Diff.	50	45	47	48
sd(% Diff.)	5	8	4	9

	NON-RT TASK			
WARNING INTERVAL	0	250	500	1000
Mean % Correct	81	85	88	88
sd(% Correct)	12	11	10	9
Mean % Diff.	51	49	50	47
sd(% Diff.)	7	5	7	6

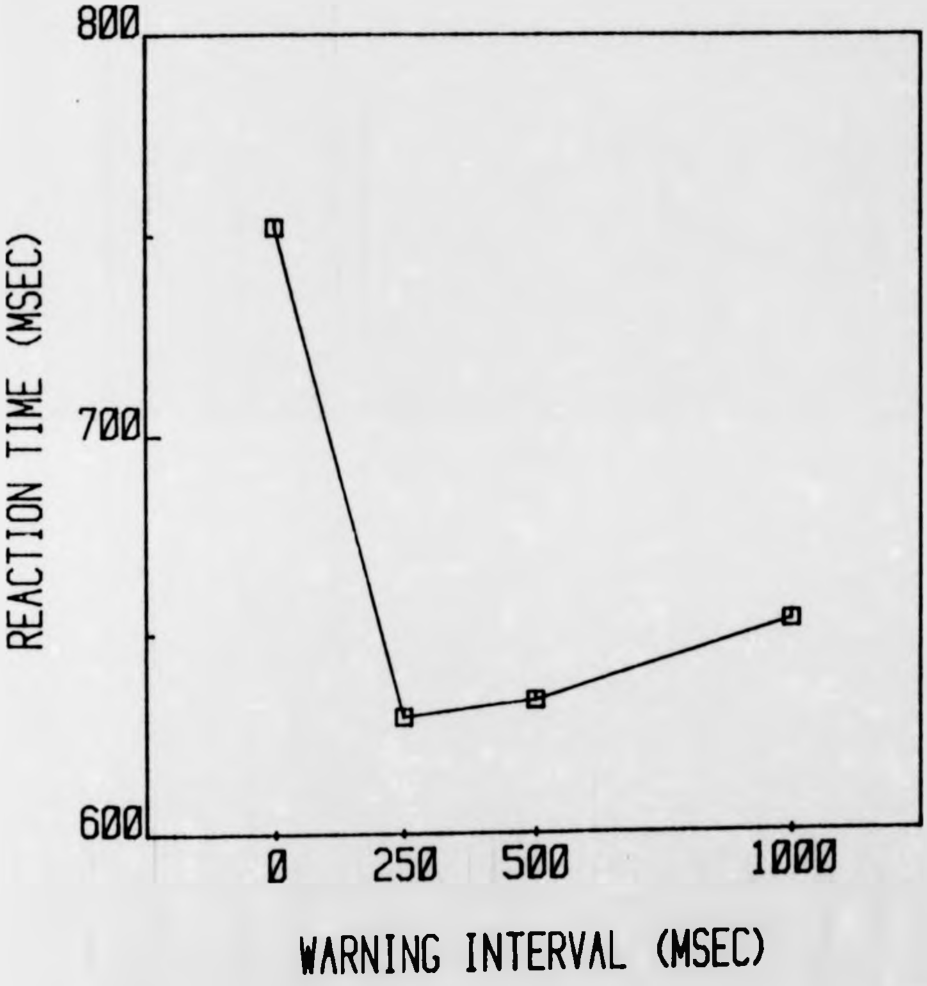


Figure 17 Experiment 5

Reaction time as a function of warning interval.

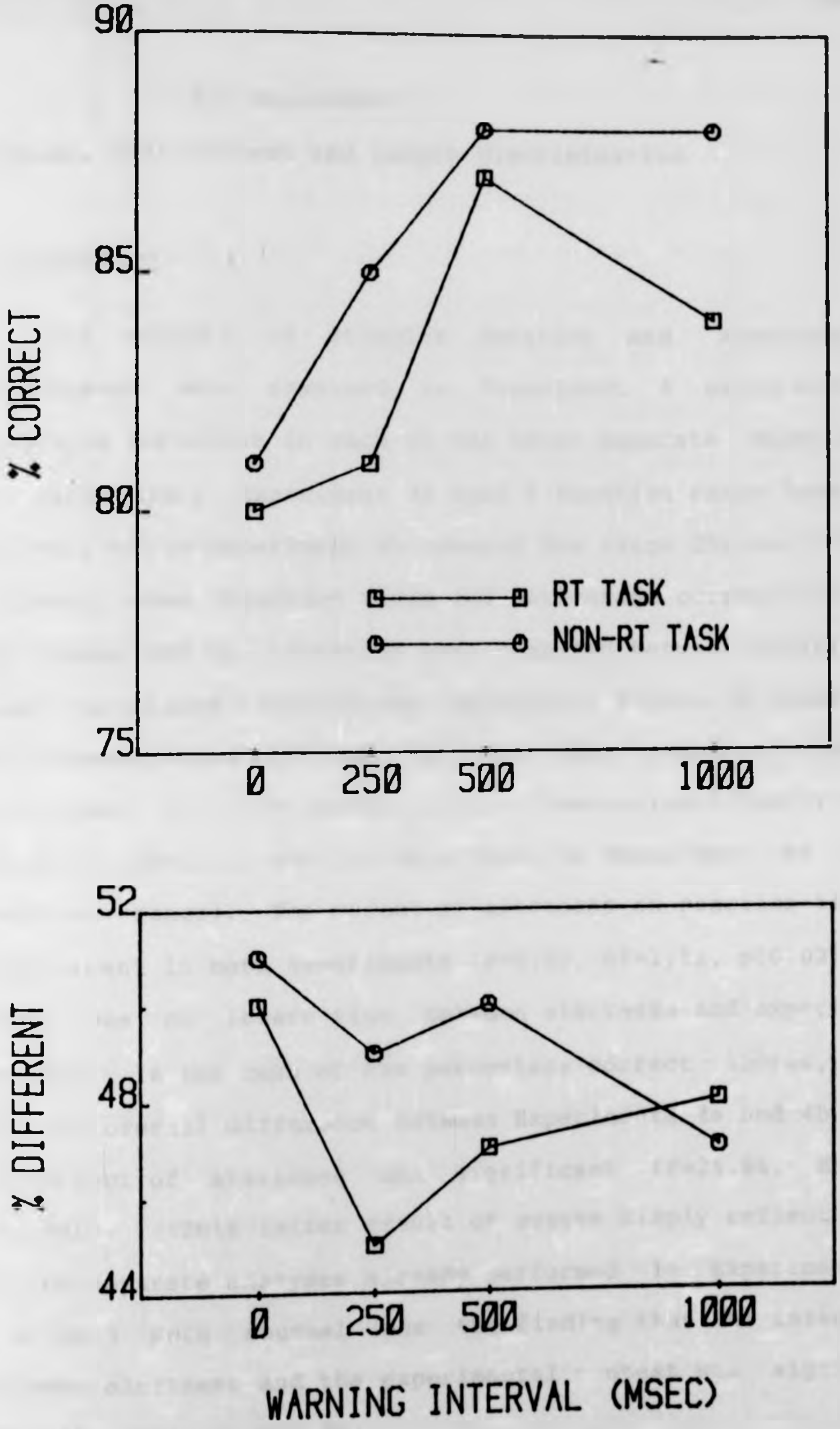


Figure 18 Experiment 5

Accuracy (upper panel) and bias (lower panel) as functions of warning interval in RT and Non-RT tasks.

2.6 Experiment 6

Alertness, Task Context and Length Discrimination

2.6.1 Introduction

The effects of stimulus duration and alertness on performance were examined in Experiment 4 using different ranges of durations in each of the three separate experiments. In particular, Experiment 4a used a duration range from 50 to 250 ms., while Experiment 4b covered the range 250 to 1000 ms. However, when reaction times and percentage correct scores at the common 250 ms. duration were compared between experiments, some surprising differences appeared. Figure 19 shows these differences, and it can be seen that reaction times in Experiment 4b (long duration range) were significantly faster ($F=15.85$, $df=1,12$, $p<0.01$) than those in Experiment 4a (short duration range). The effect of alertness on reaction time was significant in both experiments ($F=6.60$, $df=1,12$, $p<0.025$), and there was no interaction between alertness and experimental setting. In the case of the percentage correct scores, there was no overall difference between Experiments 4a and 4b, while the effect of alertness was significant ($F=24.86$, $df=1,12$, $p<0.001$). (This latter result of course simply reflects those of the separate analyses already performed in Experiments 4a and 4b.) More unusual was the finding that the interaction between alertness and the experimental context was significant ($F=4.89$, $df=1,12$, $p<0.05$).

The first explanation which suggested itself to account for this large difference in reaction times between the two experiments was that the mean difficulty level set during "subject calibration" was different between the two groups of subjects. However, on inspection this did not prove to be the case; mean difficulty levels were the same in both groups. Alternatively the results could simply have been due to individual differences, but the statistical analyses described above, based on a between-subjects unequal N analysis of variance, suggest that this might not be so. This leaves the possibility that the nature of the tasks and/or the strategies adopted by the subjects may have influenced their performance.

From the subjective viewpoint of the author, the long duration range experiment (4b) appeared to be an easier task to perform than did the short duration range experiment (4a). This may have led to faster overall responding by subjects in Experiment 4b. However, comparing error rates for the 250 ms. duration, the significant interaction mentioned above means that although there was no difference between the groups when alert, when they were not alert the long duration range group were less accurate than the short duration range group. Another way of expressing this is to state that there was a speed-accuracy tradeoff when subjects were non-alert, but none when they were alert. Keeping in mind the fact that the only difference between the two groups at the 250 ms. stimulus duration was the context of the other durations within which the task was performed, these results require some explanation. It may be that the manner in which task context influences subjects' strategies (and thereby performance) is itself affected by alertness. Indeed, on the basis of the present results, it would appear that alerted subjects can increase their speed without losing accuracy, whereas non-alerted subjects cannot do so.

Support for this view comes from suggestions by Moray (1967) and by Vaughan and Ritter (1973) that processing capacity may depend upon the context in which a task is performed. Kahneman's (1973) flexible allocation model of attention also allows for performance to be influenced by perceived task demands, and Walley and Weiden's (1973) neurophysiological model of attention contains an explicit mechanism for mediating the effects of instructions, previous stimulation or context. Empirical support comes from Nickerson (1965), who found that reaction time was related to both relative and absolute foreperiod durations, suggesting a form of context effect perhaps analogous to the present one. It is also interesting to note that in an experiment by Posner, Klein, Summers, and Buggie (1973, Experiment II), performance with a stimulus of 500 ms. in duration presented on its own was considerably faster than with a 400 ms. stimulus presented along with a 40 ms. duration stimulus. This performance difference was greater then that which the 100 ms. difference in durations would suggest, and indeed was greater than the difference in performance between the 400 and 40 ms. stimuli. Thus it may have been that in this situation, task context or content may have been affecting subjects' speed-accuracy tradeoff strategy.

The experimental evidence for the present claim that alertness and task context may interact is somewhat weak, coming as it does from a post-hoc analysis of unmatched and unequal sized groups of subjects. For this reason it was decided to try and replicate the results using a properly designed within-subjects paradigm. This involved subjects participating in two experimental sessions in which stimuli of

250 ms. in duration were paired with stimuli of either 100 ms. or 1000 ms. in duration. Thus each subject performed the discrimination task at the 250 ms. duration in two distinct contexts, hereafter referred to as the Short context and the Long context, respectively. It was the potential interaction between alertness and context at the 250 ms. duration which was the main effect of interest.

In addition to this replication of the comparison between Experiments 4a and 4b, the experiment was also run as a pure discrimination task, without any reaction time demands (as in Experiment 5), in order to determine whether task context could influence accuracy independently of speed. Such a finding would have interesting theoretical implications for the traditional view of stimulus discriminability as being a fixed characteristic of the receiver, unaffected by variables such as context or strategy.

2.6.2 Design and Method

All subjects participated in two experimental sessions, run at approximately the same times on consecutive days. In one of the sessions, stimulus durations of 250 and 100 ms. were presented, and in the other session the stimulus durations used were 250 and 1000 ms. Stimuli were presented under alerted (500 ms. warning interval) and non-alerted (zero warning interval) conditions in both sessions. Thus each session consisted of four conditions in a 2 by 2 design. Each condition involved a practice block of 10 trials, followed by a block of 30 experimental trials. The ordering of sessions, and of conditions-within-sessions was balanced across subjects.

In Experiment 6a, eight subjects performed the normal discrimination reaction time task as described for Experiment 4, whereas in Experiment 6b, another eight subjects performed in a Non-RT situation as described for Experiment 5. Setting of the task's difficulty level was done for all subjects prior to the first session, using a stimulus duration of 250 ms. and an intermediate level of alertness (250 ms. warning interval), and once set, the difficulty was not altered throughout the experiment. Prior to beginning the experiment, subjects were given examples of the stimulus durations to be used in that session, as it was thought that this might help to enhance the context effect.

2.6.2 Design and Method

Design Summary:

2 x 2 x 2 within-subjects design = 8 conditions;

Alert/Non-alert(blocked) x

Task Context (blocked: Short/Long) x

Stim. Duration (blocked: Short:250/100; Long:250/1000);

8 subjects, 30 trials per condition =

240 observations per data point;

Measures: Expt. 6a: Reaction Time, % Correct, % Different;

Expt. 6b: % Correct, % Different.

2.6.3 Results and Discussion

Table 11 presents the results for both sessions of Experiment 6a. When analysed as separate sessions, the data follow a similar pattern to that found in Experiments 4a and 4b, and the main points are summarised briefly as follows.

Considering reaction times first, the main effect of alertness produced significantly faster responding in both sessions (Short context: F=19.06, df=1,7, p<0.01; Long context: F=47.60, df=1,7, p<0.001). There were no effects of stimulus duration, but in the Short session there was a trend towards slower reaction times at the 100 ms. stimulus duration (F=4.14, df=1,7, p=0.08). There were no significant interactions.

Looking at the percentage correct scores, the main effect of stimulus duration was significant in both sessions, showing that accuracy was higher with increased stimulus duration (Short context: F=27.79, df=1,7, p<0.01; Long context: F=37.37, df=1,7, p<0.01). However, alertness had no effect upon accuracy in either of the context sessions, and there were no interactions between duration and alertness.

The percentage different scores for both sessions of Experiment 6a are displayed in the upper panel of Figure 20. Analysis of these data showed that there were no significant main effects or interactions.

Of more interest were the between-sessions differences at the common 250 ms. stimulus duration. Reaction times and percentage correct scores are presented together as a speed-accuracy tradeoff in Figure 21 in order to highlight this aspect of the data. The differences between the Short and Long contexts are represented by the dashed lines. The overall difference in reaction times between the two contexts at the 250 ms. duration was not significant, although there was a trend towards faster responding in the Long context session (F=3.72, df=1,7, p=0.09). There was no effect of context on accuracy.

A priori it might have been expected that any effect of context upon reaction time would be accompanied by an effect of context upon accuracy (regardless of the presence or absence of an alertness/context interaction). That this speed-accuracy tradeoff was not observed, may be in part related to the finding that the facilitating effect of alertness on accuracy found in Experiments 4 and 5 did not show up in this experiment. Furthermore, in the absence of any clearly observable context-induced shift in speed-accuracy tradeoff, it is impossible to determine any potential interaction with alertness. Thus the overall results are somewhat inconclusive, and do not provide support for the alertness/context interaction which was found in the comparison between Experiments 4a and 4b. As a contrast, these latter data are also presented as a speed-accuracy tradeoff in Figure 22. By comparing this with Figure 21, it can be seen that while the difference in reaction times between groups found in Experiment 4 is at least tentatively supported by the present findings, the effect of context upon accuracy, and its interaction with alertness, are not replicated, and so this latter phenomenon cannot be regarded as a valid one.

