# THE EXTERIOR-LETTER ADVANTAGE IN LINEAR MULTI-LETTER ARRAYS

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**Instrument and agent**

In my eye I've no apple; every object
Enters in there with hands in pockets.
I welcome them all, just as they are,
Every one equal, none a stranger.

Yet in the short journey they make
To my skull's back, each takes a look
From another, or a gesture, or
A special way of saying *Sir*.

So tree is partly girl; moon
And wit slide through the sky together;
And which is star - what's come a million
Miles or gone those inches farther?

Norman MacCaig

## Acknowledgements

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# Contents

## Abstract


When linear arrays of unrelated letters (e.g., 'sfdthnc') are presented tachistoscopically centred across a fixation point, letters presented at exterior positions (e.g., 's-----c') are generally reported more accurately than letters presented in interior positions. This "exterior-letter advantage" suggests that processing is more efficient for exterior letters than for interior letters. Previous researchers have argued that the exterior-letter advantage can be fully accounted for by the influences of lateral interference and mask configuration. However, the processes responsible for the exterior-letter advantage are far from resolved, despite the robustness of the phenomenon and its occurrence in numerous investigations into visual information processing.

The experiments reported in this study investigated the role of lateral interference and backward pattern masking in the exterior-letter advantage. To investigate the role of lateral interference, performance was compared across complete 7-letter arrays and arrays in which the presence and proximity of flanking letters was varied by (i) presenting only exterior letters and their immediately flanking interior letter, (ii) varying the number blank letter-spaces by which these letter-pairs were separated, (iii) varying the nature of the characters presented in these displays, and (iv) presenting each exterior/interior letter-pair in isolation. The role of backward pattern masking was investigated (i) using different mask configurations which either matched or exceeded the left and right boundaries of complete letter arrays, and (ii) using masks which overlay only the positions of each exterior/interior letter-pair.

The findings indicate that while lateral interference and mask configuration each played a part, neither an imbalance in the number of immediately flanking letters for interior and exterior letters nor mask configuration can entirely account for the exterior-letter advantage.

## Introduction

The visual system is of prime importance in the control of our actions. Through the visual system, information about the world necessary for initiating and guiding our actions can become available. Our actions are typically controlled by the objects which occupy the world surrounding us. For example, cars need to be avoided when crossing the street, and when laying the table knifes have to be distinguished from forks and spoons. Therefore, the visual system should necessarily provide suitable descriptions for each of the objects in the visual field to allow us to *recognise*, for example, a fork as a 'fork', and a knife as a 'knife'. In other words, these descriptions of objects must be matched with one of a set of stored representations of the visual characteristics of different kinds of objects. The study of visual object recognition is concerned with the nature of the stored representations of objects, along with the nature of the object descriptions that allow these stored representations to be activated.

A great number of studies in visual object recognition are particularly concerned with studying the processes involved in recognising printed words. In skilled readers the process of recognising words is fast, effortless, and usually very accurate. Yet, physically, a word printed on a page is not much more than an arrangement of squiggles contrasting with a homogeneous background. The arrangement of squiggles leads to some pattern of activation in the visual system, which encodes the physical characteristics of words, and which skilled readers have (through an elaborate learning process) managed to associate with representations of words (visual, phonetic, semantic) stored in memory. The study of visual word recognition is concerned with the nature of the representations of words in memory, and with the nature of the descriptions of visual information through which these representations are activated and, ultimately, accessed. For example, by severely limiting the amount of time during which a word, nonword, or single letter is presented, information can be gained to determine which physical characteristics of words are encoded by the reader and over what time scale this encoding takes place. In particular, when subjects are instructed to make judgments about the displays, differences between the encoding of letters in words and nonwords can be addressed. A general finding in these studies is that subjects report letters in words more accurately than letters in nonwords: *The word-superiority-effect* (e.g., Johnston & McClelland, 1973; see Jordan, 1990). In an attempt to explain this effect, many researchers have argued for the existence of 'perceptual units' through which words are recognized, representing familiar subword letter groups (e.g., functional parts of words like digrams, trigrams, prefixes, suffixes, etc.; see Taft, 1985, for a review of this approach; see also Jordan, 1990). Jordan (1990, p.893), for example, presented a tentative example of how such a system could produce the observed effect: "... the perception of words will be relatively fast because words can be perceived by processing just a few features. Thus, under tachistoscopic conditions when viewing time is severely limited, this rapid perceptual encoding will contribute to superior report accuracy for words over other stimuli".

Occasionally, studies in visual word recognition have emerged which present strong evidence for the exterior letters of words combining to form perceptual units through which words are recognised (e.g., Bouma, 1973; Forster & Gartlan, 1975; Humphreys, Evett & Quinlan, 1990; Jordan, 1990, 1994; McCusker, Gough & Bias, 1981).[1] For example, McCusker et al. (1981) primed the perception of 4-letter words (e.g., *trap*) by briefly presenting both exterior letters (*t p*) or both interior letters ( *ra* ), in their appropriate positions, immediately before the whole word was shown. Over a series of experiments, McCusker et al. (1981) found that words were named

[1] Letters in the first and last positions of words and nonwords will invariably referred to as *exterior letters*. Letters in any of the other positions will be referred to as *interior letters*.

more quickly when both exterior letters preceded each whole word display. Comparable findings are reported by Humphreys et al. (1990), using a technique in which subjects were presented with four brief consecutive visual fields on each trial; the first and fourth fields contained a pattern mask, and the second and third field contained a prime and target string respectively. Humphreys et al. found that the perception of word targets (e.g., *TRAP*) was facilitated more when primes and targets shared both exterior letters (*tvup*) rather than both interior letters (*hrag*). More evidence for the importance of exterior letters in word recognition was also obtained by Jordan (1990; 1994). Jordan presented letter pairs from the exterior positions of 4-letter words (e.g., *d  k* from dark) in brief, backward pattern masked displays, in the positions they would occupy if the whole word were shown centred across the fixation point. Letters presented in pairs were reported more accurately than letters presented alone (the *pair-letter effect*).

However, information about the relative position of letters in the prime appears to play a crucial role in the special role of exterior letters in the word recognition process. For example, in Humphreys et al's (1990) study, exterior letters were able to prime subsequently presented words only when these letters maintained their relative position within the array. The perception of 5-letter word targets (e.g., *BLACK*) was facilitated even when primes of only three letters were used (*b*v*k*), but not when exterior letters of words were moved from prime boundaries (t*b*v*k*u). Furthermore, when primes and targets shared the first two or last two letters, the effect of priming was the same as when prime and target shared both interior letters. This suggests that it is the combination of exterior letters that caused an increase in the effect of priming, rather than merely the presence of the first or last letter in the prime. Furthermore, in Jordan's (1990) study (see also Jordan, 1994), the pair-letter effect was obtained only when just the four positions of the 4-letter words from which the letter pairs were taken were covered by a subsequently presented pattern mask (*backward pattern masking*); when only the presented letters were masked, or when the masks were much wider than

4-letter words, performance with letter pairs fell to that observed with single letters.[2] Furthermore, when letter pairs were not the exterior letters of real 4-letter words (e.g., *y f*) no pair-letter effect and no selective effect of mask width was found. Jordan (1990) argued that these results suggest that the exterior letters of 4-letter words, plus information about their relative position in the word (provided by the boundaries of the masks), are sufficient to activate stored representations aiding the recognition of these letters.

In order to understand the preferential role of exterior letters in word recognition, we need to know how information about letters in linear multi-letter arrays becomes available, and how this availability differs for exterior letters compared to other letters in the display. In an attempt to explain the importance of exterior letters in word recognition, Bouma (1973, p.768) suggested that interference between neighbouring letters negatively affects their perceptibility, but "in isolated words, initial and final letters have neighbours on one side only and would therefore be expected to suffer less interference than embedded letters". Thus, it may be that extra processing time is needed to overcome the effects of interference between neighbouring letters when letters are presented in linear multi-letter arrays. Information about exterior letters could become available first, because these letters receive interference from neighbouring letters on one side only, and would, therefore, be particularly suited to 'kick-start' the word recognition process.

However, as indicated by the findings of Humphreys et al. (1990) and Jordan (1990), for exterior letters of words to play a special role in the word recognition process, more is needed than information about their presence in the display. That is, information about the position of exterior letters relative to other letters in the array

[2] In Jordan's study, pattern masks consisted of random arrangements of letter fragments presented after target stimulus offset. Each mask covered an area in the display with approximately the same height as words. The width of each mask was varied, but the pair-letter effect was found only when the width matched that of a 4-letter word, and presented such that letter pairs were positioned at the horizontal boundaries of masks.

plays a crucial role. In particular, Jordan's (1990) study suggested that mask boundaries may provide crucial information about the relative position of exterior letters. Jordan argued that physical characteristics of masks may combine with characteristics of linear arrays to form a percept that incorporates aspects of both stimulus fields, such that when mask boundaries match the boundaries of linear arrays, the position of exterior letters in relation to the boundaries of the array is defined by the mask. When mask boundaries extend beyond the boundaries of arrays, however, the position of exterior letters in relation to the boundaries of the arrays may be disrupted.

In the light of these effects of lateral interference and backward pattern masking, the present study investigated the effects of lateral interference and backward pattern masks on the perceptibility of letters in linear arrays. Information about these effects promises to provide valuable information about the special role of exterior letters in the word recognition process. However, rather than concentrating on the perception of letters in words, the present study concentrated on the perception of letters in nonwords (linear arrays of unrelated letters). Even though Johnston (1978) found that, even under forced choice conditions, the redundancy in words did not effect performance, arrays of unrelated letters were used to make absolutely sure that redundancy did not affect the difference in performance for interior letters and exterior letters. Furthermore, the effects of lateral interference are not restricted to letters in words. Indeed, lateral interference would also predict a difference between exterior letters and interior letters of nonwords; interior letters would receive lateral interference from flanking letters on both sides, while exterior letters would receive lateral interference only from flanking letters on one side. This suggests that the effect of lateral interference on the perception of exterior letters and interior letters can be studied independently of the effects of the higher level structure present in words.