The findings of Experiment 6b are presented in Table 12, with the percentage different results being shown in the lower panel of Figure 20, and the percentage correct results in Figure 23. Analysis of the percentage different scores showed no significant effects of the experimental manipulations. Looking at percentage correct in the Short session, stimulus duration had a significant effect (F=66.96, df=1,7, p<0.001), whereas the effect of alertness failed to reach significance, and there was no interaction. In the Long duration session, both stimulus duration and alertness had significant effects on percentage correct (F=15.68, df=1,7, p<0.01 and F=6.35, df=1,7, p<0.025 respectively), without any interaction.

A between-sessions analysis of responses to the 250 ms. duration stimuli in Experiment 6b showed that the only significant effect was that of alertness on percentage correct (F=8.12, df=1,7, p<0.025), with no main effect of context, and no interaction between context and alertness. These results merely confirm the prior expectation that context would probably not have any effect upon accuracy in a Non-RT situation. This is particularly so in the light of the outcome of Experiment 6a, where the effect of context was minimal even though speed and accuracy could readily have been traded off against one another.

When the differences in the percentage correct and percentage different scores between experiments 6a and 6b were examined, these were all found to be non-significant, although there was an overall trend towards better accuracy in Experiment 6b, i.e., the Non-RT group (F=4.18, df=1,14, p=0.058). This trend closely reflects the similarly weak suggestion of better accuracy observed in the Non-RT condition of Experiment 5, and these will both be considered further in the discussion of Experiment 7 (section 2.7.3). In this overall analysis of Experiments 6a and 6b, which combines two groups of eight subjects, the effect of stimulus duration upon accuracy was highly significant (F=90.14, df=3,42, $p<0.001$), reflecting the results already found from the separate analyses. However, the effect of alertness upon accuracy, which did not reach significance in the separate analyses, was found to be significant in this pooled analysis (F=7.14, df=1,14, $p<0.025$). This suggests that the failure to find an effect of alertness in the separate groups may have been due in part to a lack of sufficient data. Combining the results of the two groups doubled the number of subjects, increasing the number of observations per data point from 240 to 480, a figure closer to that used in Experiments 4 and 5. While this is not a very satisfactory explanation, it nevertheless remains as a possible reason for the absence of any reliable effect of alertness in these experiments.

In a more recent experiment by Bartz (1979), subjects responded differently depending upon the order of presentation of the experimental conditions, which varied in perceived task complexity. Although presentation order was balanced across subjects in the present experiment, Bartz's observations, along with Poulton's (1978) finding of an asymmetrical transfer effect between quiet and loud noise conditions, suggested to the author that incorporating explicit statistical control for presentation order effects might influence the results. For this reason the main between-session analyses at the common 250 ms. duration were repeated for both experiments 6a and 6b, taking session order and condition-within-session order into account as covariates. These analyses indicated that order effects did not interact with alertness and did interact with context, but in only one instance was the pattern of results significantly altered. This was the effect of task context upon reaction time in Experiment 6a, which originally appeared only as a trend towards faster responding in the Long duration session; when session and condition orders were included as covariates this trend reached significance ($F=9.03$, $df=1,5$, $p<0.05$). Thus, this analysis suggests that the context effect observed in these experiments is a relatively weak one and highly subject to interference from order effects. The relatively small number of conditions within each session when compared to experiment 4 may have contributed to this failure to observe a reliable context effect, and this suggests that a mixed blocks design, (such as was used in the next experiment) might have been more effective in creating a context effect.

Taken as a whole, the results of Experiment 6, along with the comparisons between Experiments 4a and 4b, suggest that task context probably acts to alter the positioning of the decision criterion used to trade speed off against accuracy, but that the technique employed in the present experiment was not sufficiently powerful to generate a reliable effect of context upon accuracy. Consequently, the possible interactions between alertness and context were not adequately tested, and the exact nature of the effect of alertness on the relationship between speed and accuracy therefore remains undetermined.

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Table 11 Experiment 6a

Reaction times, accuracy and bias, as functions of alertness and stimulus duration, in short and long duration range sessions.

SHORT DURATION RANGE SESSION

	ALERT		NON-ALERT	
STIM. DURATION	100	250	100	250
Mean Correct RT	1081	956	1329	1132
sd(RT)	186	252	307	314
Mean % Correct	57	86	55	78
sd(% Correct)	15	12	11	10
Mean % Diff.	45	46	40	44
sd(% Diff.)	10	6	7	11

LONG DURATION RANGE SESSION

	ALERT		NON-ALERT	
STIM. DURATION	250	1000	250	1000
Mean Correct RT	892	839	1016	1025
sd(RT)	274	116	258	232
Mean % Correct	84	95	79	93
sd(% Correct)	8	5	16	7
Mean % Diff.	46	48	42	45
sd(% Diff.)	8	4	10	7

Table 12 Experiment 6b

Accuracy and bias as functions of alertness and stimulus duration, in short and long duration range sessions in a Non-RT task.

SHORT DURATION RANGE SESSION

	ALERT		NON-ALERT	
STIM. DURATION	100	250	100	250
Mean % Correct	63	91	58	84
sd(% Correct)	11	7	12	9
Mean % Diff.	48	47	49	49
sd(% Diff.)	12	5	14	6

LONG DURATION RANGE SESSION

	ALERT		NON-ALERT	
STIM. DURATION	250	1000	250	1000
Mean % Correct	90	98	85	98
sd(% Correct)	5	2	11	2
Mean % Diff.	45	48	49	49
sd(% Diff.)	5	2	9	3

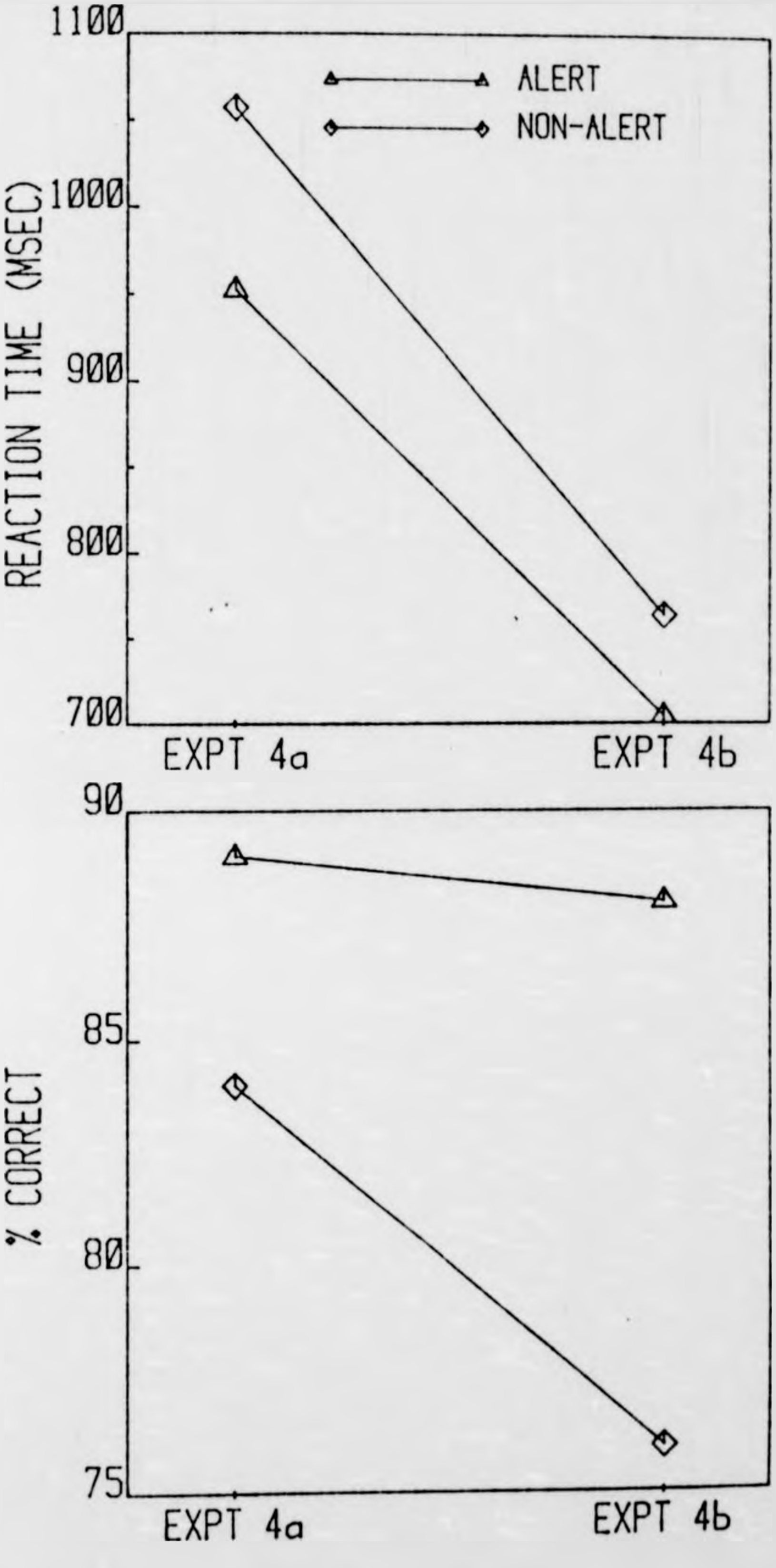

Figure 19 Experiments 4a and 4b re-plotted

Reaction time (upper panel) and Accuracy (lower panel) as functions of alertness at the common 250 ms. stimulus duration.

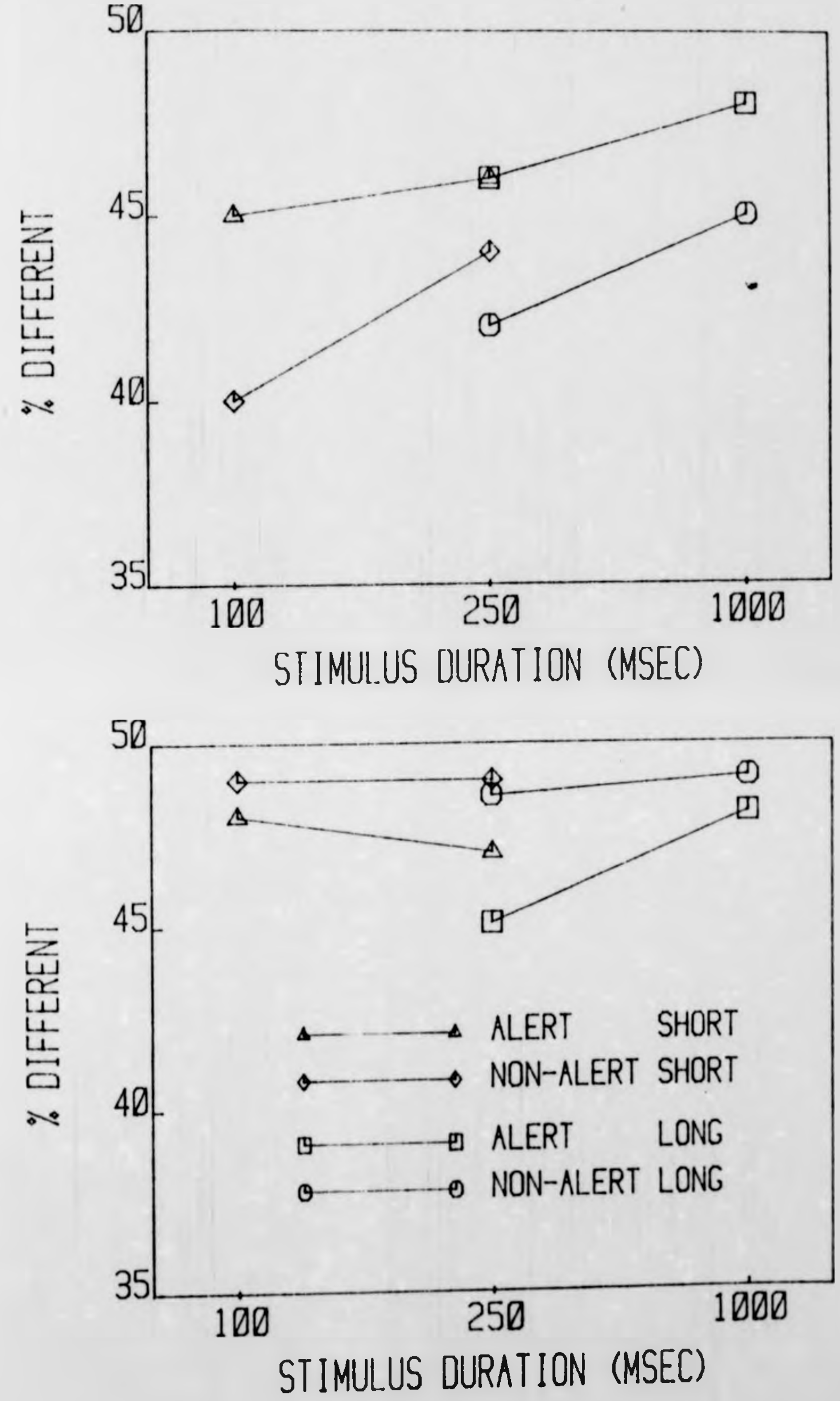

Figure 20 Experiment 6

Bias as a function of stimulus duration, alertness and task context, in an RT task (Experiment 6a: upper panel) and in a Non-RT task (Experiment 6b: lower panel).

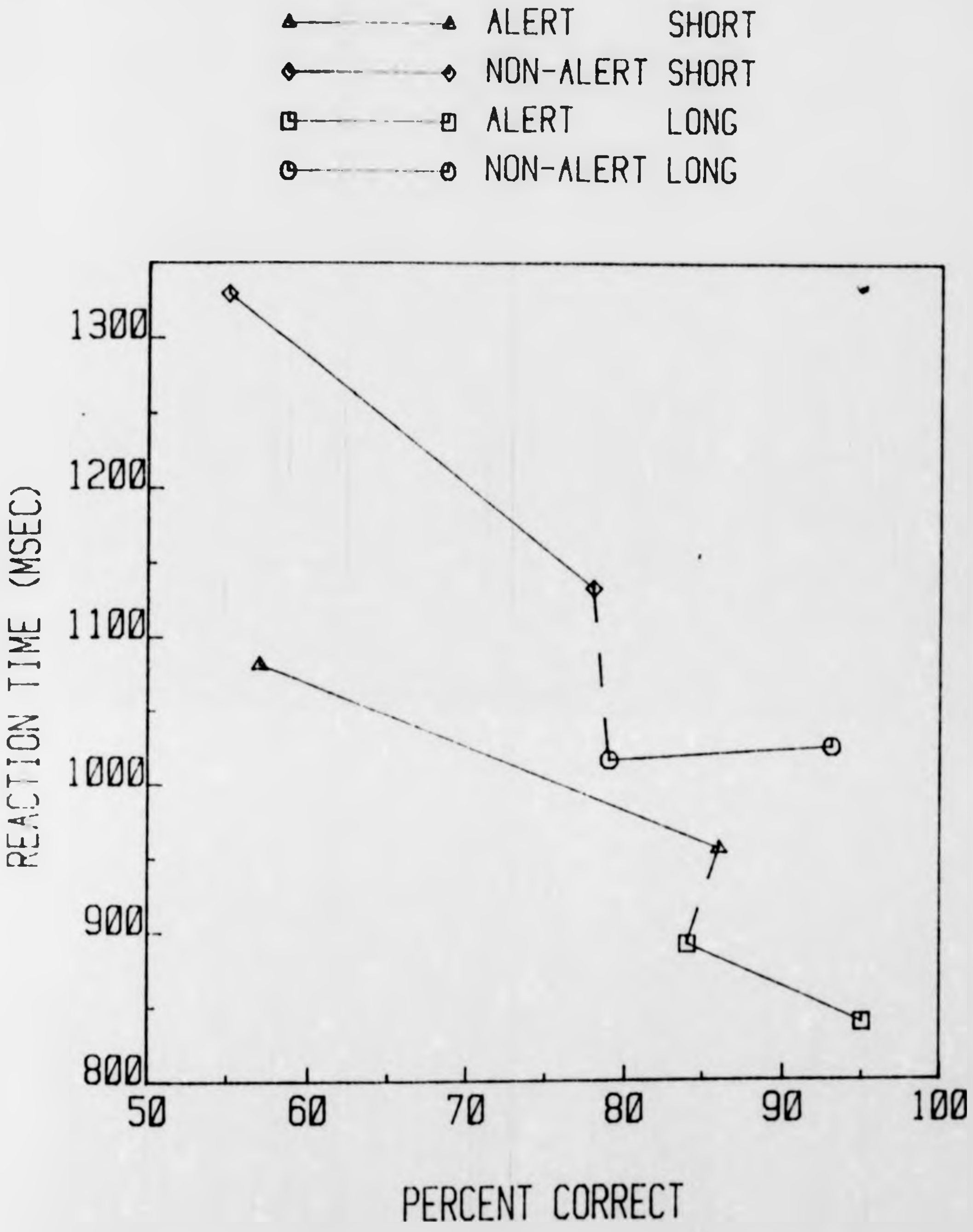

Figure 21 Experiment 6a

Speed-accuracy tradeoff as a function of alertness and task context. The points represent different stimulus durations, with the common 250 ms. durations joined by the dashed lines.