In addition, to study the effects of backward pattern masks, it is crucial that the relative position of letters is not restricted by the orthographic structure of words. Indeed, Humphreys et al. (1990) suggested that superior priming was obtained with exterior letters than with any other combination of two letters, because exterior letters may be (a) more perceptible than other letters in the prime and (b) more accurately tied to their relative positions within a linear array than interior letters. To determine if exterior letters are more accurately tied to their relative positions than interior letters, arrays of unrelated letters need to be used, because the orthographic structure in words may already tie letters to a relative position.

## The bar-probe task: A literature review

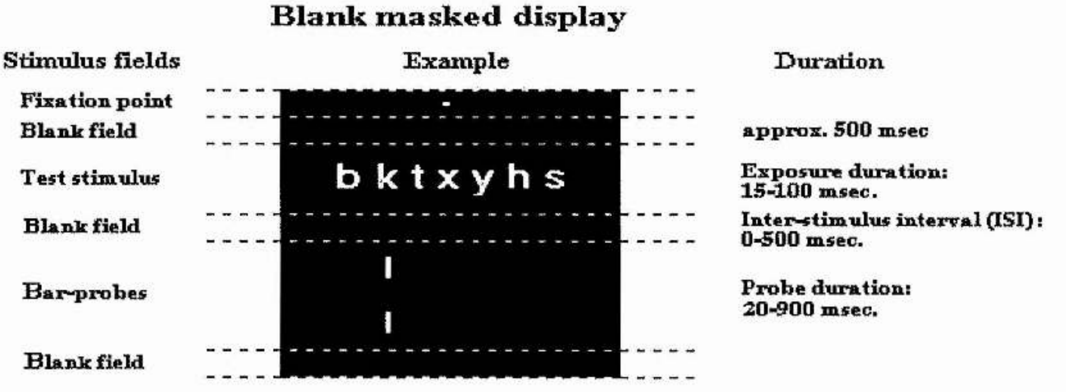
Chapter One was concluded suggesting that an investigation into the relative perceptibility of exterior letters and interior letters in linear arrays of unrelated letters may provide valuable insights into the special role of exterior letters in word recognition. Using linear arrays of unrelated letters also has the advantage that the same letters can be tested in each of the positions in the array, such that the effects of serial position on the identifiability of letters in linear arrays can be studied.

The serial position curve for correct reports is one of the most frequently reported empirical functions from tachistoscopic studies, using linear multi-letter arrays. Scores of these curves have been reported, and have been obtained in either full report tasks or partial report tasks. In full report tasks, subjects are simply instructed to report as many letters as possible from a tachistoscopically presented array (usually centred around the fixation point). With probed report, however, a cue (usually a bar-marker; *the bar-probe task*) indicates the position of one letter within the array which the subject is required to report. Figure 2.1 shows the sequence of events for each trial in the "standard" bar-probe task.

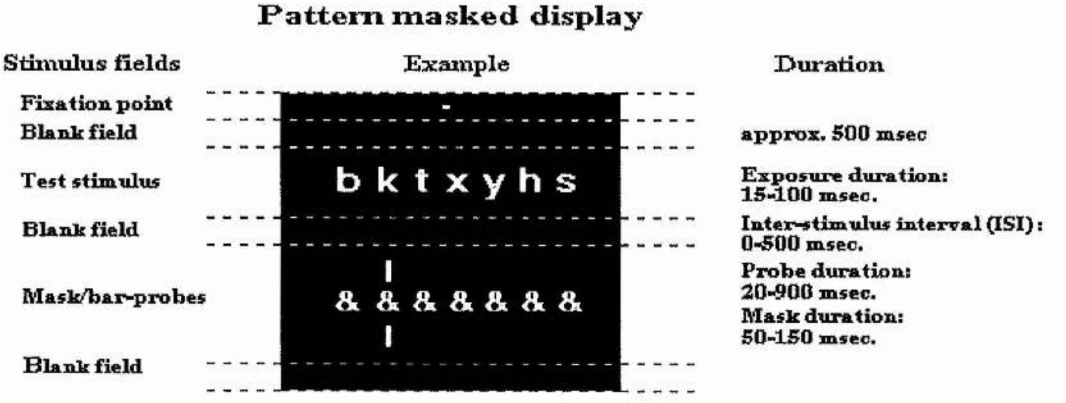
Particularly, the results of *the partial-report bar-probe task* (hereafter bar-probe task) will be discussed. The bar-probe task is one of the most widely used techniques for exploring the time scale of letter recognition in linear multi-letter arrays (see Van der Heijden, 1992, for an overview), and it is particularly useful for comparing the perceptibility of letters in different positions. One of the most characteristic (and robust) findings in the bar-probe task is the exterior letter advantage in serial position curves for correct report (Averbach, & Coriell, 1961; Campbell & Mewhort, 1980; Dick, 1974; Haber & Standing, 1969; Hagenaar, 1990; Hagenzieker, Van der Heijden

**Figure 2.1.** The sequence of events in the bar-probe task, when 7-letter linear arrays are presented (a) followed by blank fields and (b) followed by pattern masks. The pattern mask in this example consists of seven ampersands presented in the positions occupied by letters in the target array (after Mewhort, Campbell, Marchetti & Campbell, 1981).

(a)




(b)

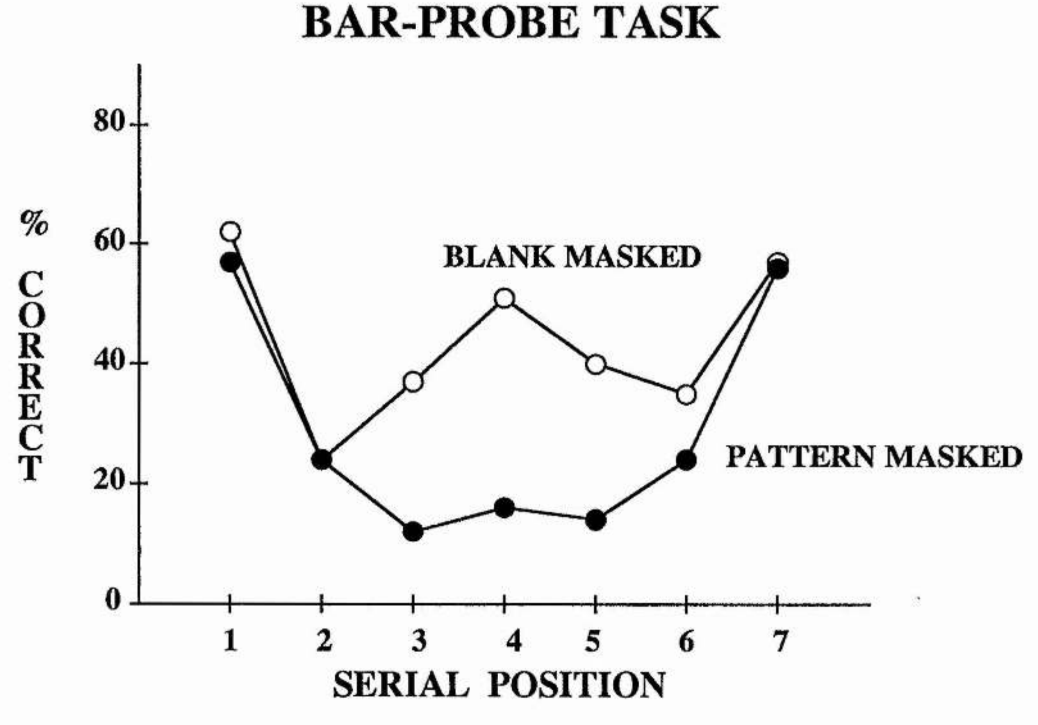


& Hagenaar, 1990; Lowe, 1975; Merikle & Coltheart, 1972; Merikle, Coltheart, & Lowe, 1971; Merikle & Coltheart, 1972; Merikle, Coltheart & Lowe, 1971; Merikle & Glick, 1976; Mewhort & Campbell, 1978; Mewhort, Campbell, Marchetti & Campbell, 1981; Mewhort, Marchetti & Campbell, 1982; Styles & Allport, 1986; Townsend, 1973). That is, accuracy is highest for the exterior letters, but is considerably lower for letters in interior positions, rising again only for letters in the positions at, or adjacent to, the fixation point when blank post-target fields are used. Two typical serial position curves obtained in the bar-probe task are shown in Figure 2.2; one for arrays followed by blank fields, and one for arrays followed by pattern masks.

However, the exterior-letter advantage is a feature which is not restricted to the bar-probe task, as it has also been found in other types of probed report tasks. The exterior-letter advantage has been found when the position of the target letter was indicated by a voice-probe (Mewhort & Leppmann, 1985), by a digit-probe (Campbell & Mewhort, 1980), and when the target letter was indicated by the colour in which it was printed, which differentiated it from the other letters in the display (Butler, Mewhort & Tramer, 1987). Furthermore, the exterior-letter advantage is also apparent in the full report serial position curve although somewhat obscured by the effect of the order in which letters are reported; letters occurring later in the sequence are less likely to be reported than letters at the start of the sequence (Bryden, 1966, 1970). Because letters are usually reported in a left-to-right order (possibly due to reading habits), accuracy for letters at the left of fixation is higher than for letters at the right (Bryden, 1966, 1970; Mewhort, 1974; Mewhort & Beal, 1977).

The generally higher accuracy for exterior letters compared to letters in interior positions in centrally presented linear multi-letter arrays actually contrasts with a fall in the ability to resolve fine detail when the distance from the point of fixation is increased (the visual acuity gradient; Alpern, 1962; Anstis, 1974; Sloan, 1968). That is, the minimum visual angle of a stimulus, in order for it to be recognised, increases when the

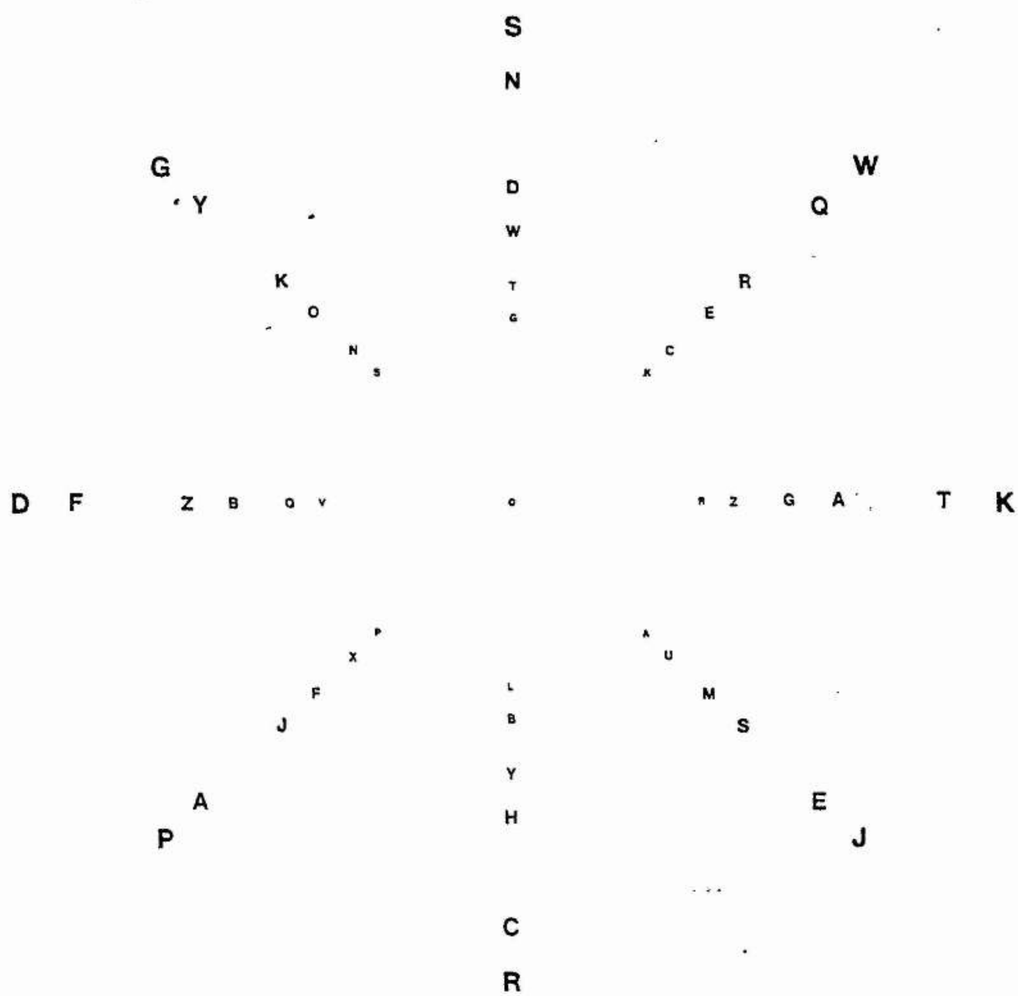
**Figure 2.2.** Examples of serial position curves for correct reports in the bar-probe task under blank masked and patten masked conditions. Similar curves were reported by Merikle, Coltheart and Lowe (1971).



distance of presentation from the fovea is increased. Anstis (1974) presented a chart plotting the threshold sizes of letters as a function of distance from the point of fixation (see Figure 2.3). Threshold size increases almost linearly with eccentricity (in visual angle). It is not clear, however, how this relates to the perception of letters in the type of displays used in the bar-probe task, since the dimensions of the letters used are generally clearly above threshold size. Nonetheless, it may be conceivable that when near threshold exposure durations are used, visual acuity could affect the recognition of letters presented at some distance from the fixation point. Indeed, the accuracy of reporting single letters presented tachistoscopically at various distances left or right of the fixation point shows an inverted U-shaped position curve for correct reports (e.g., Bouma, 1971, 1973; Merikle, Coltheart & Lowe, 1971). Therefore, while performance with single letters may exhibit a strong visual acuity component, an advantage for letters occupying more eccentric locations (exterior letters) over letters occupying more foveal locations (interior letters) appears to be specific for letters in linear arrays.

In the present study, an approach was adopted which is common to many investigations into visual information processing, revolving around studying the effects of different stimulus characteristics on subjects' performance in a particular task. In order to investigate the effects of varying stimulus characteristics on performance, near threshold conditions for the given task were set up, such that any effects of varying stimulus characteristics on processing of the information is likely to show up as a change in performance. To achieve near threshold conditions, stimuli were presented tachistoscopically. In order to study the perceptibility of letters, performance was measured in the bar-probe task. The bar-probe task was used, because over the years the perceptibility of letters in linear arrays has been frequently studied using the bar-probe task, so that the results of the present study can be compared with the results of previous studies. Because the role of backward pattern masking and lateral interference in the exterior-letter advantage was investigated, two stimulus fields were used; a target

**Figure 2.3.** All letters should lie at threshold when centre of this chart is fixated. Threshold letter size increases linearly with increasing distance from fixation point. (From Anstis, 1974, p.590).



stimulus, containing linear multi-letter arrays, and a mask stimulus, containing pattern masks composed of irregular arrangements of letter fragments. In several of the experiments reported in this thesis, the characteristics of stimuli in both stimulus fields were systematically varied, in order to find answers to questions that have arisen from investigations reported in the literature concerning the effects of backward pattern masking and lateral interference. However, before any specific questions are formulated in Chapter Three, a consideration of some of the processes basic to bar-probe task performance is appropriate here.

**Encoding of individual letters**

Several models for the encoding of individual letters have been proposed, and it would be outside the scope of this study to deal with them all (see Estes, 1978, for an overview). However, one type of model is particularly relevant to what is going to follow, and will therefore be discussed in some detail. The currently most popular type of model for the encoding of individual letters assumes that each letter in the alphabet is initially encoded as a configuration of a number of critical features (critical feature models; e.g., Gibson, 1969; Massaro, 1975; McClelland & Rumelhart, 1981). The nature of the critical features is different for each particular model, but they could, for example, distinguish between curved letters (e.g., 'O' and 'C') and angular letters (e.g., 'H' and 'N'). Alternatively, letters could be distinguished according to the particular strokes needed to draw the letter (e.g., a T would be encoded as a horizontal bar and a vertical bar). Thus, every letter in the alphabet would be represented as a list whose values signal the presence or absence of a particular feature. In such a system recognition is achieved on the basis of matching a set of values computed for a newly occurring sensory pattern to the feature lists maintained in memory.

Support for critical feature models comes predominantly from studying the pattern of confusions between letters in single letter recognition tasks. When letters are not recognised correctly, responses are not generated at random, but some letters are given in response to particular letters more than others. It has been suggested that confusable letters share a number of critical features, such that when one of these letters is presented, either letter can be given as a response, if only those features in common to the two letters are successfully extracted.

However, for letter recognition, detection of individual features is probably not sufficient. Other information, like, for example, the spatial relationships between features also needs to be extracted (see Humphreys & Bruce, 1989). Furthermore, although feature models can to some extent account for many aspects of individual letter recognition (see Estes, 1978), when letters are presented simultaneously in multi-letter displays, other factors determine the perceptibility of letters relative to each other. Therefore, critical-feature models can necessarily serve only at the front end of more extensive models for the processing of letters in multi-letter arrays (e.g., McClelland & Rumelhart, 1981; Rumelhart, 1970).

**Lateral interference**

When a target letter is presented simultaneously with and in close spatial proximity to other (distractor) letters, accuracy of report is generally lower than for targets presented in isolation. Often, the term *lateral interference* has been used to denote this adverse effect of distractor letters on the perceptibility of target letters (e.g., Banks, Larson & Prinzmetal, 1979).[1] Over the past decades, lateral interference has been studied extensively, and several properties of lateral interference have been established. Lateral interference is stronger in the periphery of the visual field than in the centre (Bouma, 1970), and lateral interference between letters decreases if the distance between them is increased, until, at a certain separation, no lateral interference

[1] This phenomenon has been referred to also as "lateral masking" (e.g., Estes, 1978; Van der Heijden, 1992). The term lateral interference is adopted here to avoid confusion with "backward masking", which specifically refers to the effects of a stimulus in a second stimulus field presented after target field offset, whereas lateral interference refers specifically to adverse effects of distractor letters presented simultaneously and in close spatial proximity to the target in the target stimulus field (e.g., Bouma, 1970).

is observed (Bouma, 1970; Wolford & Chambers, 1983). However, the spatial extent of lateral interference is greater in the periphery of the visual field than in the centre (Bouma, 1970). Furthermore, an irrelevant character interferes more with the perception of a target letter, and the spatial extent of this lateral interference is greater, when it flanks the target letter on the peripheral side than when it flanks the target letter on the foveal side (Banks, Bachrach & Larson, 1977; Banks et al, 1979; Bouma, 1970; Chastain & Lawson, 1979). Finally, lateral interference appears to be to some extent feature specific, in that letters sharing many features with the target letter interfere more than letters sharing none, or just a few, of the features with the target letter (Bjork & Murray, 1977; La Heij & Van der Heijden, 1983; Santee & Egeth, 1982).