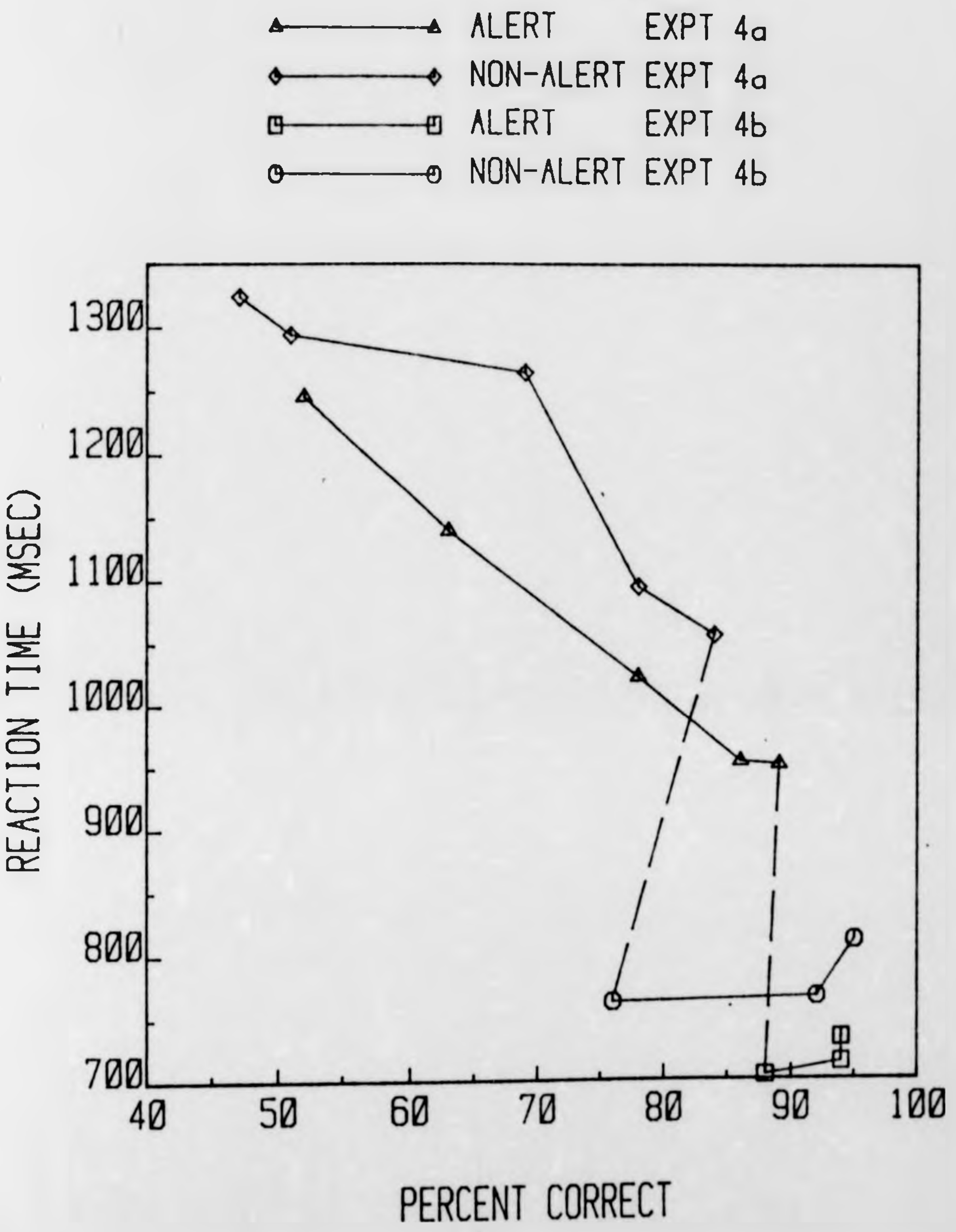

Figure 22 Experiments 4a and 4b re-plotted

Speed-accuracy tradeoff as a function of alertness and task context. The points represent different stimulus durations, with the common 250 ms. durations joined by the dashed lines.

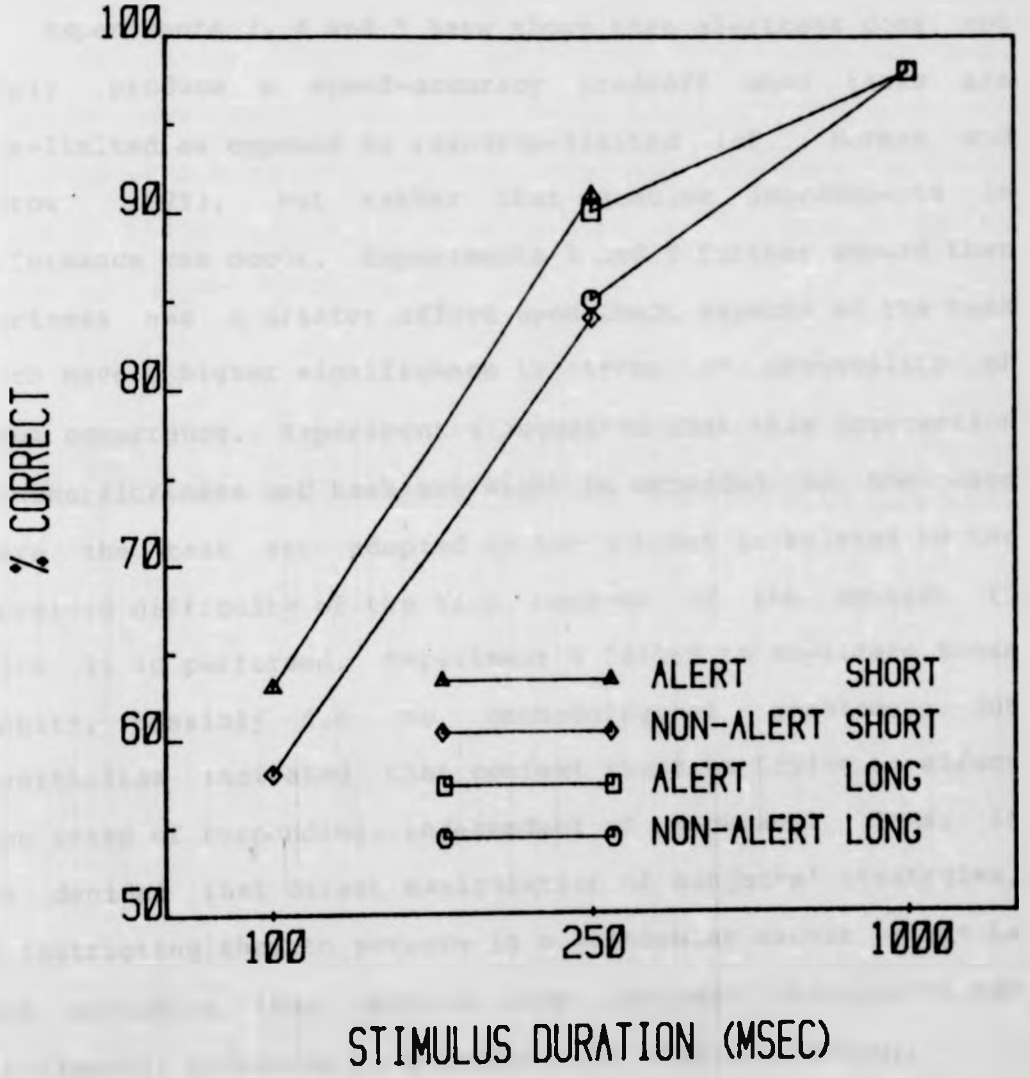

Figure 23 Experiment 6b

Accuracy as a function of stimulus duration, alertness and task context in a Non-RT task.

2.7 Experiment 7

Alertness, Task Instructions and Length Discrimination

2.7.1 Introduction

Experiments 3, 4 and 5 have shown that alertness does not simply produce a speed-accuracy tradeoff when tasks are data-limited as opposed to resource-limited (cf. Norman and Bobrow, 1975), but rather that genuine improvements in performance can occur. Experiments 1 and 2 further showed that alertness has a greater effect upon those aspects of the task which have a higher significance in terms of probability of event occurrence. Experiment 4 suggested that this interaction between alertness and task set might be extended to the case where the task set adopted by the subject is related to the perceived difficulty of the task because of the context in which it is performed. Experiment 6 failed to replicate these results, possibly due to methodological problems, but nevertheless indicated that context might be having an effect upon speed of responding, independent of accuracy. Thus, it was decided that direct manipulation of subjects' strategies, by instructing them to perform in a particular manner, might be more effective than relying upon inherent features of the experimental situation to determine the adopted strategy.

Again this experiment made use of the visual length discrimination paradigm employed in the preceding experiments. In this case however, subjects performed sessions in which they were instructed either to respond as fast as possible without worrying unduly about their accuracy, or else to respond as accurately as possible without being too concerned about speed. A number of researchers (e.g. Hick, 1952; Hale, 1969; Pew, 1969; Stanovich and Pachella, 1976) have shown the effectiveness of instructions in manipulating strategy in terms of changes in speed-accuracy tradeoff. The prediction being made in this experiment was that the differences in performance between these Speed and Accuracy conditions should be more pronounced under alertness, indicating that when alerted, subjects have more control over their available resources and abilities than when they are not alerted, and are able to allocate these resources more optimally in favour of the emphasised aspect of the task.

For comparison purposes, the experiment was also performed as a pure discrimination, in which reaction times were not required. In terms of strategy, it might be expected that in the absence of any pressure to respond rapidly, subjects should be able to perform more accurately than in the Speed and Accuracy conditions. Furthermore, the present view that alertness should enhance the efficacy of a chosen strategy implies that the improvement in accuracy in the Non-RT condition should be even greater when alerted. Related evidence on this point comes from Experiments 5 and 6, but these only show trends towards better performance in the Non-RT conditions, and no evidence of an interaction with alertness, so the results of the present experiment may help to clarify this issue.

Three stimulus durations of 150, 250 and 350 ms. were presented in all sessions, in order to provide a somewhat broader base from which to draw conclusions, and also to enable the effect of alertness on speed-accuracy tradeoff to be examined as a function of duration. Experiment 4 suggested that alertness had a more pronounced effect upon accuracy at shorter durations, due to the greater likelihood of perceptual error, and consequently the interaction between speed-accuracy tradeoff and alertness, if observed, should be greater at shorter duration stimuli.

2.7.2 Design and Method

There were three experimental sessions for each subject in this experiment. In one of the sessions (Speed condition) the subject was given written and verbal instructions to respond as rapidly as possible to the stimuli without worrying too much about being accurate. In another session (Accuracy condition) the instructions stated that subjects should respond as accurately as possible without trying to be fast. The remaining session (Non-RT condition) did not require timed responses in that there was an enforced gap of 1.5 seconds between stimulus presentation and the subject being allowed to respond, as explained in greater detail for Experiment 5. Order of presentation of sessions was balanced across the twelve subjects who took part in the experiment, and the sessions were performed at approximately the same times on successive days.

Although the visual length discrimination task already described was used again in this experiment, the paradigm was slightly different in that a mixed blocks design was used. This was because with three stimulus durations, two alertness levels and three sessions, the number of separate blocks of trials would otherwise have become prohibitive and rather confusing. In addition, the apparent ineffectiveness of the blocking methods used in Experiment 6 in producing context effects suggested that a fully mixed design might be a more appropriate technique to adopt. The stimulus durations of 150, 250 and 350 ms. and the alertness conditions of zero and 500 ms. warning interval (6 treatment combinations in all) were mixed in a randomly ordered sequence and presented as one entire session, divided into blocks simply to provide rest periods. Thus each session consisted of a block of 24 practice trials, followed by 192 experimental trials broken into 4 blocks of 48, giving 32 trials per condition.

Prior to the first session, calibration of difficulty level was done for each subject using a stimulus duration of 250 ms., an intermediate warning interval of 250 ms., and "neutral" instructions to respond as rapidly and as accurately as possible. Once set, the difficulty level was not altered throughout the experiment. Prior to each session, the instructions on how to respond were emphasised strongly, and in addition, to provide added contrast, the feedback during the Speed session consisted solely of reaction time feedback, with no accuracy information. Conversely, in the Accuracy and Non-RT sessions, accuracy feedback alone was presented.

Design Summary:

2 x 3 x 3 within-subjects design = 18 conditions;

Alert/Non-alert(mixed) x

Stimulus Duration(mixed:150/250/350 ms.) x

Instructions(blocked:Speed/Accuracy/Non-RT);

12 subjects, 32 trials per condition =

384 observations per data point;

Measures: Choice Reaction Time, % Correct, % Different.

2.7.3 Results and Discussion

All of the results for Experiment 7 are presented in Table 13. Performance within each session will be analysed first, and then the differences between sessions will be examined. Reaction times and percentage correct scores for the Speed and Accuracy sessions are displayed together in Figure 24 for subsequent comparison purposes.

In the Speed session, alertness produced a reduction in reaction time ($F=24.26$, $df=1,11$, $p<0.01$), whereas stimulus duration had no effect on reaction time and did not interact with alertness. The main effect of alertness on percentage correct was not significant, but accuracy was greater at the longer durations ($F=3.80$, $df=2,22$, $p<0.05$). The interaction between alertness and duration was significant ($F=3.47$, $df=2,22$, $p<0.05$), indicating that alertness tended to reduce accuracy at longer stimulus durations. Bias scores (percentage different) in the Speed condition were not affected by either alertness or duration. It should be emphasised that although not significant as an overall main effect, the effect of alertness on accuracy at all durations was in the direction of increasing error rate. This is in contrast to most of the results so far obtained; in previous experiments reported in this thesis, alertness has usually produced an improvement in accuracy, especially at shorter stimulus durations. In the present experiment it would appear that there is less deterioration or speed-accuracy tradeoff due to alertness at shorter durations. Thus, the interaction between alertness and duration appears to follow the same pattern as before, and it seems that when subjects are instructed to respond as rapidly as possible, alertness helps them to do so, albeit at the expense of reduced accuracy, particularly at longer stimulus durations.

In the Accuracy condition, both alertness and increasing stimulus duration produced significant reductions in reaction times, with no significant interaction ($F=29.66$, $df=1,11$, $p<0.001$ and $F=4.64$, $df=2,22$, $p<0.05$ respectively). Accuracy was greatest at the longer durations ($F=20.18$, $df=2,22$, $p<0.001$) but was not affected by alertness, although there was a trend towards better accuracy at the shortest duration when alerted (interaction: $F=2.61$, $df=2,22$, $p=0.09$). Analysis of the percentage different scores for this session showed no significant effects. The lack of an effect of alertness on accuracy in this session was somewhat disappointing, since it was expected that alertness should have enabled subjects to obey the task instructions more closely, sacrificing reaction time reduction for an improvement in accuracy (i.e., the "inverse" of the findings in the Speed condition). However, since there was a significant reduction in reaction time and no change in accuracy due to alertness, it would appear that subjects did not adopt a strategy of this sort.

The results from the Non-RT session are presented in Figure 25, and analysis showed that both alertness and increased duration had the effect of increasing accuracy ($F=32.33$, $df=1,11$, $p<0.001$ and $F=23.74$, $df=2,22$, $p<0.001$ respectively). There was a significant interaction between these main effects ($F=6.40$, $df=2,22$, $p<0.025$), indicating that there was a greater improvement due to alertness at the shorter duration stimuli. These findings in general confirm the results of the previous experiments regarding the interacting effects of alertness and duration upon accuracy. Analysis of the percentage different scores for this session indicated that alertness produced a bias towards responding "same" (F=5.01, df=1,11, $p<0.05$). No explanation suggests itself for this, particularly as it was the only significant effect on percentage different scores in the entire series of experiments. Thomas (1973) and Posner (1978) have also failed to observe any effect of foreperiod on response bias, and so it seems likely that this is a chance result.

A particularly interesting aspect of the data was the contrast between performance in the Speed and the Accuracy sessions, since according to the present view the speed-accuracy tradeoff between these conditions should be greater when subjects are alerted. Remembering that in Figure 24 a diagonal shift from lower left to upper right represents a trading of speed for accuracy, then it can be seen from these graphs that at all three durations, there is a suggestion that the degree of shift, or of tradeoff, between the two sessions was greater when subjects were alert than when they were not. To determine the statistical reliability of these shifts, the difference scores between the two sessions for both reaction times and percentage correct were computed for each subject, and the mean scores are presented in Table 14 and Figure 26. These difference scores were analysed, first of all separately, and then as a bi-variate analysis of variance.

Analysis of the reaction time difference scores showed that task instructions produced a greater shift at the shorter durations (F=3.78, df=2,22, $p<0.05$), whereas the shift in reaction time due to alertness was not significant. In the case of the difference scores for percentage correct, the shift in accuracy was significantly larger when subjects were alert then when they were non-alert (F=5.74, df=1,11, p<0.05), but the difference in accuracy between sessions was not influenced by stimulus duration. There was no interaction between alertness and duration either for the reaction time shift or for the percentage correct shift.

Thus it would seem that the effect of the interaction between alertness and task instructions was to cause a greater improvement in accuracy when alerted, whilst the shift in reaction time between sessions did not appear to be affected by alertness. In order to conclude that this was definitely an alertness induced shift in speed-accuracy trade-off, an analysis which takes both reaction time and percentage correct into account simultaneously was desirable. As, a priori, no particular combinatorial formula can be used to compute a single measure of speed-accuracy tradeoff, a bi-variate analysis of variance was performed, following a recommendation by Pachella (1974). This in essence uses a linear combination based on a least squares estimate for evaluating the data. The analysis confirmed that when taken together, the difference scores for reaction time and for percentage correct were greater when subjects were alert than when they were not alert (F=4.95, df=2,21, p<0.025). The analysis also showed that the overall differences between sessions was greater at shorter durations (F=2.98, df=4,42, p<0.05). The potential interaction between alertness and duration in this analysis did not prove to be significant.

An analysis of the differences in accuracy between the Speed and the Non-RT sessions showed, as might have been expected, that performance was significantly better in the latter condition (F=10.97, df=1,11, p<0.01). There was a significant interaction between sessions and alertness (F=15.35, df=1,11, p<0.01), reflecting the findings already noted in the separate analyses that alertness improved performance in the Non-RT session, whereas if anything there was a trend towards lower accuracy when alerted in the Speed session. More interesting is the comparison of percentage correct scores between the Accuracy and Non-RT conditions, and this is depicted in Figure 27. Analysis of these data showed that there was no overall difference between the sessions. However, sessions interacted with alertness (F=5.72, df=1,11, p<0.05), again indicating, as already found from the separate sessions analyses, that in the Non-RT session performance was improved by alertness, whereas in the Accuracy session there was no difference between alerted and non-alerted conditions. The only actual between-sessions difference was that performance was better in the Accuracy session than in the Non-RT session, but only when subjects were non-alerted. Similarly, Experiments 5 and 6 merely showed trends towards better accuracy in Non-RT conditions. Taken together, these results imply that a situation in which responses do not need to be made rapidly may not always be the one in which accuracy is best.

A possible explanation for this collection of seemingly disparate results is now presented. Rabbitt and Vyas (1970), Thomas (1973) and Wickelgren (1977) have all pointed out that there is an upper limit to performance, above which no gain in accuracy can be obtained by sacrificing speed. In Norman and Bobrow's (1975) terms, performance up to a certain point is resource-limited and can exhibit a speed-accuracy tradeoff, but beyond this point it becomes data-limited and cannot be improved any further simply by trading speed for accuracy. In the present case it may be that subjects were performing at this asymptotic level in both the Accuracy and Non-RT sessions, and so no differences in percentage correct were observed between these sessions. Alertness however, by effectively improving the quality of the available data, enables a genuine improvement in performance to occur. In the Non-RT condition of this experiment (and of Experiments 5 and 6), this could only be manifested in an increase in accuracy. In the Accuracy session, on the other hand, subjects appear to have maintained a constant level of accuracy while reducing their reaction times, even though the emphasis in the instructions was upon accuracy rather than speed. In contrast to these two conditions, the strong emphasis upon fast responses in the Speed session may have imposed resource limitations upon the task, resulting in a situation where speed-accuracy tradeoff could occur. The reduction in reaction time produced by alertness in this resource-limited situation would then result in an increase in errors, as in fact the observed trend in the data suggests.

In conclusion, while these proposed distinctions between the strategies adopted in the various conditions are somewhat more complex than envisaged in the introduction to this experiment, they nevertheless do not negate the original hypothesis that alertness enables the individual to perform more closely in accordance with task instructions. The analysis of the performance tradeoffs between the Speed and Accuracy sessions indicates that alertness does have the effect of facilitating optimal resource allocation to the task in hand. The results also indicate that the greatest accuracy does not necessarily always occur in the absence of a timed response requirement: rather, there seems to be an upper limit to performance, above which speed-accuracy tradeoff does not occur.

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Table 13 Experiment 7

Reaction times, accuracy and bias, as functions of alertness and stimulus duration, under speed instructions, accuracy instructions and under Non-RT conditions.

SPEED

	ALERT			NON-ALERT		
STIM. DURATION	150	250	350	150	250	350
Mean Correct RT	474	484	493	563	554	561
sd(RT)	81	74	82	135	70	85
Mean % Correct	70	76	74	73	76	84
sd(% Correct)	11	10	14	12	13	10
Mean % Diff.	45	49	47	42	47	49
sd(% Diff.)	15	13	10	11	10	12

ACCURACY

	ALERT			NON-ALERT		
STIM. DURATION	150	250	350	150	250	350
Mean Correct RT	718	690	690	837	735	741
sd(RT)	159	136	137	239	102	103
Mean % Correct	84	93	94	78	91	96
sd(% Correct)	13	8	6	9	7	5
Mean % Diff.	41	49	50	48	51	51
sd(% Diff.)	12	6	4	18	7	4

NON-RT

	ALERT			NON-ALERT		
STIM. DURATION	150	250	350	150	250	350
Mean % Correct	83	94	95	72	89	91
sd(% Correct)	10	8	7	13	9	8
Mean % Diff.	44	48	47	48	51	54
sd(% Diff.)	12	6	6	14	5	8

Table 14 Experiment 7

Shifts in Mean Reaction Time and percentage correct between the Speed and the Accuracy sessions.

	ALERT			NON-ALERT		
STIM. DURATION	150	250	350	150	250	350
RT Shift	244	205	197	274	186	178
% Correct Shift	14	16	20	6	14	12

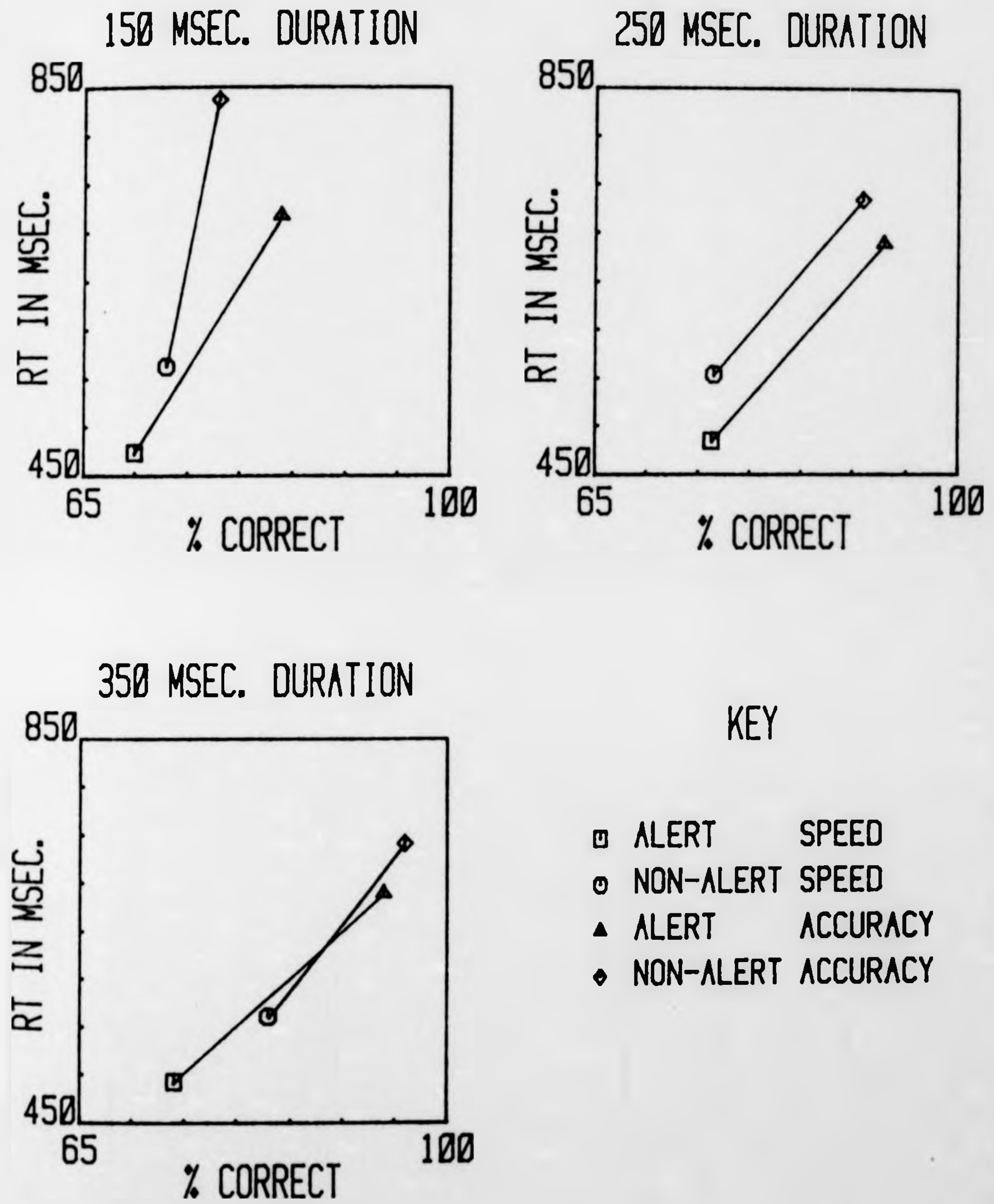

Figure 24. Experiment 7

Speed-accuracy tradeoff as a function of alertness and task instructions, at different stimulus durations.

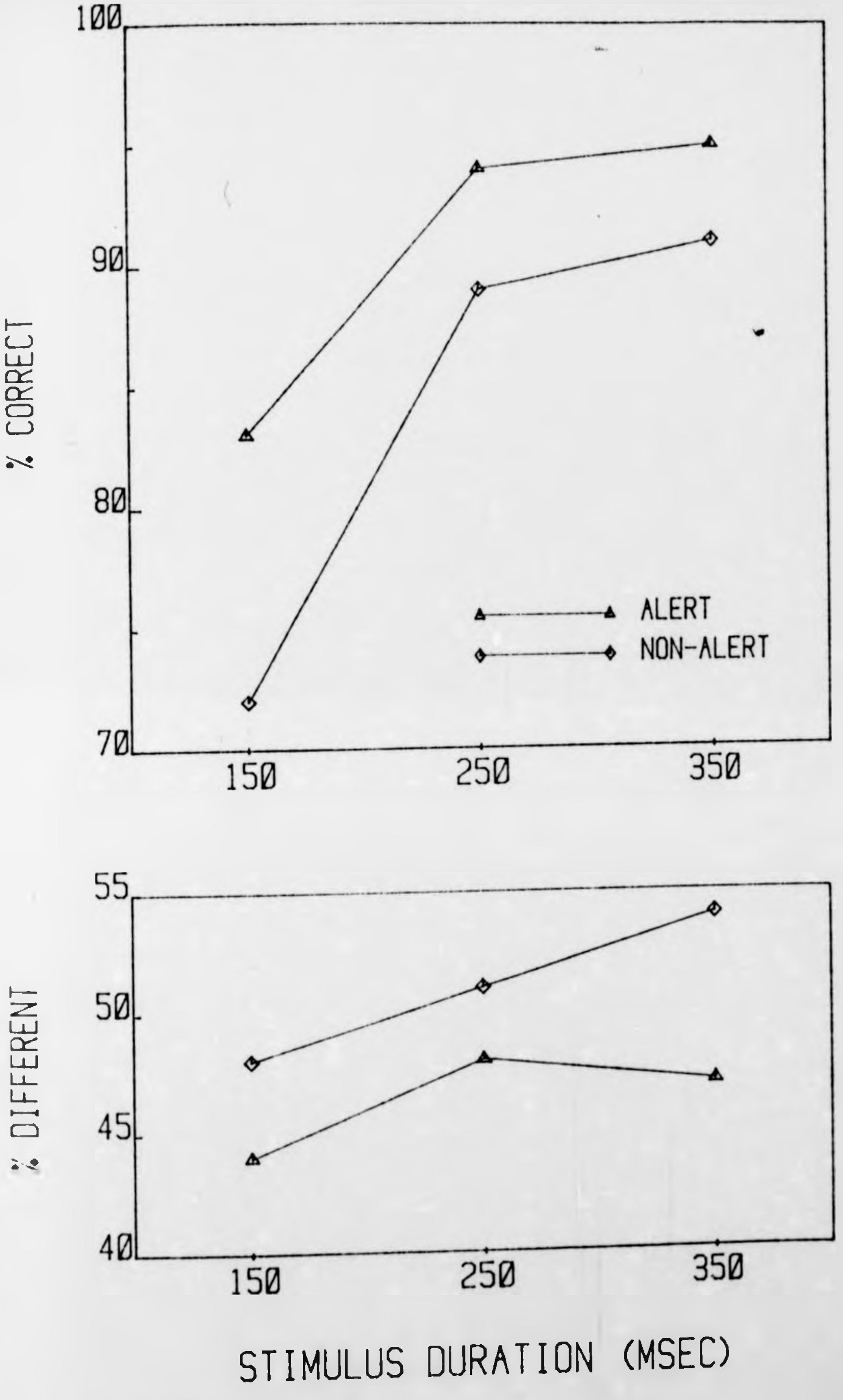

Figure 25 Experiment 7

Accuracy (upper panel) and bias (lower panel) as functions of stimulus duration and alertness in a Non-RT task.