**A short-term visual buffer, and Short-Term Memory [STM]**

It is generally accepted that the report of tachistoscopically presented material, to some extent, reflects limitations in immediate memory (e.g., Estes & Taylor, 1964; Rumelhart, 1970; Sperling, 1960). For example, if the number of presented letters is varied in a full report task, the number of letters reported is remarkably constant. Sperling (1960) presented from 6 to 18 items at any one time, with exposure durations ranging between 15 and 500 ms. In a typical display containing 12 letters, three rows of four letters were arranged around the fixation point. Regardless of the number of letters in the display or the exposure duration, an average of about 4.5 letters was reported correctly. If, however, a tone was presented immediately after offset of the display indicating from which row the letters had to be reported (probed report), subjects averaged about 3 letters correct from the 4 letters in the row. These results suggested that immediately after display offset much more information was available (3 rows x 3 letters = 9 letters) than could be measured in a full report task. As the tone in Sperling's (1960) study was delayed, the number of letters reported correctly decreased monotonically with probe delay, until, at a delay of about 300 ms, an asymptotic level of about 1.5 letters correct per row was reached, which is similar to full report accuracy (3 rows x 1.5 letters = 4.5 letters).

In order to account for this partial report advantage with short probe delays, the notion of a short-term visual buffer with a large information capacity (but short information persistence) was introduced, referred to here as *visual buffer* (see Coltheart, 1975, 1980, for extensive reviews). Information about the letters in a display is available in this visual buffer for a brief time after display offset, during which information may be selected for transfer into a more durable memory (short-term memory [STM]; Sperling, 1967; see also Estes, 1978), where it can be held for an extended period of time, and used to generate a response. The maximum amount of information that can be transferred from the visual buffer into STM is limited, which is reflected by the limit in full report performance. However, by using the probe in the probed report task, relevant information can be selectively transferred from the visual buffer into STM, while irrelevant information can be ignored.

Thus, the results of the bar-probe task have contributed to an almost generally accepted view of the first stages of visual information processing, in which the major emphasis is on the need to select information from a large capacity visual buffer before a response can be initiated (see Coltheart, 1980, for an overview). The availability of information in a visual buffer after display offset can account for the difference in performance for full report and performance for probed report. Therefore, using the bar-probe task the initial stages of information processing can be investigated while circumventing limitations in short-term memory apparent in full report performance. That is, according to this view of information processing, performance in the bar-probe task probably provides a more precise estimate of the quality of information in the visual buffer than performance in the full report task. Such a conclusion would certainly be in agreement with the difference in the shape of the serial position curves for full report and partial report, which is almost symmetric for both sides of the fixation point for partial report, but markedly skewed across the fixation point for full report.

**The effect of delaying the bar-probe**

Averbach and Coriell (1961) introduced the bar-probe task as a variation on Sperling's (1960) probed report task. In Averbach and Coriell's (1961) study, subjects were shown brief presentations of a multi-letter stimulus (two linear letter arrays), while a bar marker, presented at various intervals before or after stimulus onset, indicated the position within the array of the letter which the subject had to report. Performance in this task was greatly affected by variations in the time between termination of the target stimulus and presentation of the bar-probe. When the probe preceded the stimulus, or when it was presented simultaneously with the stimulus, accuracy was high (75% correct reports), but as the delay between stimulus offset and probe onset increased, accuracy rapidly dropped to an asymptotic value of about 35% at a delay of approximately 200 ms. Over the past thirty years the basic results of Averbach and Coriell (1961) have been replicated many times (see Van der Heijden, 1992, for an overview), and, the effect of probe delay has generally been taken as evidence for a rapid loss of information from a very short term visual buffer. However, the fact that performance does not reach chance level even at very long probe delays, but remains at a level of performance similar to that in the full report task, suggests that information can enter short-term memory before the bar-probe is presented (Hagenaar, 1990). Thus a distinction needs to be made between performance with short probe delays (i.e., shorter than 200 ms), and long probe delays (i.e., longer than 200 ms). With short probe delays the probe is used to select information from the visual buffer for report, as evident in the advantage of probed report over full report. At long probe delays performance is likely to reflect predominantly the report of letters entered in short-term memory before presentation of the probe.

Surprisingly, however, the length of the delay of the probe after stimulus offset does not seem to have an appreciable effect on the shape of the serial position curve (Averbach & Coriell, 1961; Haber & Standing, 1969; Hagenaar, 1990; Hagenzieker, Van der Heijden & Hagenaar, 1990; Mewhort, Campbell, Marchetti & Campbell, 1981; Townsend, 1973; see also Van der Heijden, 1992). That is, although accuracy decreases with longer probe delays, it decreases at approximately the same rate for all letter positions. This suggests that the same basic processes are reflected in the serial position curve at both short and long probe delays.

**Localisation**

In early studies using the bar-probe task only proportions correct report were analysed (e.g., Averbach & Coriell, 1961; Haber & Standing, 1969). Correct responses were taken as an unbiased measure of how well the letters in the display could be identified. Errors were assumed to be exclusively the result of failures to correctly identify the letter in the probed position. Later studies, however, suggested that in order for a letter to be selected for report more is involved than identification (e.g., Dick, 1969, 1974, and Townsend, 1973). That is, the use of a bar-probe, indicating the location of the letter that has to be reported, implies that, in order to perform the task well, subjects must know not only the identity of the target letter, but also the position of letters in the array, and the position of the bar-probe relative to the target. Thus, a failure to report the target letter could arise not only from a failure to correctly identify the target letter, but also from a failure to correctly localise the target letter.

In order to distinguish between the loss of identity and location information, Townsend (1973) distinguished between two types of errors which were assumed to correspond to failures of identification and failures of localization. When subjects reported a letter present in the string, but not in the probed position, it was scored as a *location error* (or inversion error: Estes, 1975; Mewhort & Campbell, 1978). Location errors were assumed to reflect failures of localization, but not identification. When subjects reported a letter not present in the string it was scored as an *intrusion error* (or item error; Hagenaar, 1990; Van der Heijden, 1992). Intrusion errors were assumed to reflect failures of identification (i.e., the operation that assigns a label to the configuration of features).

Mewhort and colleagues (Mewhort, Butler, Feldman-Stewart & Tramer, 1988; Mewhort & Campbell, 1978; Mewhort, Campbell & Marchetti, 1982; Mewhort et al., 1981; Mewhort & Leppmann, 1985) collected a complete set of data on the properties of location and intrusion errors in the bar-probe task. The main findings were that errors in the bar-probe task are predominantly location errors, whereas a guessing strategy, adopted in cases where target letters were not identified, would predict that errors were predominantly intrusion errors.[2] Furthermore, location errors mirror the typical W-shaped serial position curve for correct reports. That is, the serial position curve for location errors is clearly M-shaped, whereas intrusion errors show a shallow U-shaped serial position curve. From these data, Mewhort and Campbell (1978, p.100) concluded "performance in the bar-probe task largely reflects spatial addressing processes".

However, as Hagenaar (1990) has clearly shown, there is no one-to-one relationship between a particular type of error and one particular type of process, be it identification or localisation. That is, location errors and intrusion errors may be the result of a combination of failures to locate and identify the letters in the array. One type of location error may reflect the perception of a nontarget letter in the target position (hereafter called an inversion), but it may also reflect a misidentification of the target letter or a misidentification in combination with an inversion. In addition, there may be a distinct possibility that subjects, when unable to correctly identify the target letter, reported a letter from another position, although they were not sure if the reported letter was in the position indicated by the probe (unintentional false location errors), or even when they knew that the reported letter was not the target letter (intentional false location errors; Hagenaar, 1990). Thus, there may be a distinct

[2] When in each trial seven different letters were presented, selected from the entire alphabet, the chance that guessing will result in report of a letter presented in a position other than the target position is 6/25th, whereas the chance that the letter reported was not present in the array is 19/26th.

possibility that location errors do not reflect only, or even primarily, inversions. Likewise, an intrusion error may reflect a misidentification of the target letter or a combination of a misidentification and an inversion. Nevertheless, the chance that a combination of a misidentification and an inversion occurs may be assumed to be relatively small. Therefore, it may seem reasonable to assume that intrusion errors reflect primarily misidentifications of target letters.

Another source of location errors, which is independent of the occurrence of inversions of letters in the array, arises from failures to accurately align the bar-probe with the position of the target letter. Evidence suggesting that sometimes subjects are unsure about the position indicated by the probe was obtained in a digit naming task (Hagenaar, 1990; Hagenzieker, Van der Heijden & Hagenaar, 1990; Lowe, 1975; Mewhort & Campbell, 1978). In the digit naming task a constant digit array (the digits 1-7 in sequence, i.e., 1234567) was flashed up briefly, followed by the probe (after a variable delay). Subjects had to report the digit indicated by the probe. Because the identity of the items and the order in which they occurred in the displays were known to the subjects beforehand, misidentifications and mislocalisations were unlikely to occur (see Van der Heijden, 1992). Therefore, errors in this task are most likely to reflect failures to align the probe with the target position, causing the wrong position to be taken as the target position. The results of the digit naming task indicated that the bar-probe was located most accurately when it indicated digits in the exterior positions of the array, and less accurately when digits in the interior positions were indicated. In the standard bar-probe task, the probe has to be aligned with the target arrays in exactly the same way as in the digit naming task, so the same probe alignment problems are likely to be encountered (Van der Heijden, 1992). Thus, in the standard bar-probe task, probe misalignments may benefit accuracy of report and lower the number of location errors when exterior positions are probed compared to when interior positions are probed.

Thus several different mechanisms may give rise to location errors and intrusion errors. In particular, intentional false location errors and probe misalignments may account for the preponderance of location errors. Thus, the conclusion, based on the relative occurrence of location errors and intrusion errors, that bar-probe task performance is primarily limited by the ability to localise letters in the arrays is highly problematic, and the possibility that failures to correctly identify letters in linear multi-letter arrays might affect performance in the bar-probe task cannot be excluded. Indeed, Van der Heijden (1992) presented a numerical model, which simulated the pattern of location errors and intrusion errors presented by Mewhort et al.(1981), assuming that performance was determined only by identification and probe misalignments. Thus, although the possibility of inversions was not excluded, the pattern of incorrect reports cannot be taken as conclusive evidence for the occurrence of inversions of letters in the array.

**Conclusion**

The literature discussed in this chapter reveals that, when some precautions are taken, performance in the bar-probe task may reveal differences in the quality of perceptual information for interior letters and exterior letters, while circumventing limitations in short-term memory.