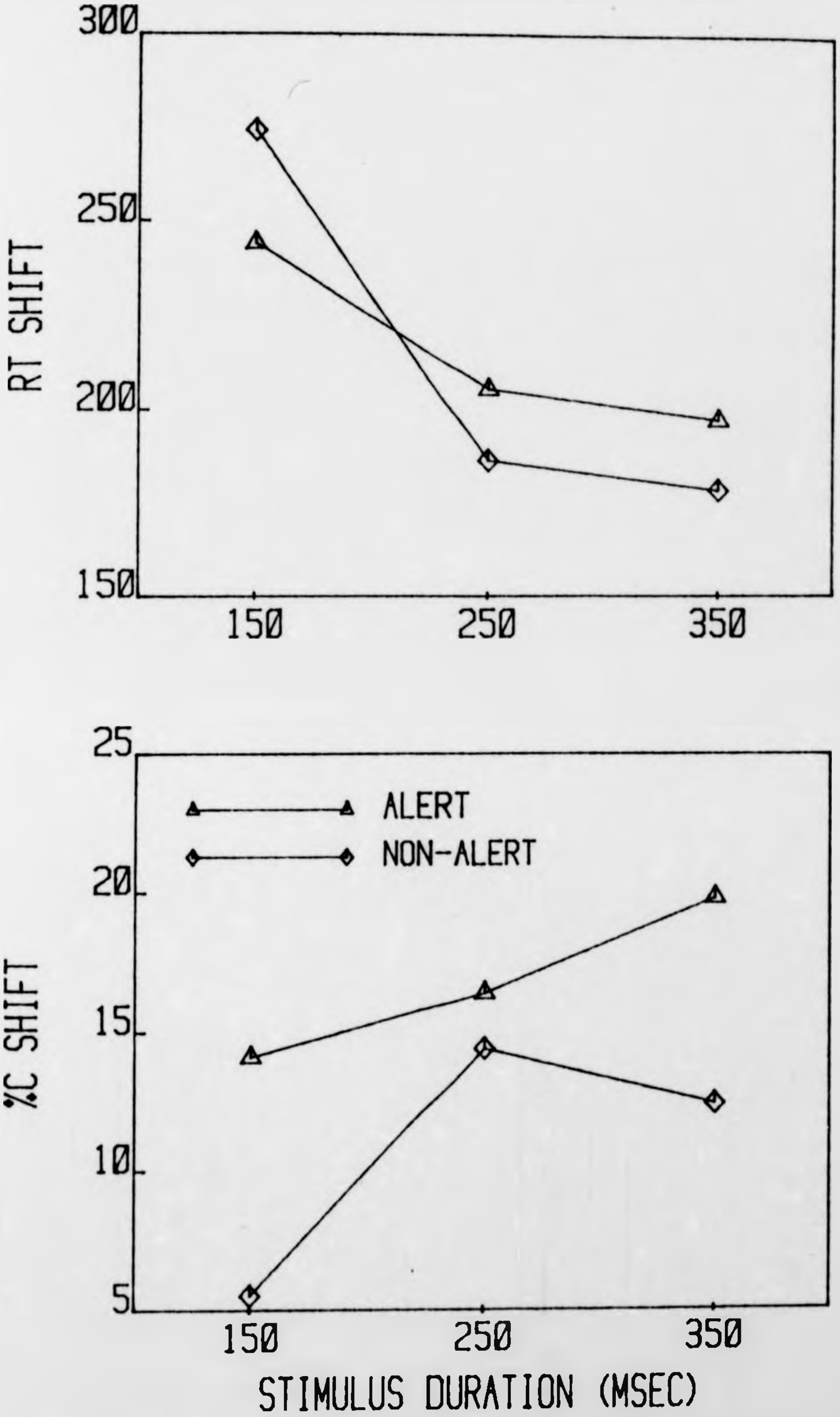

Figure 26 Experiment 7

Shifts in reaction time (upper panel) and accuracy (lower panel) between Speed and Accuracy emphasis conditions, as functions of stimulus duration and alertness.

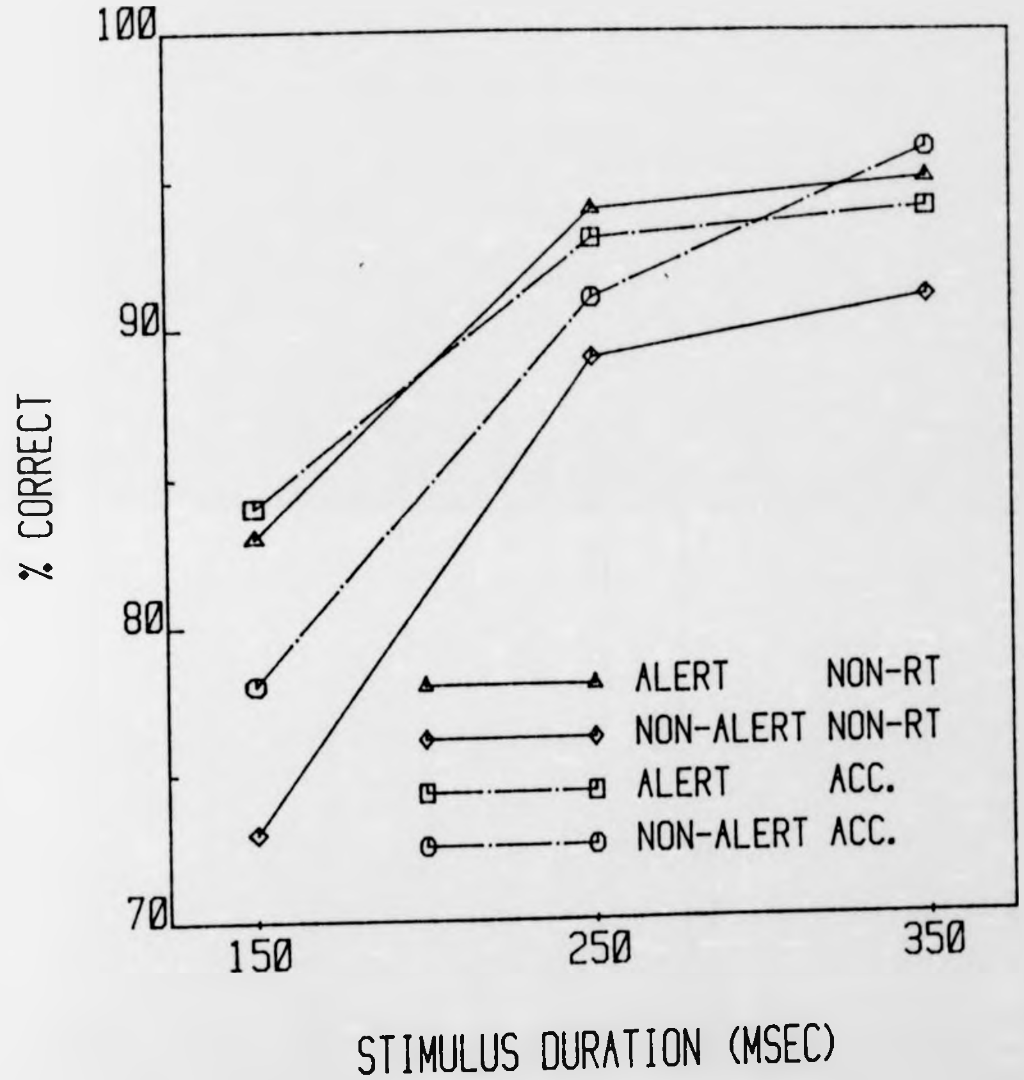

Figure 27 Experiment 7

Accuracy as a function of stimulus duration and alertness under Accuracy instructions and Non-RT task conditions.

ALERTNESS AND THE
CONTROL OF ATTENTION

Section 3. General Discussion

3.1 Summary of Empirical Findings

As a prelude to a general discussion of the experiments presented in this thesis, a brief summary of the main empirical findings will now be presented.

Experiment 1 showed that for foreperiods of less than one second in duration, expectancy, or stimulus predictability, did not play a significant role in determining simple reaction times. Rather, the actual foreperiod duration and the presence or absence of catch trials were the main determinants of reaction time.

Experiment 2 was designed to examine the effect of alertness upon the relationship between stimulus probability and choice reaction time. The results suggested that, as hypothesised, the reduction in reaction time observed for higher probability stimuli was enhanced by alertness. This conclusion was also supported by a post-hoc analysis of the relationship between simple reaction time and probability at the different foreperiods in Experiment 1.

The prediction of Posner's (1974) early-sampling theory that alertness could improve both speed and accuracy of reaction to a briefly presented stimulus was confirmed in Experiment 3. The results of Experiment 4 showed that this type of improvement in both speed and accuracy was not in fact restricted simply to stimuli of brief duration, leading to the conclusion, in line with Kahneman's (1973) prediction, that alertness can genuinely improve performance wherever there is a possibility of perceptual errors occurring.

Experiment 3 also involved a detailed analysis of reaction time distributions, which showed that within an experimental condition, and independent of alertness manipulations, faster responses to brief stimuli had a higher probability of being correct than did slower responses. Furthermore, a comparison of the relationships between speed and accuracy within and between conditions suggested that early-sampling theory could only account for a small part of the observed variations, and that some additional speed-accuracy tradeoff must also have been taking place as a result of alertness.

In addition to confirming in a visual discrimination paradigm the existence of the classical relationship between reaction time and foreperiod, the results of Experiment 5 showed that alertness can improve accuracy even in the absence of a requirement to respond rapidly. This provided support for the view that alertness can enhance the encoding process, and these conclusions were confirmed by subsequent results from Experiments 6 and 7 which also involved untimed responding.

Experiment 6 set out to explore the interaction between alertness and task context which was suggested by a re-analysis of the results from Experiments 4a and 4b. While there was an indication of an effect of context upon reaction time, the results were generally insignificant, allowing no firm conclusions to be drawn. As an alternative to the methods employed in Experiment 6, instructions were adopted in Experiment 7 as a means of manipulating subjects' strategies. The results showed that when alerted, subjects appeared better able to conform to the task instructions, in agreement with prediction.

From the foregoing summary it would appear that the most general conclusion which can be drawn is that alertness tends to improve performance in a manner which is most appropriate to the demands of the task in hand. This was the case both when particular task demands were emphasised by means of instructions, as in Experiment 7, and when the emphasis was via inherent properties of the task such as stimulus probability, as in Experiments 1 and 2. Improvements in both speed and accuracy were observed in Experiments 3, 4 and 5, in some situations simultaneously. This general enhancement of attentional control was not observed when task context was systematically manipulated, as in Experiment 6, and a number of possible methodological causes for this discrepancy were considered.

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3.2 Towards a Theory of Alertness

By no means have all of the possible questions concerning alertness been attacked or answered in this thesis. However, when taken together with the literature reviewed in the introduction, the present findings would appear to provide enough information about the nature of the alertness process to form the basis of a theory of alertness. Such a theory can be viewed as a summary of the author's opinions concerning alertness and its relationship to the control of attention. Noticeable by its absence from the discussion which follows is a detailed elaboration of the control process or processes underlying alertness. This and a number of other unresolved issues are considered further in section 3.3.

The present theoretical position can be summarised by the following six postulates, and these are discussed one by one in the remainder of this section, in the context of more recent related research work where appropriate.

1. Alertness is a state of enhanced receptivity and increased readiness to respond;
2. The time course of alertness from rise to fall is around one second;
3. Alertness is a phenomenon of the central nervous system;
4. Alertness causes an increase in attentional selectivity;
5. Alertness enables greater flexibility in the allocation of attentional resources;
6. The control of alertness can be active and voluntary.

Postulate 1
Alertness is a state of enhanced receptivity and increased readiness to respond

The numerous findings of reduced reaction times and increased accuracy when subjects are alert, which were discussed in the introduction, form the basis of this simple claim. Most of the experiments in the present thesis showed a reduction in reaction time as a function of alertness, and in particular, Experiments 3, 4 and 5 showed that alertness can produce genuine performance improvements, and is not limited simply to producing speed-accuracy tradeoffs. The physiological similarities noted in the introduction between alertness and the orienting response further support the view of alertness as a state of enhanced receptivity and increased readiness to respond. The possible implications of this similarity will be examined in section 3.3.

The present view can be contrasted in particular with that held by Posner (1974, 1978), who argues that alertness does not increase receptivity, but rather that it simply causes earlier processing of incoming sensory data. However, Experiments 3 and 4 showed that such a model does not adequately account for the observed results, and that a view which allows for enhanced encoding as a function of alertness, such as that proposed by Kahneman (1973), is more appropriate.

Postulate 2
The time course of alertness from rise to fall is around one second

Evidence was presented in the introduction which suggested that following warning signal onset, physiological and behavioural measures both change rapidly during the first 200 ms., and appear to peak fairly consistently after about 500 ms. During the next second, alertness falls back towards pre-warning levels. Beyond this, however, it is difficult to make any meaningful observation because other factors such as expectancy and strategy begin to play a dominant role in determining performance at these longer intervals.

The relatively short time course of alertness reflects the fact that considerable effort is required for the build-up and maintenance of alertness, a point which was noted as early as 1890 by James, and by Breitweiser in 1911, in their discussions of the "attention wave." As noted in the introduction, Naatanen (1970a) has described the build-up of alertness as resulting in a state of "short-term exhaustion," and the whole notion of the effort demanded by states of high attention has been examined in detail by Kahneman (1973). The use of strategies and expectancies to control alertness and optimise allocation of effort, and the question of a possible refractory period for alertness, are discussed in the next section (3.3).

Postulate 3
Alertness is a phenomemon of the central nervous system

From the literature review presented in section 1.2.3, it was concluded that the mechanisms whereby alertness influences behaviour are central in nature. There have also been a number of recent investigations into the locus of attentional control, particularly by Posner and his colleagues (Posner, Nissen and Ogden, 1978; Posner, 1980; Posner, Snyder and Davidson, 1980). They have found considerable evidence that visual attention can be allocated and directed independently of eye movements, in different paradigms involving mental set, orientation, and detection respectively. In addition, Sperling and Melchner (1978) have observed that subjects are able to distribute their attention between two spatially distinct sets in accordance with instructions from the experimenter, while keeping their eyes positioned on a central fixation point. Klein (1980) has also shown that preparing to move the eyes to a particular location (occulomotor readiness) does not facilitate signal detection in that location. These studies, taken in the context of with those examined in the introduction to this thesis, provide further evidence that alertness, as an aspect of the attentional control process, is a central phenomenon.

Postulate 4
Alertness causes an increase in attentional selectivity

The conclusions drawn from Experiments 1 and 2 were that attention was focussed by alertness onto those locations which had a higher probability of stimulus occurrence. In Experiment 2 these locations were distributed spatially, and the results were in accord with those of Hockey (1970a), who found that noise-induced arousal caused an increase in selectivity towards high probability spatial locations. Experiment 1 of the present thesis varied temporal rather than spatial probability, and showed a similar increase in selectivity. Hockey (1970b) also observed a focussing of attention, independent of spatial location when he manipulated stimulus probabilities. These results support the view that alertness produces a general increase in attentional selectivity, which is not restricted to the spatial domain. A complementary conclusion by Hamilton and Hockey (1974) relating to the temporal control of attention was that individuals can voluntarily adjust their alertness level over time so that they will maximise their receptivity for target stimuli within a sequence. This view of alertness is consistent with the traditional view of arousal expressed in the introduction, namely as that of an agent which generally narrows the span of attention.

Postulate 5
Alertness enables greater flexibility in the allocation of attentional resources

One important conclusion drawn from the present empirical work, and given in section 3.1, is that alertness simply acts to improve the control of attention. This is essentially similar to Kahneman's (1973) view that alertness facilitates the allocation of resources from a limited capacity pool of effort. The requirements of the task determine the way in which the additional capacity provided by alertness will be put to use. Naatanen and Merisalo (1977) have also expressed the essence of this viewpoint by stating that "the subject performs in advance what can be performed in advance," a strategy for which flexibility is essential.

An example of this can be found in an experiment in which the warning signal only provided probabilistic information about the task, by Nickerson, Collins and Markowitz (1969). They observed that subjects employed a wide variety of response strategies to cope with the uncertainty in the task. The significance of flexibility in the control of attention is illustrated by Johnson and Heinz (1978), who have proposed a multi-mode model of attention to account for their data. In this model the stage of processing at which selective perception operates is determined by the individual, depending on the needs of the task. They have shown that two spoken messages can be distinguished either from the sound of the voices (sensory selection), or on the basis of the actual content of the messages (semantic selection). Both of these strategies were observed in the same subjects, dependent upon various task constraints and instructions, the important point being that subjects could choose whichever was most appropriate to the situation.

Postulate 6
The control of alertness can be active and voluntary

Experiment 7 showed that subjects could exert a degree of voluntary control over how they made use of the additional resources available to them when alert, in order to satisfy task requirements. The notion of an adaptable, active control mechanism for the control of attention has come to the fore increasingly in recent years. As already mentioned, Hamilton and Hockey (1974) have proposed that individuals may be able to control their activation level (and hence their receptivity) at critical times during stimulus presentation. Their experiments involved the scanning of lists of words or digits to be recalled, attending either passively or actively to selected items. The results suggested that subjects were able to control their receptivity to coincide with target items in the sequence. Hamilton, Hockey and Rejman (1977) developed this suggestion into a model of active state-selection, whereby the individual can quickly switch to a processing mode appropriate to the needs of the situation, providing the flexibility required for moment-to-moment control of behaviour. These authors consider alertness to be a fast-processing state for dealing with environmental input, as opposed to a thoughtful or ruminating state. Their "closed system thinking" experiments involved a simultaneous combination of perception and memory tasks, the results from which suggested that subjects could optimally switch between the two processing modes approximately every half-second, closely reflecting the typical time taken for the build-up of alertness.

Hockey (1979) has pointed out the importance of being able to exert voluntary control over one's own state in order to compensate for externally induced state changes. The example he cites in this context is that of driving under the influence of alcohol, where considerable effort may be required to counteract drowsiness. Gottsdanker and Kent (1978) have also noted that motivational factors can over-ride the physical attributes of a task. They found a large drop in reaction time for a high probability probe trial embedded in a block of low probability trials, but a much smaller rise for a low probability trial embedded in high probability trials. This asymmetry they ascribed to poor motivation, or unwillingness of subjects to respond, in the low probability circumstances. (Experiment 6 in the present thesis was an attempt to observe an analogous asymmetry in the relationship between alertness and task context.)

Thus, in view of the fact that a state of high attention or alertness can only be maintained continuously for about one second, the importance of a mechanism for controlling the allocation and distribution of this resource in a flexible and voluntary manner is clear. The evidence presented in this thesis supports the view that individuals have better control over how they distribute their attention when they are alert than when when they are not.

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3.3 Problems, Limitations and Speculations

As mentioned under Postulate 2, a limiting factor of alertness is its high cost in terms of the effort required for its maintenance. This encourages the use of optimising strategies, and in particular the use of expectancy to predict stimulus occurrence time, as discussed in sections 1.2.1 and 1.3.2.

As an alternative to the use of strategies to minimise effort, it has been suggested that individuals can maintain meduim levels of alertness for longer periods than they can maintain a state of high alertness. Loveless and Sanford (1975) have presented evidence that the amplitude of the CNV (contingent negative variation in the electro-encephalogram) is less at longer foreperiods, up to 8 seconds in duration. They suggest that this may indicate a lower overall level of preparation, maintained over a prolonged time period. However, such evidence is not conclusive, since an expectancy model could equally produce such results when CNVs with widely varying peaks (reflecting imperfect estimation or prediction of stimulus onset time) are averaged across trials. A trial-by-trial examination of the data would be required to support Loveless and Sanford's claim.

In contrast, there are numerous studies which suggest that subjects do readily adopt a variety of strategies in order to avoid having to maintain a prolonged state of attentiveness. Granjon and Reynard (1977) have observed that subjects seem to try to minimise the cost or effort of preparation by using expectancy strategies to predict stimulus occurrence, even though this was not the optimal strategy for achieving the best performance in their experiment. Botwinick (1969) found an interaction between warning interval and stimulus intensity, which he ascribed to motivational effects or guessing, at the low intensities. Buckolz and Rugins (1978) have also observed that simple reaction time is not solely dependent upon foreperiod, and they consider that various strategies such as time-keeping are frequently employed. Rabbitt and Vyas (1980) investigated the ways in which subjects anticipate and prepare for stimuli over a range of response-stimulus intervals from 20 to 1600 ms., and concluded that subjects actively control their performance and prepare for each signal, in order to deal with it as effectively as possible. At the shorter interval ranges, subjects appeared to use their own responses as signalling the start of a foreperiod. When dealing with the longer intervals however, they endeavoured to make use of statistical regularities to predict or estimate the stimulus occurrence time. Here it can be seen that at least two different strategies are being actively applied in the same paradigm, with the experimental context determining the response pattern.

These observations all serve to emphasise the point that the various strategies adopted are simply methods whereby individuals can exert some form of control over the way in which they distribute their attention throughout the task. It would seem that such factors are likely to counteract any tendency towards the maintenance of medium levels of alertness over longer periods, other than in a true vigilance situation, although a detailed examination of CNV data such as those produced by Loveless and Sanford would be desirable in order to confirm this view.

Another limiting factor affecting the time course of alertness is how soon after having been alerted can the whole process restart? Clearly some such recovery period must exist since a continuously alert state cannot be maintained for more than about one second. As discussed in section 2.0.3, the present experiments used a range of inter-trial-intervals (ITIs) from 1.5 to 5 seconds (the minimum of 1.5 seconds being chosen in order to minimise interference from potential stimulus repetition effects or from inter-stimulus-interval (ISI) repetition effects). These ITIs were generated randomly and were not recorded, so an analysis of performance in terms of preceding ITI is not possible. Neither is there a great deal of information in the literature on the recovery period of the alertness mechanism, most manipulations having been applied either to the warning interval (WI), the response-stimulus-interval (RSI), or the ISI, (RSI and ISI effectively being combinations of ITI and WI). The controlled activation experiments of Hamilton and Hockey (1974) indicated that subjects could voluntarily switch their attention on and off at at rate of about once every second when listening selectively for targets in a list. This would suggest a very short recovery period for the development of voluntarily controlled alertness, perhaps only limited by the amount of energy resources available to the individual.

Alegria (1974) approached this question from a slightly different angle, adopting a variant of the catch-trial technique, in which stimuli could occur either at the expected time, or else were delayed by up to 900 ms. The results showed that reaction times rose to a maximum after a delay of about 250 ms., but by 900 ms., performance had recovered, and responses were as fast as to the non-delayed stimuli. Timing cues were provided by the experimenter, ruling out an explanation based on time estimation inaccuracy, and the results were observed in both blocked and mixed designs, also ruling out explanations based on stimulus predictability. This, Alegria argued, indicated that preparation dissipates rapidly over the 250 ms. following the first peak of preparedness, and recovers again within about one second. This view is in accord with the general picture of alertness presented in Postulate 2. However, it remains unclear as to whether Alegria's conclusions would hold valid in a situation in which a first response has already been made. It would be interesting to carry out some experiments involving the controlled manipulation of short duration ITIs, independent of warning interval, to determine whether the pattern of results found by Alegria could also be observed in the alertness paradigm. Because of the increased significance of repetition effects at shorter intervals, it is the view of the author that it would be difficult to produce any clear findings from such a study without very sophisticated control for sequential dependencies.

Any organism which can focus upon one aspect of its environment runs the risk of ignoring other events which may be taking place, and which may have significance for the survival of the organism. The very fact that alertness (and hence narrowed attention) can only be maintained for brief periods, may reflect the operation of a regulatory mechanism which serves the useful function of ensuring that aspects of the environment outside the current focus of attention are not permanently neglected. From an adaptive viewpoint it would seem inappropriate for attention to be concentrated on one object for a prolonged period, lest significant extraneous cues be ignored, cues which perhaps may be indicative of danger or food. Rather, the bursts of high arousal associated with alertness appear to permit the attention to "zoom in" only briefly on specific objects for a detailed analysis.

A contrasting view of the alertness mechanism however, emphasises the way in which alertness <u>can</u> be developed rapidly and selectively, in order to deal with specific problems as and when required. The adaptive value of having a flexible, non-specific alertness mechanism which can cope with rapidly changing S-R contingencies has already been pointed out by Thomas (1974). Posner, Nissen and Klein (1976) also consider the adaptive value of alertness in their examination of the phenomenon of visual dominance. They point out that non-visual stimuli are more alerting than visual stimuli, and they argue that this is a consequence of the intrinsic attentional bias towards visual input which most individuals exhibit. They further state that because of this bias, the alerting effect of a non-visual stimulus permits an intrusion into consciousness, such that the intruding stimulus becomes the focus of attention. In discussing the role of arousal in stress, Mandler (1979) reaches a similar conclusion regarding the manner in which arousal can facilitate the interruption of ongoing thought processes. Thus alertness would seem to play a useful role in providing a means of facilitating the re-direction or re-distribution of attention and consciousness towards potentially relevant information sources.

While a precise, empirically-based, specification of the control process underlying alertness cannot be given at this point, some suggestions as to its possible nature can be made. The similarities between the innate orienting response, particularly at the physiological level, have already been discussed in the introduction, but it has also been shown, both in the present experiments, and in the work discussed under Postulate 6, that alertness can be voluntarily controlled and can show directionality with regard to the object of attention. On this basis it may be that the alertness mechanism is some form of operant response, moulded or derived from the orienting reflex. Habituation of the orienting reflex to a tone such as that used in the present experiments would occur rapidly, but it has been observed (e.g., by Sokolov, 1963) that stimuli which have become habituated can be conditioned so that the orientation response re-appears. In the alertness paradigm, the test stimulus may act as the unconditioned stimulus, and the (habituated) warning signal as the to-be-conditioned stimulus, thereby re-eliciting a conditioned orientation response to the warning signal. In terms of performance it would be in subjects' interests for such conditioning to take place, although in the work reported by Sokolov, subjects stated that they were not conscious of paying any special attention to the habituated stimulus. In the light of the preceding discussions of active control under Postulates 5 and 6, it is likely that subjects may voluntarily be able to manipulate their state over and above the effects of this type of conditioning. This may perhaps occur via some form of implicit verbal control (e.g., "concentrate"), or alternatively, alertness may be initiated by some type of goal-directed system, as a result of a mis-match between the current state of the organism and the desired or optimal processing state for the given task.

The views expressed above are necessarily somewhat speculative, and further investigations, both physiological and behavioural, are needed to clarify these issues. The next section outlines a number of possible approaches intended to attack at least some of the questions raised. The aim of the present thesis was to make some contribution to the body of knowledge about attention and its control, and I hope that this has been achieved to some degree. It is my view that alertness is intimately linked with the control of attention, and, probably mediated via a conditioned orienting response, is instrumental in producing more efficient allocation of resources appropriate to immediate task demands. Certainly alertness serves a more adaptive and strategic role than the relatively mechanistic one ascribed to it by Posner (1974). Rather, it would appear that Moray's (1969) simple statement that alertness is "getting ready to deal with whatever happens next" is a more apt description, taken in the widest sense, than was perhaps originally intended.

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3.4 Further Tests of the Alertness Hypothesis

In the course of producing this report, a number of situations have suggested themselves to the author, additional to those discussed throughout the text, in which the general hypothesis that alertness facilitates attentional control could be tested further, and consequently elaborated upon and modified accordingly. These are primarily tasks in which there is some potential conflict or interference inherent in the experimental paradigm. The prediction made in all cases is that alertness should reduce interference and resolve conflict in the direction of satisfying the task's primary goals.

3.4.1 The Stroop Phenomenon

The Stroop phenomenon is a well known effect where printed colour names interfere with the vocal naming of the actual colours in which the words are printed (Stroop, 1935). There are numerous analogous situations in which a similar interference occurs between verbal and non-verbal stimuli, though to a lesser degree than the word-colour effect. Reviewing the area, Dyer (1974) concluded that the Stroop effect is most probably due to a failure of selective attention. This view is supported by a variety of studies (e.g., Hock and Egeth, 1970; Williams, 1977; Seymour, 1977) which argue that interference occurs at the stimulus input and encoding stages, although it has also been proposed that the Stroop effect is a result of response conflict (e.g., Morton, 1969; Neill, 1977). Evidence that the phenomenon is a central rather then a peripheral one comes from Gatti and Egeth (1978), who have found that interference persists even when the conflicting stimulus (colour name words) and the test stimulus (coloured patch) are spatially separated by 5 degrees of arc. This implies that the interference does not occur at the sensory receptor level. Dyer has also observed that there is no Stroop interference at fast stimulus presentation rates. This, he suggests, may imply that briefly presented stimuli are not processed in sufficient detail to result in interference between the conflicting stimulus attributes.

Elliott (1969) and Elliott, Bankart and Light (1970) monitored physiological responding during performance of the Stroop test and found that both heart rate deceleration and palmar conductance were greatest during the interference condition. This would appear to reflect a state of alertness or arousal induced by the inherent nature of the task. In Mandler's (1979) terms, the stimulus conflict, or negative interruption, causes arousal, which in turn enables additional resources to be brought to bear to resolve the task's ambiguities, and at the same time increases attentional selectivity. Houston and Jones (1967) and Houston (1969) found that loud noise had the effect of reducing word-colour interference, but they rejected the hypothesis of focussed attention due to noise-induced arousal because they observed no concurrent changes in pulse rate. (However, this may have been because any expected increase in pulse rate due to noise may have been cancelled out by a reduction in pulse rate, such as was observed in Elliot's experiments, induced by the very nature of the Stroop task itself.)

O'Malley and Gallas (1978) have also observed improvements in Stroop colour naming performance in noise, with least interference occurring at moderately high (85 db) levels. Hartley and Adams (1974) observed that during a 10 minute period of noise exposure interference dropped, but increased when the task was performed at the end of a 30 minute period. Since the arousing effects of noise begin to habituate quite rapidly (Glass and Singer, 1972), the results of Hartley and Adams could be interpreted as suggesting that arousal reduces interference. In contrast, Hartley and Shirley (1976) have found Stroop interference to be greatest in the evening, a point in the diurnal cycle at which arousal is generally regarded as being highest (Hockey and Colquhoun, 1972).

Although the above evidence does not conclusively indicate a relationship between arousal and performance on the Stroop test, it does suggest that they are related in some way, and that the Stroop phenomenon probably does reflect a limitation in the operation of the attentional control mechanism. The present view is that alertness improves the operation of this mechanism, and so it is hypothesised that alertness should result in a reduction of interference in a suitably designed Stroop paradigm. Since the effects of alertness operate over a short time scale, the traditional card-sorting techniques which have been employed in Stroop tests in the past would not be appropriate for such an investigation. A paradigm involving a forced-choice between, say, two colour names, written in one or other of the actual colours, and presented either with or without a warning signal, could be used instead. A neutral colour (probably black or white) and neutral or nonsense text would be suitable as control stimuli. Such an experiment could be performed in a very similar manner to those described in the present thesis, by using a computer-controlled colour display screen.

3.4.2 Recognition Performance

A number of studies relating arousal and learning were carried out in the 1960s , the general conclusions from which were that there is an inverted-U relationship between arousal and immediate recall, and a monotonic relationship between arousal and delayed recall (Berry, 1962; Kleinsmith, Kaplan, and Tarte, 1963; Kleinsmith and Kaplan, 1963,1964; Berlyne, Borsa, Hammacher, and Koenig, 1966; McLean, 1969). These results have been interpreted in terms of trace consolidation theory (Walker and Tarte, 1963), which states that each input sets up a consolidation process which serves to make the neural memory trace more permanent. This process has a high resistance to disruption, and is enhanced at increased levels of arousal, giving rise to the observed results. This can also be viewed as a problem of directing one's attention appropriately, i.e., one in which the focussing effects of arousal may be beneficial. More recently, Wynn (1977) has shown that when subjects are aroused or alerted by means of a 300 ms. burst of noise presented 800 ms. prior to stimulus presentation, their subsequent recognition of these stimulus items is improved. Wynn's paradigm was very similar to the techniques used in the present thesis to manipulate alertness, and so it would be of interest to examine the relationship between alertness and recognition or recall in more detail, and a possible approach is outlined as follows.

Schulman (1971) has observed that lists of items which are scanned semantically are subsequently recognised better than lists scanned simply on a structural criterion. This suggests that in a semantic scan (where the actual meanings of the words must be considered), items are processed to a greater degree than during a structural scan (where the only feature being searched for is a structural one, e.g., the presence or absence of the letter A). Further evidence of minimal processing during a structural scan comes from Schulman's finding that recognition performance was an increasing function of ordinal position of the letter A in the word, suggesting that target identification precedes perception of the word itself.