# Chapter Three

## The exterior-letter advantage in linear multi-letter arrays

In Chapter One, it was suggested that two factors may be of particular importance in the special role of exterior letters in the word recognition process; these are lateral interference (e.g., Bouma, 1973) and backward masking (Jordan, 1990, 1994). Lateral interference is specific for multi-element displays, while backward pattern masks are often used to limit the perceptibility of letters in the display. In Jordan's (1990) study the special role for exterior letters in the word recognition process depended critically on the configuration of backward pattern masks. Therefore, in addition to examining the role of lateral interference in the exterior-letter advantage, an investigation into the effects of mask configuration on the exterior-letter advantage may provide valuable information about the special role of exterior letters in word recognition.

### Lateral Interference

An often propagated and powerful explanation of the exterior-letter advantage in linear multi-letter arrays is that information for exterior letters is more readily available because of reduced lateral interference (e.g., Estes, 1978; Estes, Allmeyer & Reder, 1976; Flom, Weymouth & Kahneman, 1963; Haber & Standing, 1969; Hagenzieker et al., 1990; Van der Heijden, 1987, 1992). The effect of lateral interference would necessarily be greatest in the interior of linear multi-letter arrays, where target letters are flanked by distractor letters on both sides, and least at the exterior, where targets are flanked by distractors on only one side. Conceivably, this reduced amount of lateral interference for exterior letters could offset the disadvantage following from the visual acuity gradient (see Van der Heijden, 1987, for a simple model combining the effects of the visual acuity gradient and lateral interference to produce a W-shaped serial position curve for displays followed by blank fields).

However, the precise role of lateral interference in the exterior-letter advantage is not clear, because the properties of lateral interference have been most easily demonstrated in studies that have not used the bar-probe task. The bar-probe task has been used primarily to study the availability of information immediately after brief presentations of multi-letter displays (see Chapter Two). Therefore, in the bar-probe task every letter in the display is a potential target until the bar-probe is presented indicating the position of the letter that has to be reported. Lateral interference between targets and distractors has been studied using targets and distractors selected from different sets of letters, such that distractor letters were never used as targets and vice versa (e.g., Bouma, 1970; Banks, Bachrach & Larson, 1977; Banks, Larson & Prinzmetal, 1979; Banks & White, 1984; Wolford & Chambers, 1983; Chambers & Wolford, 1983). For example, in Wolford and Chambers' (1983) study *H*'s served as distractor letters while the target was either an *A*, *U*, *T* or *Y*. In addition, targets in lateral interference studies are generally presented in a predictable position in the displays, whereas in the bar-probe task the position of the target letter is specified only after stimulus offset. These differences between procedures used in the bar-probe task and in lateral interference studies may induce different processing requirements which may affect performance differently. Therefore, the properties of lateral interference, observed using a different procedure, have to be tested using the bar-probe task, to study the importance of lateral interference in the exterior-letter advantage.

Few studies have been reported in which the role of lateral interference in the exterior-letter advantage has been examined directly (Haber & Standing, 1969; Hagenzieker et al., 1990; Mewhort, Marchetti & Campbell, 1982). For example, Haber and Standing (1969) presented 7-letter linear arrays bounded by parentheses, and found that, although the exterior-letter advantage was much reduced compared to when arrays were presented without parentheses, an advantage still remained for exterior letters over letters next in from the ends. In view of these findings, Haber and

Standing (1969) suggested that either lateral interference cannot account for the exterior-letter advantage entirely, or parentheses do not produce the level of interference that would be provided by flanking letters.

Thus, even though lateral interference has not been ruled out, its precise role is not clear, all the more so because the effects observed by Haber and Standing were induced by nonletter characters, which might not generalise to flanking letters (e.g., Hammond & Green, 1982; Mason & Katz, 1976). Indeed, an advantage for items presented in the exterior positions of linear multi-item arrays appears to be specific to arrays of letters as it has not been observed in arrays of other types of item (Hammond & Green, 1982; Mason, 1982; Mason & Katz, 1976). For example, when arrays of *nonsense* characters are presented (e.g., "letter-like" characters), accuracy of report is actually *worse* for items in exterior positions (Hammond & Green, 1982).

A different approach, to study the role of lateral interference in bar-probe task performance, was adopted by Mewhort, Marchetti and Campbell (1982, Experiment 2; see also Campbell & Mewhort, 1980). Mewhort et al. (1982) controlled the amount of lateral interference between letters in 8-letter linear arrays by spacing out the letters, such that each letter was separated further from its neighbours. Performance for spaced arrays was compared with performance for nonspaced arrays. However, by increasing the space between letters the location in the visual field of each letter was shifted away from the fixation point (especially the locations of exterior letters), increasing the total visual angle spanned by the array. Therefore, in addition to a control condition in which nonspaced arrays were presented, Mewhort et al. (1982) introduced a second control condition in which letters occupied the same locations in the visual field as letters in the spaced arrays, while the size of the letters was increased such that the spacing between letters was comparable to the spacing in nonspaced arrays.

They found that increasing the spaces between letters considerably reduced the exterior-letter advantage compared to both nonspaced control conditions, which was almost entirely matched by a decrease in the advantage of exterior positions over interior positions for location errors. However, although the effect of spacing on the exterior-letter advantage suggests that the imbalance in the amount of lateral interference suffered by interior letters and exterior letters was reduced, report of exterior letters was still more accurate than report of interior letters, when letters were spaced further apart. Furthermore, the effect of spacing on the advantage for exterior letters for the number of location errors prompted Mewhort et al. (1982) to suggests that spacing mainly reduced the difference in spatial uncertainty between interior letters and exterior letters.

However, there are at least two reasons why drawing conclusions from the findings of Mewhort et al. (1982), about the role of lateral interference in the exterior-letter advantage may be problematic. First, it is not clear whether the findings reflected only the effects of spacing. A comparison between the spaced condition and the nonspaced condition in which the letters had the same size included the effects of a shift in the location of letters towards the periphery of the visual field. A comparison between the spaced condition and the nonspaced condition in which the letters had the same location included the effects of a difference in letter size. Thus, neither of the two control conditions allowed a direct assessment of the effects of spacing. Second, even in the spaced condition, the spacing between letters was well within the range in which lateral interference between letters is expected to occur (e.g., Bouma, 1970). Therefore, the exterior-letter advantage in spaced arrays may still have been the result of lateral interference. Thus, although lateral interference may play a role in the exterior-letter advantage, the precise nature of this role is not yet clear.

**Backward Pattern Masking**

Up to this point, only the importance of characteristics of target stimuli for the exterior-letter advantage have been discussed. However, although the exterior-letter advantage depends on the use of linear multi-letter arrays, the extent of the advantage depends on the nature of the post-target field. In order to investigate the different rates at which information about letters in different positions becomes available, several studies have used post-target fields containing irregular arrangements of contours (*backward pattern masks*). Backward pattern masking appears to accentuate the exterior-letter advantage in linear multi-letter arrays; generally, exterior letters are reported more accurately than *most* interior letters when linear multi-letter arrays are followed by blank fields, exterior letters are reported more accurately than *all* interior letters when backward pattern masks are used (Butler & Merikle, 1973; Campbell & Mewhort, 1980; Henderson & Park, 1973; Lowe, 1975; Merikle, 1974; Merikle & Coltheart, 1972; Merikle et al., 1971; Merikle & Glick, 1976; Mewhort, & Campbell, 1978; Mewhort et al., 1981). For example, Merikle and Glick (1976) examined the exterior-letter advantage in backward pattern masked displays by varying the time interval between onset of the target stimulus and onset of a masking stimulus (Stimulus Onset Asynchrony; SOA), and found that exterior letters were the first to benefit from an increase in SOA. Accuracy for interior letters did not benefit appreciably until SOA was sufficiently large to allow almost perfect accuracy for exterior letters. According to Merikle and Glick (1976) these findings suggest that exterior letters are encoded before interior letters at a level where pattern masks are unable to affect further processing (*the ends-first processing hypothesis*; see also Butler & Merikle, 1973; Merikle, 1974; Merikle & Coltheart, 1972; Merikle et al., 1971).

Merikle and Glick's (1976) conception of backward pattern masking corresponds to a widely held view stressing the time limits imposed on the processing of letters in linear multi-letter arrays followed by pattern masks. That is, information about pattern masks entering the system prevents further processing of letters in a previously presented linear multi-letter stimulus that have not yet activated some kind of more stable visual representation. Thus, according to this view, an increase in SOA is equivalent to an increase in the time available for processing of target information. If exterior letters are encoded before interior letters, possibly because of reduced lateral interference, increasing the SOA will allow exterior letters to escape disruption by a subsequently presented pattern mask before interior letters.

However, the precise influences of backward pattern-masks on the perception of letters in linear multi-letter arrays have yet to be fully revealed (e.g., see Breitmeyer, 1984; Eriksen, 1980; Felsten & Wasserman, 1980; Jordan, 1990, 1994; Jordan & Bevan, 1994a, 1994b; Jordan & de Bruijn, 1993). Indeed, while pattern masks may limit performance, the interpretation of this finding suggested by Merikle and Glick (1976) ignores effects of mask size. For example, in a series of studies, Jordan and colleagues (Jordan, 1990, 1994; Jordan and Bevan, 1994a, 1994b; Jordan & de Bruijn, 1993) have demonstrated some of the complexity in the effects of mask size relative to target size on the perceptibility of letters in linear multi-letter displays. For example, in Jordan' (1990) study, discussed briefly in Chapter One, the pair-letter effect cannot be explained in terms of the characteristics of the target stimuli alone, as the effect was observed only when the mask contours covered all four positions of 4-letter words, even when only the exterior letters were actually presented; when masks overlay only the letters that were actually presented, or when masks overlay an area wider than 4-letter words, performance with letter pairs fell to that observed for single letters. Jordan argued that the position information that was not present when only exterior letters were presented could be provided by the mask. That is, the identity of each letter pair and the position of these letters in relation to the horizontal boundaries of word size masks were consistent with the presentation of letter pairs in their natural position at the extremities of a word. Furthermore, the loss of the pair-letter effect when masks overlaid only the letters presented or when the masks exceeded the width of 4-letter words indicates that these masks did not provide the proper position information. Thus, according to Jordan (1990) the boundaries of pattern masks may provide information about the position of letters in the stimulus.