According to the present view of alertness, subsequent recognition of items from a list scanned structurally should be worse if subjects are alert when the items are first presented than if they are not alert. This is because alertness should enable subjects to attend more closely to the task's requirements and to ignore irrelevant attributes such as the semantic content of the words. It might also be predicted that recognition should show an interaction between alertness and position of the target letter within the word. In a semantic scan on the other hand, the perception and processing of each item is central to the scanning task, and hence the attention focussing effect of alertness should not impair subsequent recognition of the words. Indeed, on the basis of Wynn's results, alertness should improve recognition of semantically scanned lists. An experiment designed along these lines would constitute a powerful test of the degree to which alertness influences attentional selectivity.

3.4.3 Field Dependence

Field dependence is the term introduced by Witkin et al. (1954) to describe the extent to which an individual's perception of the vertical is influenced by the surrounding visual field. An example of this is in the rod-and-frame test (Witkin and Asch, 1948), in which the subject sits in a darkened room observing a luminous movable rod which is surrounded by a luminous frame. Both rod and frame can be tilted independently at any angle by the experimenter, and the subject's task is to report when the rod appears vertical, ignoring the position of the frame. The degree to which the tilt of the frame influences the subject's judgements, i.e., the degree of field dependence, varies from individual to individual and appears to be a relatively stable perceptual trait.

More recently Blowers and O'Connor (1978) have correlated eye movements with error rate on the rod-and-frame test in groups of field dependent and field independent subjects. There was no relationship in the former group, but for the latter they found that larger rates and magnitudes of eye movements were associated with fewer errors. They interpreted this as implying that an ability to be selective about which areas of the display to attend to was the main determinant of field independence. Further examination of eye movement patterns also suggested that ignoring the frame, rather than active suppression of it, produced better performance.

Direct attempts at manipulating attentional selectivity by having subjects perform the rod-and-frame test in loud noise situations have been somewhat inconclusive, with Oltman (1964) finding a reduction in field dependence in noise whereas O'Malley and Gallas (1977) observed no differences between noise and quiet conditions. In a recent review of the area, Witkin and Goodenough (1981) did not consider these types of experimental manipulation in detail, but they do state that field independence can be described as "overcoming embedding contexts in perception," pointing out that the relative salience of the frame can influence test scores.

To determine whether alertness can exert an influence upon this embedding context, an appropriate paradigm would need to be developed. The rod-and-frame test involves the physical adjustment of an actual rod, set inside a square frame, in order to align it with the percieved vertical, essentially using the method of limits, which would be unsuitable for investigating alertness. Some form of forced-choice reaction time task could be employed instead, perhaps involving stimuli covering a range of tilts of the frame, but with a fixed vertical rod, or similar manipulation. This would allow speed and accuracy measures to be used an an indication of field dependence, in both alerted and non-alerted conditions. The view of alertness taken in this thesis, particularly in the light of Blowers and O'Connor's findings, would suggest that field dependence should be less when subjects are alert than when they are not alert.

3.4.4 Visual Illusions

A topic which appears to the author to bear some relation to field dependence is that of the common visual illusions, in that both represent types of visual misperception. These types of illusion all involve two-dimensional geometric figures with intersecting lines, such as the Poggendorf, Ponzo and Müller-Lyer illusions, and there are a variety of theories which purport to account for them. Gregory (1968) has proposed what is essentially a social learning view in his perspective theory, which incorporates the concept of unconsciously perceived depth as an explanatory mechanism. At the other extreme, several quantitative accounts of the illusions have been presented which are based upon neurophysiological models of, e.g., the cortex (Hoffman, 1971), and the retina (Walker, 1973). Non-reductionist mathematical models have also been proposed, e.g., by Watson (1977) and by Smith (1978), although Watson draws a strong analogy between his force-field model and the physiological mechanism of lateral inhibition. However, he leaves unspecified the stage at which this inhibition might occur and give rise to the distorted visual, non-Euclidean visual space upon which the theory is based.

Experiments have shown that illusions persist even when the figure and background components are presented separately to each eye, either via a stereoscopic viewer (Walker, 1978) or through polarised lenses (Weiss, Hewett, and Mentzer, 1979). Teuber (1960) has also pointed out that there is a tactile analogue for most illusions, and that congenitally blind children are capable of perceiving these. Taken together, this evidence is indicitave of of a central rather than a peripheral locus for the origin of illusions. Gregory has shown that the

Müller-Lyer "arrow-head" illusion is stronger when the drawings are replaced by pictures of the interior corner of a room and the exterior corner of a building. It has also been observed that illusions are weaker in children and in non-Westernised societies (Segall, Campbell and Herkovits, 1963), and that repeated exposure to an illusion can weaken or destroy the effect (Teuber). This information implies that there is a significant cognitive component involved in the perception of illusions.

Walley and Weiden (1973) argue that during attention there is an increase in general arousal which facilitates lateral inhibition, and Shallice (1972) considers that inhibition probably has a role to play in attending and conscious processing. It seems possible then that the alertness paradigm, by providing a means of facilitating lateral inhibition through increased arousal level, may be capable of affecting illusion strength. The observations above concerning the central and cognitive nature of illusions serves to reinforce this proposal. The directionality of the hypothesised effect is however not immediately obvious. For simplicity, most of the examples presented by Watson assume that the influence of the test lines in distorting visual space is negligible compared with the background field lines (for instance the horizontal lines versus the converging rays in the Ponzo and Hering illusions), and this is put down to differences in relative intensity. The present general hypothesis of enhanced attentional selectivity due to alertness implies that alertness and relative intensity of the test and field lines should interact in their effects upon illusion strength. With a dominant field, alertness might be expected to enhance the illusion, whereas in a display in which the test figure is predominant and the illusory effect consequently less, alertness may serve to reduce the illusion strength even further. The role of selective attention and motivational factors in the perception of visual illusions represents to the author a particularly intriguing and potentially fruitful research area.

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Section 4. References

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Section 6. Appendix

6.1 Sample Experimental Control Computer Program

This section contains a listing of the program which was used to control Experiment 7. There are a number of non-standard subroutine calls in the program, and these are described below.

Fortran routines (written by the author)

ALFAB4	Converts an integer number (a reaction time) in the range 0 to 9999 to alphanumeric format with leading spaces, suitable for displaying on the GT40 screen.
BRAN	Generates a random number from a uniform distribution in the range -1 to +1.
ENDEXP	Displays a flashing message on the GT40 screen which says: "End of Experiment: Thank you".
IBWAIT	Displays the message "Press any key to continue" on the GT40 and waits for the subject to press a key.
NOREP	Generates a random sequence of numbers from 1 to N with no replication, which can be used to generate a stimulus presentation schedule.

Macro-11 assembly language routines (written by Charlie Foster)

CLSTOP	Stops the computer's real-time clock.
CLSTRT	Starts the computer's real-time clock running with a "tick size" of 1 millisecond.
CLTIME	Reads the real-time clock and returns the time as a 32-bit double precision integer.
CLWAIT	Causes the computer to pause until a specified number clock ticks have elapsed following a given time.
DPSUB	Subtracts two 32-bit double precision integers.
DRAW	Creates pictures to be shown on the GT40 screen by

	constructing appropriate sequences of graphic computer machine instructions.
GT40	Sends commands and data to the GT40 instructing it to store and/or display specific pictures, and optionally reads the times at which the display was started and initialises a "listen" for a response.
INTFDP	Converts a double precision integer into a normal 16-bit integer.

The program listing follows.

```
C       CONTROL PROGRAM FOR MIXED BLOCKS DESIGN
C       DISCRIMINATION REACTION TIME EXPERIMENT:
C       (SPEED/ACCURACY/NON-RT) X (ALERT/NON-ALERT).
C
C PAUL W. O'RIORDAN, PSYCHOLOGY DEPT., UNIVERSITY OF STIRLING.
C
C       FOR A DEC PDP-11/45 COMPUTER WITH RK05 DISC AND
C       REAL-TIME CLOCK, LINKED TO A DEC GT40 GRAPHICS
C       COMPUTER VIA A HIGH SPEED 16-BIT PARALLEL INTERFACE.
C       THE PDP-11/45 RAN DEC'S DOS OPERATING SYSTEM, AND THE
C       GT40 RAN A SPECIAL PURPOSE EXECUTIVE CONTROL PROGRAM
C       for COMMUNICATING WITH PDP-11/45.
C
C INPUT PARAMETERS:
C NDIFF  - DIFFICULTY OF THE DISCRIMINATION, IN SCREEN UNITS
C X      - A SEED VALUE FOR THE RANDOM NUMBER GENERATOR
C NTRCND - NUMBER OF TRIALS OF EACH TYPE PER CONDITION
C NBLOKS - NUMBER OF BLOCKS OF TRIALS TO BE PRESENTED
C SESSN  - 0 = ACCURACY SESSION
C          1 = SPEED SESSION
C          2 = NON-RT SESSION
C
C MAIN INTERNAL DATA STORAGE ARRAYS:
C PICARR - PICTURE DEFINITIONS FOR GRAPHICS
C PORDER - PRESENTATION ORDER. ARRAY OF TRIAL TYPE CODES:
C       CODE      STIM. DUR.    WARNING         STIMULUS
C       1/2/3     150/250/350   500 MS.         SAME
C       4/5/6     150/250/350   0   MS.         SAME
C       7/8/9     150/250/350   500 MS.         DIFFERENT
C       10/11/12  150/250/350   0   MS.         DIFFERENT
C COUNT  - COUNTERS FOR EACH (BLOCK X RESP. TYPE X CONDITION)
C RTDATA - CUMULATIVE RT DATA FOR EACH (BLOCK X TYPE X COND.)
C PERCOR - PERCENT CORRECT SCORES FOR EACH (BLOCK X COND.)
C PERDIF - PERCENT DIFFERENT SCORES FOR EACH (BLOCK X COND.)
C AVRT   - AVERAGED REACTION TIMES FOR EACH (TYPE X COND.)
C       BLOCK:  1 TO 10
C       TYPE:   1=CORRECT, 1=ERROR, 3=DIFFERENT, 4=SAME
C       COND.:  1=150A, 2=250A, 3=350A, 4=150N, 5=250N, 6=350N
C
C CURRENT VARIABLES ON EACH TRIAL:
C ITI    - INTER-TRIAL-INTERVAL
C STMDUR - STIMULUS DURATION
C IWI    - WARNING INTERVAL
C ISTIM  - STIMULUS
C STMPTR - STIMULUS POINTER FOR GRAPHICS
C IRESP  - RESPONSE
C ICURRT - REACTION TIME = (TSTART-TRESP)
C ITRIAL - TRIAL NUMBER
C IBLOCK - BLOCK NUMBER
C ICOND  - CONDITION CODE
C
C
C DEFINE ARRAYS AND VARIABLES ETC
        LOGICAL*1 QUERY,BELL
        INTEGER SESSN,STMDUR,POINTR(2),STMPTR(2),PICARR(150)
        INTEGER PORDER(200),COUNT(10,4,6),IREQ(10)
        REAL RTDATA(10,4,6),AVRT(4,6)
        REAL PERDIF(10,6),PERCOR(10,6)
        DATA BELL,NUMRUN/7,1/
        DATA POINTR(1),STMPTR(1)/"160000,"160000/
C
```

```
C *** PHASE 1 - SET UP GENERAL EXPERIMENTAL DETAILS ***
C
C
C ASSIGN LOGICAL UNIT 6 TO THE CONSOLE TERMINAL
        CALL ASSIGN(6,'TT:')
C
C ASSIGN LOGICAL UNIT 1 TO DISC FILE FOR SAVING RAW DATA
        CALL ASSIGN (1,'DK:RTSAVE.DAT')
C
C START OF AN ENTIRE EXPERIMENTAL RUN
C
20      CONTINUE
C PRINT A RECORD OF THE RUN NUMBER
        WRITE(6,21)NUMRUN
21      FORMAT(' RUN NO. ',I2)
C
C GET THE PARAMETERS FOR THE EXPERIMENT FROM THE CONSOLE
        WRITE(6,8)
8       FORMAT
     .(' NDIFF(I2) X(F5.3) NTRCND(I2) SESSN(I1) NBLOKS(I2):'/)
        READ(6,9)NDIFF,X,NTRCND,SESSN,NBLOKS
9       FORMAT(I2,F5.3,I2,I1,I2)
C ECHO THEM BACK TO ENSURE THEY ARE CORRECT
        WRITE(6,10)NDIFF,X,NTRCND,SESSN,NBLOKS
10      FORMAT(I10,F8.3,I11,I10,I11)
C
C
C *** PHASE 2 - GENERATE DISPLAY FILE FOR ALL THE PICTURES ***
C
C
C DEFINE THE ARRAY FOR STORING THE SCREEN PICTURES
        CALL DRAW('FIRST',PICARR,150)
C FIRST TWO WORDS ARE A DISPLAY-JUMP & OFFSET
        CALL DRAW('O',"160000,0)
C
C NOW DRAW THE PICTURES
C
C "SAME" STIMULUS
        CALL DRAW('I',L)
        ISAME=L+1
        CALL DRAW('PCD',488,409)
        CALL DRAW('SCI',0,-50)
        CALL DRAW('SND',48,50)
        CALL DRAW('SNI',0,-50)
        CALL DRAW('O',"173400,0)
C "DIFFERENT" STIMULUS
        CALL DRAW('I',L)
        IDIFF=L+1
        CALL DRAW('PCD',488,409-NDIFF)
        CALL DRAW('SCI',0,NDIFF-50)
        CALL DRAW('SND',48,50)
        CALL DRAW('SNI',0,-50)
        CALL DRAW('O',"173400,0)
```

```
C "RESPOND" COMMAND
      CALL DRAW('I',L)
      IRES=L+1
      CALL DRAW('PCD',472,500)
      CALL DRAW('CCN',7,'RESPOND')
C STIMULUS MASK
      CALL DRAW('I',L)
      MASK=L+1
      CALL DRAW('PCD',464,415)
      CALL DRAW('SCI',0,-62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,-62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,-62)
      CALL DRAW('O',"173400,0)
C FIXATION POINT
      CALL DRAW('I',L)
      IFIXPT=L+1
      CALL DRAW('PCD',505,375)
      CALL DRAW('CCN',1,'+')
      CALL DRAW('O',"173400,0)
C "CORRECT" MESSAGE
      CALL DRAW('I',L)
      ICORCT=L+1
      CALL DRAW('PCD',472,500)
      CALL DRAW('CCN',7,'CORRECT')
      CALL DRAW('O',"173400,0)
C "WRONG" MESSAGE
      CALL DRAW('I',L)
      IWRONG=L+1
      CALL DRAW('PCD',486,500)
      CALL DRAW('CCN',5,'WRONG')
      CALL DRAW('O',"173400,0)
C "END OF BLOCK" MESSAGE
      CALL DRAW('I',L)
      IEOBLK=L+1
      CALL DRAW('PCD',444,375)
      CALL DRAW('CCN',12,'END OF BLOCK')
      CALL DRAW('O',"173400,0)
C REACTION TIME FEEDBACK
      CALL DRAW('I',L)
      IFEEDB=L+1
      CALL DRAW('PCD',486,500)
      CALL DRAW('CCN',4,'9999')
C (ACTUAL RT VALUE WILL BE INSERTED HERE AT RUN TIME)
      CALL DRAW('I',L)
      INSERT=L-1
      CALL DRAW('O',"173400,0)
      CALL DRAW('I',LENGTH)
C
C **** END OF DISPLAY FILE GENERATION ****
C
```

```
C "RESPOND" COMMAND
      CALL DRAW('I',L)
      IRES=L+1
      CALL DRAW('PCD',472,500)
      CALL DRAW('CCN',7,'RESPOND')
C STIMULUS MASK
      CALL DRAW('I',L)
      MASK=L+1
      CALL DRAW('PCD',464,415)
      CALL DRAW('SCI',0,-62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,-62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,62)
      CALL DRAW('SND',24,0)
      CALL DRAW('SNI',0,-62)
      CALL DRAW('O',"173400,0)
C FIXATION POINT
      CALL DRAW('I',L)
      IFIXPT=L+1
      CALL DRAW('PCD',505,375)
      CALL DRAW('CCN',1,'+')
      CALL DRAW('O',"173400,0)
C "CORRECT" MESSAGE
      CALL DRAW('I',L)
      ICORCT=L+1
      CALL DRAW('PCD',472,500)
      CALL DRAW('CCN',7,'CORRECT')
      CALL DRAW('O',"173400,0)
C "WRONG" MESSAGE
      CALL DRAW('I',L)
      IWRONG=L+1
      CALL DRAW('PCD',486,500)
      CALL DRAW('CCN',5,'WRONG')
      CALL DRAW('O',"173400,0)
C "END OF BLOCK" MESSAGE
      CALL DRAW('I',L)
      IEOBLK=L+1
      CALL DRAW('PCD',444,375)
      CALL DRAW('CCN',12,'END OF BLOCK')
      CALL DRAW('O',"173400,0)
C REACTION TIME FEEDBACK
      CALL DRAW('I',L)
      IFEEDB=L+1
      CALL DRAW('PCD',486,500)
      CALL DRAW('CCN',4,'9999')
C (ACTUAL RT VALUE WILL BE INSERTED HERE AT RUN TIME)
      CALL DRAW('I',L)
      INSERT=L-1
      CALL DRAW('O',"173400,0)
      CALL DRAW('I',LENGTH)
C
C **** END OF DISPLAY FILE GENERATION ****
C
```

```
C *** PHASE 3 - PREPARE FOR THE NEXT BLOCK ***
C
C RUN NBLOKS BLOCKS OF TRIALS.
        DO 16 IBLOCK=1,NBLOKS
C
C START WITH A DATA OUTPUT HEADING ON THE CONSOLE
        WRITE(6,1)IBLOCK
1       FORMAT('0BLOCK NO. ',I2)
        WRITE(6,50)
50      FORMAT
     .(' RT CODES: 1=CORRECT, 2=ERROR, 3=DIFFERENT, 4=SAME')
C
C PRINT A MESSAGE APPROPRIATE TO THE EXPERIMENTAL SESSION
        IF (SESSN-1) 2,3,4
2       WRITE(6,5)
5       FORMAT(' RT CONDITION: EMPHASIS ON ACCURACY')
        GOTO 11
3       WRITE(6,6)
6       FORMAT(' RT CONDITION: EMPHASIS ON SPEED')
        GOTO 11
4       WRITE(6,7)
7       FORMAT(' NON RT CONDITION:
        1 TIMES MEASURED FROM "RESPOND" COMMAND')
C
11      WRITE(6,12)
12      FORMAT(26X,'ALERT',23X,'NON-ALERT')
        WRITE(6,13)
13      FORMAT(' DURATION:'
     .,7X,'150',7X,'250',7X,'350',7X,'150',7X,'250',7X,'350')
C
C
C START THE CLOCK
        CALL CLSTRT
C CONNECT TO THE GT40 AND INSERT THE DISPLAY FILE
        CALL GT40('OPEN')
        CALL GT40('INSERT',0,LENGTH,PICARR)
C RING THE BELL TO INDICATE A BLOCK ABOUT TO START
        CALL GT40('BELL')
C
C COMPUTE NO. OF TRIALS PER BLOCK. THERE ARE 12 TRIAL TYPES:
C 3 DURATIONS X 2 WARNING INTERVALS X SAME/DIFFERENT
        NTRBLK=NTRCND*12
C
C PRODUCE RANDOM ORDERING OF NOS. 1 TO NBLOKS IN ARRAY PORDER
        CALL NOREP(PORDER,NTRBLK,X)
C
C REDUCE THESE TO A RANGE OF 1 TO 12, TO SHOW TRIAL TYPE,
C AND STORE THE RESULTING PRESENTATION ORDER BACK IN PORDER
        DO 14 I=1,NTRBLK
14      PORDER(I)=(PORDER(I)-1)/NTRCND+1
C
C INITIALIZE RT ARRAY AND COUNTER TO ZERO
        DO 44 J=1,6
        DO 44 I=1,4
        RTDATA(IBLOCK,I,J)=0.0
44      COUNT(IBLOCK,I,J)=0
C
C INTER-BLOCK WAIT FOR SUBJECT TO START THE BLOCK OF TRIALS
        CALL IBWAIT
C
```

```
C **** START OF EXPTAL TRIALS SEQUENCE ****
C
      DO 15 ITRIAL=1,NTRBLK
C
C (RE-ENTER HERE AFTER A NON-RESPONSE)
28    CONTINUE
C
C COMPUTE THE INTER-TRIAL-INTERVAL USING A RANDOM NUMBER
      CALL BRAN(X)
C ITI WILL BE IN THE RANGE 1500 TO 5000 MS.
      ITI=ABS(X)*3500+1500
C
C FIND WHICH STIMULUS TO BE DISPLAYED AND SET POINTERS
C (A '0' RESPONSE WILL INDICATE "SAME", '1' "DIFFERENT")
      STMPTR(2)=ISAME
      ISTIM='0'
      ICOND=PORDER(ITRIAL)
      IF (ICOND.LE.6) GOTO 17
      STMPTR(2)=IDIFF
      ISTIM='1'
      ICOND=ICOND-6
C
C DETERMINE IF THERE IS A WARNING INTERVAL AND ADJUST ITI
17    IWI=500
      IDCODE=ICOND
      IF (ICOND.LE.3) GOTO 18
      IWI=0
      ITI=ITI+500
      IDCODE=ICOND-3
C
C COMPUTE STIMULUS DURATION (150/250/350 MS.)
18    STMDUR=(IDCODE-1)*100+150
C
```

```
C *** START OF TIME CRITICAL SECTION ****
C
C DISPLAY FIX. PT. & WAIT FOR ITI MS.
        POINTR(2)=IFIXPT
        CALL GT40('DISPLAY',0,2,POINTR,TBEGIN)
        POINTR(2)=MASK
        CALL CLWAIT(TBEGIN,ITI)
C
C GIVE WARNING SIGNAL & WAIT FOR IWI MS. IF REQUIRED
        CALL GT40('BELL')
        IF (IWI.GT.0) CALL CLWAIT(TBEGIN,ITI+IWI)
C
C WHICH TYPE OF SESSION?
        IF (SESSN.NE.2) GOTO 22
C
C REACTION TIMES NOT REQUIRED: DISPLAY THE STIMULUS FOR
C STMDUR MS., AND THEN MASK IT
        CALL GT40('DISPLAY',0,2,STMPTR,TSTIM)
        CALL CLWAIT(TSTIM,STMDUR)
        CALL GT40('DISPLAY',0,2,POINTR)
        POINTR(2)=IRES
C WAIT FOR 1500 MS. BEFORE ACCEPTING A RESPONSE.
        CALL CLWAIT(TSTART,STMDUR+1500)
C GIVE "RESPOND" MESSAGE AND START LISTENING FOR A RESPONSE
        CALL GT40('DISPLAY',0,2,POINTR,TSTART,IRESP,TRESP)
        GOTO 24
C
C REACTION TIMES ARE REQUIRED: DISPLAY STIMULUS FOR
C STMDUR MS., AND IMMEDIATELY LOOK FOR A RESPONSE.
22      CALL GT40('DISPLAY',0,2,STMPTR,TSTART,IRESP,TRESP)
        CALL CLWAIT(TSTART,STMDUR)
        CALL GT40('DISPLAY',0,2,POINTR)
C
C CHECK FOR A VALID RESPONSE
24      IF ((IRESP.EQ.'0').OR.(IRESP.EQ.'1')) GOTO 32
C CHECK FOR SOME OTHER RESPONSE
        IF (IRESP.NE.-1) GOTO 31
C ONLY WAIT FOR 1500 MS.
        CALL CLTIME(TNOW)
        IF (INTFDP(DPSUB(TNOW,TSTART)).LE.1500) GOTO 24
C
C RESPONSE ILLEGAL OR NOT GIVEN WITHIN 1500 MS., SO RING BELL
31      CALL GT40('BELL')
C SWAP THIS STIMULUS RANDOMLY WITH ONE NOT YET PRESENTED
C SO AS NOT TO PRESENT THE SAME STIMULUS AGAIN IMMEDIATELY
        CALL BRAN(X)
        NSWAP=ABS(X)*(NTRBLK-ITRIAL-5)+ITRIAL+5
        NSWAP=MIN0(NSWAP,NTRBLK)
        ISWAP=PORDER(NSWAP)
        PORDER(NSWAP)=PORDER(ITRIAL)
        PORDER(ITRIAL)=ISWAP
        GOTO 28
C
```

```
C GOT A RESPONSE: COMPUTE THE REACTION TIME.
32      ICURRT=INTFDP(DPSUB(TRESP,TSTART))
C
C CHECK WHETHER IT IS CORRECT OR WRONG
        IF (IRESP.EQ.ISTIM) GOTO 25
C
C RESPONSE WRONG: STORE IT AND SET FEEDBACK POINTER
        RTDATA(IBLOCK,2,ICOND)=RTDATA(IBLOCK,2,ICOND)+ICURRT
        COUNT(IBLOCK,2,ICOND)=COUNT(IBLOCK,2,ICOND)+1
        POINTR(2)=IWRONG
        GO TO 26
C
C RESPONSE CORRECT: STORE IT AND SET FEEDBACK POINTER
25      RTDATA(IBLOCK,1,ICOND)=RTDATA(IBLOCK,1,ICOND)+ICURRT
        COUNT(IBLOCK,1,ICOND)=COUNT(IBLOCK,1,ICOND)+1
        POINTR(2)=ICORCT
C
C NOW KEEP COUNT OF THE SAME/DIFFERENT SCORE
26      IF (IRESP.EQ.'0') GOTO 27
C RESPONSE DIFFERENT
        RTDATA(IBLOCK,3,ICOND)=RTDATA(IBLOCK,3,ICOND)+ICURRT
        COUNT(IBLOCK,3,ICOND)=COUNT(IBLOCK,3,ICOND)+1
        GOTO 29
C RESPONSE SAME
27      RTDATA(IBLOCK,4,ICOND)=RTDATA(IBLOCK,4,ICOND)+ICURRT
        COUNT(IBLOCK,4,ICOND)=COUNT(IBLOCK,4,ICOND)+1
C
C IF FEEDBACK OF RT IS REQUIRED, CONVERT ACTUAL VALUE
C TO ALPHANUMERIC AND INSERT INTO THE DISPLAY FILE
29      IF (SESSN.NE.1) GOTO 30
        CALL ALFAB4(PICARR(INSERT),ICURRT)
C
C PRESENT FEEDBACK
        POINTR(2)=IFEEDB
30      CALL GT40('DISPLAY',0,2,POINTR,TBEGIN)
C SAVE RAW DATA ON DISK WHILE PRESENTING FEEDBACK
        WRITE(1,33)PORDER(ITRIAL),IRESP,ICURRT
33      FORMAT(3I6)
C LEAVE FEEDBACK ON SCREEN FOR 500 MS.
        CALL CLWAIT(TBEGIN,500)
C
C **** END OF TIME CRITICAL SECTION ****
C
C END OF A TRIAL: GO AND DO ANOTHER ONE
15      CONTINUE
C
C END OF A BLOCK OF TRIALS.
C
C STOP THE CLOCK
        CALL CLSTOP
C SHOW END-OF-BLOCK MESSAGE
        POINTR(2)=IEOBLK
        CALL GT40('DISPLAY',0,2,POINTR)
C
```

```
C *** PHASE 4 -  COMPUTE SUMMARY RESULTS ETC. ***
C
C COMPUTE PARTIAL DATA MEANS IN CASE COMPUTER CONKS OUT
C
        DO 34 I=1,6
        DO 35 J=1,4
        AVRT(J,I)=0.0
        IF (COUNT(IBLOCK,J,I).NE.0)
     . AVRT(J,I)=RTDATA(IBLOCK,J,I)/(COUNT(IBLOCK,J,I)+0.0)
35      CONTINUE
        PERCOR(IBLOCK,I)=(COUNT(IBLOCK,1,I)/(NTRCND*2.))*100.
34      PERDIF(IBLOCK,I)=(COUNT(IBLOCK,3,I)/(NTRCND*2.))*100.
C
C WRITE OUT MEANS OF BLOCK DATA
        DO 38 J=1,4
        WRITE(6,36)J,(AVRT(J,I),I=1,6)
36      FORMAT(' RT TYPE ',I1,6F10.2)
        WRITE(6,37)(COUNT(IBLOCK,J,I),I=1,6)
37      FORMAT('    COUNT',6I10)
38      CONTINUE
        WRITE(6,39)(PERCOR(IBLOCK,I),I=1,6)
39      FORMAT(' % CORRECT',6F10.2)
        WRITE(6,40)(PERDIF(IBLOCK,I),I=1,6)
40      FORMAT('    % DIFF',6F10.2)
C
C END OF A BLOCK OF TRIALS: GO AND DO ANOTHER ONE
16      CONTINUE
C
C DISPLAY END-OF-EXPERIMENT MESSAGE
        CALL ENDEXP(0)
C
C ASK IF THE AVERAGE OF THIS RUN'S DATA IS REQUIRED
C
        WRITE(6,66)
66      FORMAT('$AVERAGE OF BLOCKS? (I2)')
        READ(6,67)NBREQ
67      FORMAT(I2)
        IF (NBREQ.EQ.0) GOTO 68
        READ(6,69)(IREQ(I),I=1,NBREQ)
69      FORMAT(10I2)
C
```

```
C FIND SUMS AND AVERAGES OF THE BLOCKS SPECIFIED BY IREQ
C
        DO 60 I=2,NBREQ
        DO 60 J=1,6
        DO 61 K=1,4
        RTDATA(IREQ(1),K,J)=
     . RTDATA(IREQ(1),K,J)+RTDATA(IREQ(I),K,J)
        COUNT(IREQ(1),K,J)=
     . COUNT(IREQ(1),K,J)+COUNT(IREQ(I),K,J)
61      CONTINUE
        PERCOR(IREQ(1),J)=PERCOR(IREQ(1),J)+PERCOR(IREQ(I),J)
        PERDIF(IREQ(1),J)=PERDIF(IREQ(1),J)+PERDIF(IREQ(I),J)
60      CONTINUE
        DO 63 J=1,6
        DO 64 K=1,4
        AVRT(K,J)=0.0
        IF (COUNT(IREQ(1),K,J).NE.0)
     . AVRT(K,J)=RTDATA(IREQ(1),K,J)/(COUNT(IREQ(1),K,J)+0.0)
64      CONTINUE
        PERCOR(IREQ(1),J)=PERCOR(IREQ(1),J)/(NBREQ+0.)
        PERDIF(IREQ(1),J)=PERDIF(IREQ(1),J)/(NBREQ+0.)
63      CONTINUE
C
C WRITE OUT AVERAGES FOR THIS RUN
C
        WRITE(6,65)(IREQ(I),I=1,NBREQ)
65      FORMAT('0****  AVERAGES OF BLOCKS: ',1012)
        WRITE(6,50)
        WRITE(6,12)
        WRITE(6,13)
        DO 70 J=1,4
        WRITE(6,36)J,(AVRT(J,I),I=1,6)
        WRITE(6,37)(COUNT(IREQ(1),J,I),I=1,6)
70      CONTINUE
        WRITE(6,39)(PERCOR(IREQ(1),I),I=1,6)
        WRITE(6,40)(PERDIF(IREQ(1),I),I=1,6)
C
C TEST IF ANOTHER RUN IS REQUIRED
C
68      NUMRUN=NUMRUN+1
        CALL GT40('CLOSE')
        WRITE(6,19)
19      FORMAT('0ANOTHER RUN? (Y OR N)'/)
        READ(6,23)QUERY
23      FORMAT(1A1)
        IF (QUERY.EQ.'Y') GOTO 20
        CALL EXIT
        END
```

6.2 Document Preparation

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