A similar account of backward pattern-masking was suggested by Mewhort and Campbell (1978) to account for the effects of backward pattern masks on the exterior-letter advantage. Mewhort and Campbell (1978; see also Campbell & Mewhort, 1980;

Mewhort et al., 1981) argued that the serial position curve in the bar-probe task reflects the limits in subjects' ability to accurately determine the *location* of letters in linear multi-letter arrays, rather than their *identities*. According to Mewhort and Campbell (1978) letters are localised more accurately at the *spatial anchors* of the arrays (i.e., the exterior positions and the positions at or adjacent to the fixation point), thus explaining the W-shaped serial position curve for accuracy of report when target displays are followed by blank fields. They further argued that backward pattern masks that match the boundaries of linear multi-letter arrays selectively disrupt the spatial anchor at the fixation point, but leave the spatial anchors at the exterior positions intact. To test this hypothesis Mewhort and Campbell (1978) presented constant digit arrays (the digits 1 through 8 in left to right ascending order), followed by either of two types of pattern masks; masks consisting of eight ampersands matching the boundaries of the digit arrays (appropriate masks), or masks consisting of twelve ampersands extending two letter positions beyond either side of the digit arrays (wide masks). A bar-probe, presented simultaneously with the masks, was used to indicate one of the digit positions in the array, and subjects were instructed to report the digits in the target positions. In line with the spatial anchor hypothesis, an end-position advantage over all other positions was observed only in the appropriate mask condition; in the wide mask condition performance for the end positions was actually *worse than for all interior positions*. However, it is as yet unclear how the effect of mask configuration observed in Mewhort and Campbell's (1978) digit naming task translates to backward pattern masking in the traditional bar-probe task. In particular, in the digit naming task the target arrays were entirely predictable, whereas in the traditional bar-probe task arrays are generally filled with randomly selected letters, making them entirely unpredictable. It seems unlikely that limitations in the ability to identify or to localise the elements in the array has any effect on performance, when subjects know exactly the contents of each display. Indeed, the digit naming task has been primarily used to investigate subjects' ability to align the (briefly exposed) bar-probe with the target arrays

(Hagenaar, 1990; Hagenzieker et al., 1990; Lowe, 1975). Thus, the results of Mewhort and Campbell's (1978) digit naming experiment indicates that the width of pattern masks may affect subject's ability to align the bar-probe with the target position, but they are inconclusive about the effects of mask configuration on subject's ability to localise letters in unpredictable linear arrays.

## Experiment 1

In light of the evidence reported by Jordan (1990, 1994; also Jordan & de Bruijn, 1993), suggesting that different mask configurations can have qualitatively different effects on the perceptibility of letters in linear arrays, it is imperative to determine the effects of mask configuration on the exterior-letter advantage. This is even more important considering the inconclusive evidence for the effects of mask configuration on the exterior-letter advantage presented by Mewhort and Campbell (1978). Therefore, Experiment 1 was conducted to determine whether the effects of mask configuration observed by Mewhort and Campbell (1978) in a digit naming task could also be obtained in a traditional bar-probe task using random letter arrays.

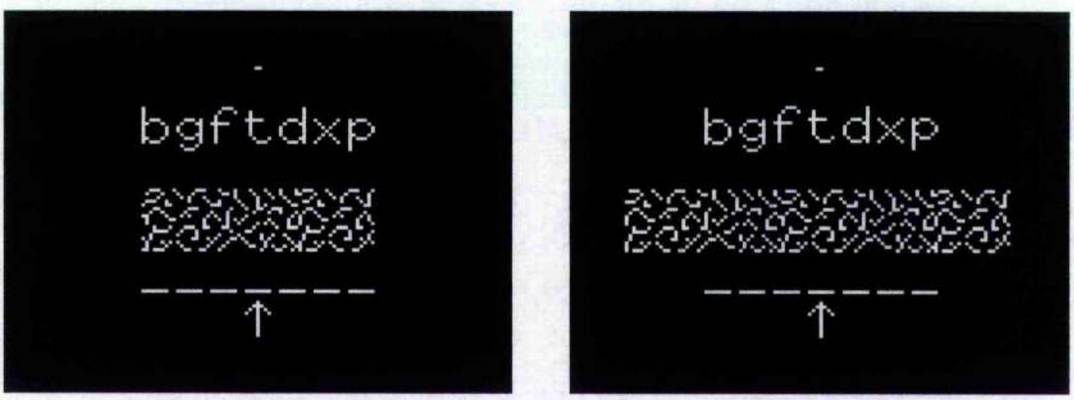
In Experiment 1, linear 7-letter arrays composed of randomly selected letters were followed by one of two mask configurations; masks with horizontal boundaries matched to those of the arrays (Appropriate masks), or masks with horizontal boundaries which extended beyond those of the arrays (Wide masks). An example of a target stimulus, and both mask configurations used in Experiment 1, are presented in Figure 3.1.

### Method

*Subjects*. 16 students served as paid subjects in two 1-hr sessions. All reported normal or corrected-to-normal vision and were native speakers of English.

**Figure 3.1.** An example of test stimuli, of each of the mask configurations and the response display used in Experiment 1. See text for explanation.

## EXPERIMENT 1




**A-MASK** **W-MASK**

*Stimuli.* 168 different test arrays and 84 practice arrays were constructed for each subject, by randomly picking seven letters without replacement from the following set of letters: b, d, f, g, h, n, p, q, t, v, x, and z. The only constraint in constructing the test arrays was that each letter appeared in each of the array positions an equal number of times, but only once in any particular array.

A different postmask was constructed for each trial, from pseudo-randomly arranged letter fragments, with the built-in constraint that no letters were formed by these fragments; a preliminary detection task showed that these masks were capable of rendering targets undetectable at sufficiently brief exposures. Mask height was determined by the height of the ascenders and the depth of the descenders in the letter set, and was kept constant throughout the experiments. Mask width was determined by the mask conditions (see Design). In the Appropriate mask condition (A-mask), the masks extended exactly from the left edge of the left most letter to the right edge of the right most letter of target arrays.[1] In the Wide mask condition (W-mask) masks were approximately 50% (to the nearest pixel) wider than A-masks, exceeding target arrays equally on both sides (see Figure 3.1).

*Visual Conditions.* Stimuli were presented on a dark-grey oscilloscope screen, in a white, evenly spaced lower-case font. Background illumination of the oscilloscope screen was approximately 1 $cd/m^2$, and the luminance of the target arrays and masks was approximately 25 $cd/m^2$.

A single letter subtended horizontal and vertical visual angles of approximately $0.20^{\circ}$. The spacing between letters was approximately $0.06^{\circ}$ from edge to edge. The horizontal angle subtended by the entire 7-letter array was approximately $1.97^{\circ}$.

The horizontal visual angle of appropriate masks matched that of the stimulus displays; the horizontal visual angle of W-masks was approximately $2.90^{\circ}$. The vertical visual angle of both mask configurations was approximately $0.50^{\circ}$.

[1] The leftmost and rightmost column of pixels of A-masks shared the same horizontal coordinates as the leftmost and rightmost pixels, respectively, of target arrays.

On each trial the target position was cued by a bar-probe (see Procedure). Simultaneously with the probe, seven dashes were presented to mark the position of the letters in the stimulus (position markers). Each position marker appeared $0.42^{\circ}$ below the position of its respective letter in the test stimuli. The probe consisted of an upward pointing arrow with the same horizontal and vertical dimensions as the test letters.

*Design.* Each of the test stimuli was shown twice during the experiment (once in each of the two Mask Conditions), but only once in a single session. Each position was tested equally often, and each of the test letters appeared in the target position 14 times during one session; seven times in each Mask Condition. Each session was divided into two sections (practice and test), with no obvious transition from one section to the next. Half the stimuli were shown in the A-mask condition, and half in the W-mask condition in one session. The stimulus/mask pairing was reversed in the second session. Assignment of stimuli to mask conditions in the first session was alternated between subjects. Stimuli were shown in cycles of 28 trials, counterbalanced across mask configuration and serial position.

*Apparatus.* The experiment was controlled by a Cambridge Electronic Design 1401 intelligent interface, slaved to a microcomputer. Stimuli were plotted on a Hewlett Packard 1332A oscilloscope equipped with rapid decay P4 phosphor with a spot persistence time of 10 microseconds to 10%. The screen of the oscilloscope was completely covered with matte black card except for an area at its centre measuring approximately $6^{\circ}$ horizontally and $3^{\circ}$ vertically. In addition, the oscilloscope had been modified to enable precise control over the visual angle of stimuli and to provide a higher resolution display (Jordan & Martin, 1987). The experiment was conducted in a darkened booth, and subjects entered their responses via an illuminated alphabetic keyboard interfaced with the computer.

*Procedure.* At the beginning of the first session subjects were familiarised with all the letters used in the experiment. The letters were presented one by one on the screen at a rate controlled by subjects, who were instructed to say each letter aloud as it appeared. The complete letter set was rehearsed three times.

At the start of each trial a small fixation point appeared at the centre of the screen. Subjects were instructed to fixate this point while initiating a display. A display was initiated by pressing a key after which the screen went blank, followed 500 ms later by the stimulus display, centred across the position of the fixation point. The stimulus remained on the screen for a predetermined time, after which it was replaced immediately by a pattern mask. The mask remained on the screen for 65 ms. Immediately after mask offset, the position markers and the probe appeared. Subjects had to type the letter previously shown in the position indicated by the probe, and were instructed to guess if unsure. In order to limit confusion over the target position, dashes and probe remained on the screen for unlimited time. A response was given by pressing the appropriate key on a keyboard. The letter given as a response appeared above the dash corresponding to the probed position, and dashes, probe and response letter remained on the screen until the subject pressed a second key to enter their response, and move on to the next trial. Before entering a response subjects were allowed to change their response as often as they liked. Only letters from the test set could be entered as a response, the keys on the keyboard corresponding with letters outside the set were disabled preventing these letters to be entered as a response. Figure 3.1 shows the sequence of display fields presented in Experiment 1.

Throughout the practice and experimental sections exposure durations were re-assessed for each subject after each cycle of 28 trials. Exposure duration was increased if the number of correct responses for targets in positions 1, 2, 6, and 7 (the exterior letters and the interior letters next in from the ends) in a cycle was below 8 (50.0%) and was decreased if the number of correct responses for targets in positions 1, 2, 6 and 7 in a cycle was above 10 (62.5%). This adjustment procedure ensured that performance averaged over positions 1, 2, 6 and 7 fell in the midrange of the performance scale (i.e., between chance performance and perfect scores, which was between 8.3% and 100% correct) and that each condition was represented at the same exposure duration an equal number of times.[2] Target exposure duration could be adjusted in steps of 3 ms, with a minimum exposure duration of 3 ms. This step size and minimum exposure duration was determined by the minimum time required for illuminating once each of the pixels in the target stimulus (*the minimum refresh rate*). The minimum refresh rate was independent of the number of pixels present in the target stimulus, which made it also independent of the number of characters in the target stimulus. For each of the subjects an average exposure duration of the test stimulus was calculated from the exposure durations set at the start of each 28-trial cycle in the test section. The average exposure duration over all subjects was 62.1 ms.

**Results and discussion**

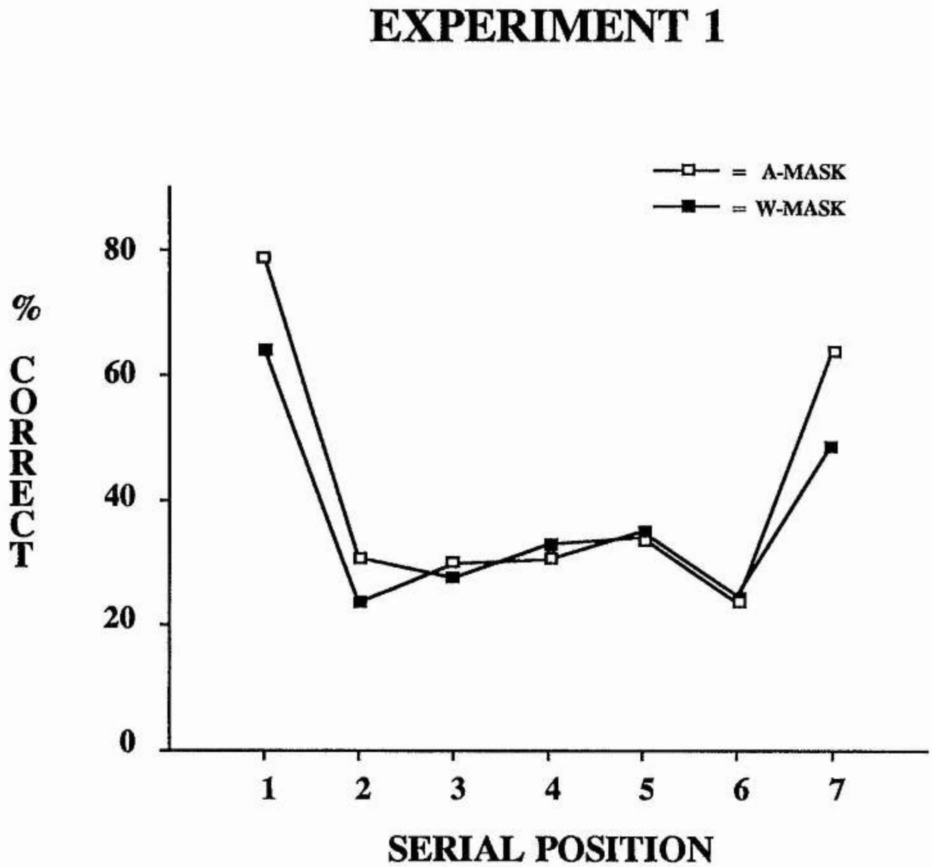
*Correct reports*

The serial position curves for correct reports are shown in Figure 3.2. The overall percentage correct reports averaged over all seven serial positions was 39.9%, and averaged over positions 1, 2, 6, and 7 was 45.0%. The data for correct reports were submitted to an analysis of variance for factorial design, with two treatment factors (mask configuration and serial position).

The main effects of mask configuration and serial position were both highly significant [$F(1,11)=9.74$ and $F(6,66)=8.62$, $ps<.01$, respectively], and the interaction between mask configuration and serial position was also highly significant [$F(6,66)=4.51$, $p<.001$]. Trend analysis showed highly significant quadratic trends in the curves for both mask conditions [$F(1,66)=47.56$ and $F(1,66)=17.91$, $ps<.01$, respectively], indicating a clear U-shape in the serial position curves. In addition, a

[2] Exposure durations were adjusted depending on accuracy of report for targets in positions 1, 2, 6 and 7. Exposure duration was adjusted depending on accuracy of report for these positions only, because these were the most important positions for comparing performance between interior letters and exterior letters. Furthermore, because in all remaining experiments presented in this thesis, those positions were the only positions tested, the same amount of control over accuracy of report for interior letters and exterior letters was obtained across all experiments.

**Figure 3.2.** Mean percentage of targets correctly reported in the A-Mask and W-Mask conditions of Experiment 1.



quartic trend was apparent in the serial position curves for both mask conditions [$F(1,66) = 14.96$ and $F(1,66) = 10.57$, $ps < .01$, respectively], indicating the presence of a W-shape. The quadratic and quartic trends accounted for 72.2% and 22.7% of the variance, respectively, in the A-mask condition, and for 56.5% and 33.2% of the variance, respectively, in the W-mask condition, indicating a shallow W-shape superimposed on a U-shape in both serial position curves, although the quadratic trend accounted for a larger portion of the variance in the A-mask condition than in the W-mask condition, indicating a more pronounced U-shape in the serial position curve when mask boundaries matched those of the arrays.

Newman-Keuls tests for paired comparisons examined the significant effects more closely. In the A-mask and the W-mask conditions accuracy was higher in positions 1 and 7 than in any of the other positions ($ps < .05$). The advantage for exterior letters over letter next in from the ends was 44.2% in the A-mask condition and 32.6% in the W-mask condition. In the W-mask condition accuracy for position 5 was higher than for position 2 ($p < .05$). Most importantly, however, the effects of mask configuration were restricted to accuracy for exterior letters; performance for positions 1 and 7 in the W-mask condition dropped 14.6% and 14.7% respectively compared to performance for exterior-letters in the A-mask condition ($ps < .05$), for interior positions there was no difference between A-mask and W-mask conditions ($ps > .05$).

The exterior-letter advantage in the appropriate mask condition replicated the findings of previous bar-probe studies, suggesting that similar recognition processes occurred in the present experiment. Furthermore, although accuracy for exterior letters was lower with wide masks than with appropriate masks, exterior letters still showed a considerable advantage over interior letters. Thus, the effect of mask configuration observed in Experiment 1 did not match the effect of mask configuration in Mewhort and Campbell's (1978) digit naming task. Specifically, when wide masks were used by Mewhort and Campbell in the digit naming task, accuracy was actually worse for exterior letters than for interior letters. This difference in the effects of mask configuration between these two studies indicates that different processes are reflected in the serial position curves obtained in the digit naming task, and those obtained in the traditional bar-probe task. Indeed, a likely account of this difference is that performance in the digit naming task reflects uncertainty about the position indicated by the bar-probe. In Mewhort and Campbell's (1978) digit naming experiment, a single bar-probe was presented briefly (for 100 msec) after the target display. When the same procedure for probing the target position is used in the bar-probe task, mask configuration could similarly affect probe alignment. In the present experiment, however, uncertainty about target position was unlikely by the use of position markers, marking each of the letter positions in the array, and presented simultaneously with the bar-probe for as long as it took subjects to respond.

However, the second indication to emerge from the findings is that the exterior-letter advantage was, nonetheless, affected by mask configuration; the exterior-letter advantage was smaller in the W-mask condition because of a decrease in accuracy for exterior letters in the W-mask condition compared to the A-mask condition. Therefore, the possibility that the use of wide masks increased spatial uncertainty for exterior letters cannot be dismissed. The decrease in the size of the exterior-letter advantage may reflect an increase in spatial uncertainty for exterior letters inspired by a disruption of spatial anchors at the boundaries of the arrays which provide reference points for the localisation of exterior letters (Mewhort & Campbell, 1978). In extreme cases, spatial uncertainty may have caused a mislocalisation of the target letter, in the experiment, resulting in an incorrect report. Therefore, an investigation into the nature of the incorrect reports was performed.

*Error analysis*

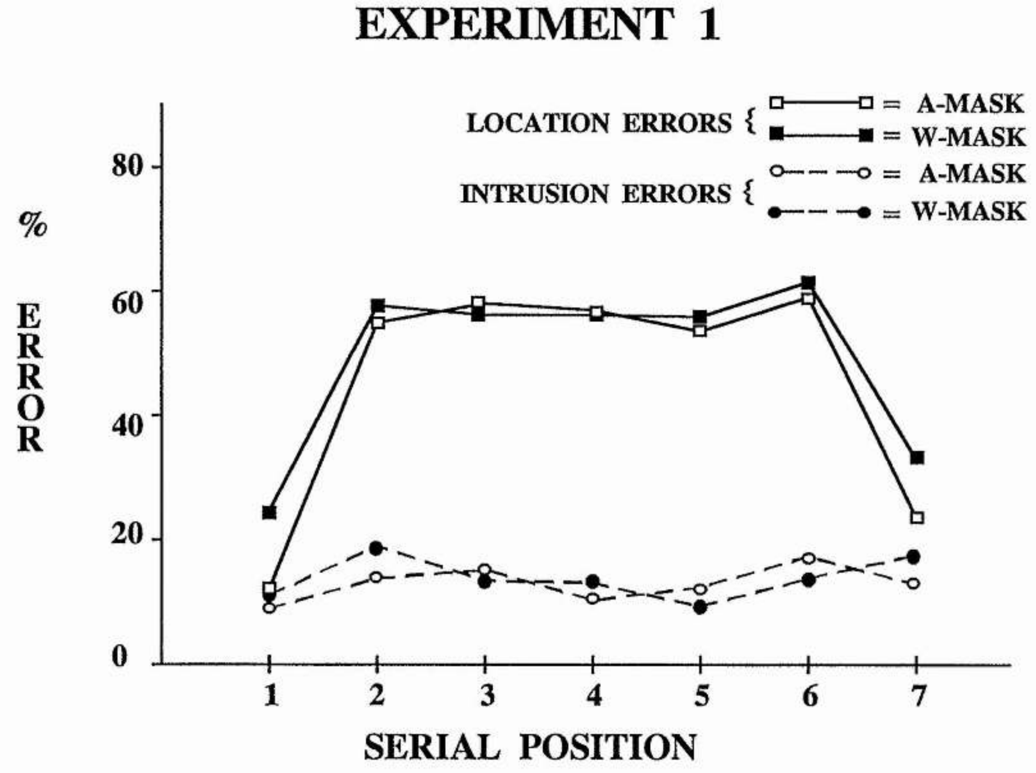
Mewhort and Campbell (1978) suggested that the exterior-letter advantage reflects the role of array boundaries as spatial anchors reducing spatial uncertainty for exterior letters compared to interior letters. Mewhort and Campbell's suggestion was inspired by the general finding that incorrect reports involve mainly location errors and only occasionally intrusion errors. According to Mewhort and Campbell, location errors reflect predominantly a loss of location information while intrusion errors reflect predominantly a loss of identity information (cf. Chapter Two). If this is the case, when exterior positions are probed for report, the disruption of spatial anchors at the exterior of the array should be reflected in an increase in location errors, but not in an increase in intrusion errors.

The serial position curves for location errors and intrusion errors are shown in Figure 3.3. 78.9% of errors made were location errors (47.4% of all responses) while only 21.1% of errors were intrusion errors (12.7% of all responses). The prevalence of location errors replicates previous findings in the bar-probe task using linear multi-letter arrays (e.g., Hagenaar, 1990; Mewhort & Campbell, 1978; Mewhort et al., 1981, 1982; Townsend, 1973). The data for location errors and intrusion errors were each submitted to an analysis of variance for factorial design, with two within-subjects factors (mask configuration and serial position).

For location errors, only the main effect of serial position was significant [$F(6,66)=11.92$, $p<.001$]. The quadratic and quartic trends in the serial position curve for location errors were both highly significant [$F(6,66)=54.82$ and $F(6,66)=13.94$ respectively, $ps<.01$], indicating a W-shape superimposed on a U-shape. For intrusion errors, none of the effects reached significance ($ps>.40$). In particular, the interaction between mask configuration and serial position was not significant for either location errors or intrusion errors [$F(6,66)=2.15$, $p=.059$, and $F(6,66)=2.02$, $p=.075$, respectively].

The absence of significant interactions between serial position and mask configuration for location errors and intrusion errors indicates that the effect of mask configuration on correct reports was not matched by increases in a single error type. That is, the decrease in accuracy of report for exterior-letters in the W-mask condition

**Figure 3.3.** Mean percentage of location errors and intrusion errors in each of the target positions and mask configurations in Experiment 1.



compared to the A-mask condition was not matched by an increase in either location errors or intrusion errors when exterior positions were tested. Thus, at first sight, the results do not support Mewhort and Campbell's (1978) suggestion that wide masks increase spatial uncertainty for exterior letters. However, a closer look at the data for location errors and intrusion errors (see Figure 3.3) reveals that the decrease in correct reports in the W-mask condition was almost completely accounted for by an increase in location errors; location errors increased by 11.1% for exterior positions in the W-mask condition compared to the A-mask condition, while intrusion errors increased by only 3.4%. If location errors reflect spatial uncertainty, then these results suggest that mask configuration affected mainly spatial uncertainty for exterior letters. However, the effects of mask configuration on accuracy of report and location errors were further investigated in Experiment 2.

## Experiment 2

While further investigating the effects of mask configuration, Experiment 2 also investigated the role of lateral interference in the exterior-letter advantage. When the effects of distractor letters on the report of target letters have previously been examined, often only *immediately* neighbouring distractor letters have been considered (e.g., Estes, 1978; Hagenzieker et al., 1990; Van der Heijden, 1987). For example, Estes (1978, p.188) argued that the exterior-letter advantage could be explained if one considers that lateral interference "would necessarily be greatest in the interior of the display, where all letters have neighbors, and least at the ends, where each terminal letter has *only a single neighbor* and blank space on the other side" (italics added). Thus, according to Estes the exterior-letter advantage is invoked by an imbalance in the number of immediately flanking letters for interior and exterior letters. Therefore, in Experiment 2, the role of lateral interference, and, in particular, whether an imbalance in the number of immediately flanking letters can account for the exterior-letter advantage, was investigated.

One way of testing the importance of the number of immediately flanking letters for interior and exterior letters in the exterior-letter advantage is to make this number equal for targets presented in both positions by replacing those letters flanking interior letters on the foveal side with blank spaces. If the advantage exterior letters have over interior letters is caused by an imbalance in the number of immediately flanking letters for exterior letters and interior letters, then the exterior letter advantage should be removed when this imbalance is removed. When the amount of lateral interference is equal for exterior letters and interior letters, interior letters should be *more* perceptible, because they occupy positions closer to the fixation point where visual acuity is higher than for positions further away from the fixation point.

A literature search revealed that an examination of the effects of removing letters from the array on the exterior-letter advantage in linear multi-letter arrays has not been conducted. However, when Wolford and Hollingsworth (1974; see also Shaw, 1969; Estes & Wolford, 1971) investigated the importance of lateral interference in the perceptibility of letters in linear multi-letter arrays, they found that letters flanked by blank spaces on one side and letters on the other were recognised more accurately than the same letters flanked by letters on both sides. Furthermore, in agreement with the properties observed for lateral interference, increases in performance were larger when letters were flanked by spaces on the peripheral side than when they were flanked by spaces on the foveal side. Thus, Wolford and Hollingsworth (1974) concluded that lateral interference limits the perceptibility of letters in linear multi-letter arrays, and that replacing letters with blank spaces can lead to a considerable increase in the perceptibility of letters flanking those spaces due to a relief of lateral interference, particularly when letters are flanked by blank spaces on the peripheral side.

However, extending Wolford and Hollingsworth's (1974) finding to conclusions about the exterior-letter advantage is problematic for several reasons. First, Wolford and Hollingsworth used a full report task, in which accuracy of report is largely determined by the position in the sequence of report. Therefore, in order to avoid letters flanked by blank spaces occurring in a different position in the sequence of report, accuracy for letters flanked by two blank spaces was compared with letters flanked by two capital A's, which were not reported. It is unclear, however, what effects flanking capital A's exert on the perceptibility of target letters, which prevents any assessment of the importance of lateral interference in linear multi-letter arrays, because the repeated use of capital A's might not provide the same amount of interference as random letters. Indeed, it is possible that two constant characters perceptually group together forming less effective distractors than changing flanking letters might do (e.g., Banks et al., 1979). Second, Wolford and Hollingsworth's (1974) study was not aimed at examining the effects of removing letters on the exterior-letter advantage. Indeed, it is not possible to assess the effect of blank spaces on the exterior-letter advantage in their study, independent of the effects of differences in the position in the report sequence and differences in position in the visual field. Surprisingly, however, in some of the conditions in Wolford and Hollingsworth's study, an exterior-letter advantage was apparent even though exterior letters and letters next in from the ends were both flanked by blank spaces on one side and the effects of position in the report sequence and position in the visual field would have predicted an interior-letter advantage.

Thus, although Wolford and Hollingsworth's (1974) findings suggest that lateral interference may play a role in the exterior-letter advantage, the precise role is not yet clear. Therefore, Experiment 2 examined the role of lateral interference in the exterior-letter advantage further. On half the trials, 7-letter linear arrays similar as those used in Experiment 1 were presented, but the letters at and adjacent to the fixation point (*middle letters*) were replaced with blank spaces, such that only exterior letters and interior letters next in from the ends remained, forming a linear array with two letters presented on either side of the fixation point with a three letter gap in the middle (*gapped arrays*; see Figure 3.4). When middle letters were replaced with blank spaces, exterior letters and the remaining interior letters were all immediately flanked by another letter on one side and a blank space on the other. Furthermore, replacing all three middle letters ensured that the distance between interior letters and letters across the gap in the middle exceeded the maximum distance within which letters are expected to suffer interference from each other.[3] On other trials, the three blank spaces in gapped arrays were filled with three nontarget letters, which were not probed for report (*complete arrays*; see Figure 3.4). In order to assess the importance of the imbalance in the number of immediately flanking letters for interior letters and exterior letters in the exterior-letter advantage, performance for gapped arrays was compared with performance for complete arrays.[4] If an exterior-letter advantage is apparent in complete arrays, and this exterior-letter advantage was due to an imbalance in the number of immediately flanking letters for interior letters and exterior letters, no such exterior-letter advantage should be apparent in gapped arrays.

In addition to the two types of stimulus described above, the two mask configurations used in Experiment 1 (appropriate and wide masks) were used also in Experiment 2. The use of appropriate and wide masks provided an opportunity to replicate the effects of mask configuration observed in Experiment 1. However, the use of these two mask configurations also enabled an examination of the effects of mask configuration in arrays without middle letters (*gapped arrays*), and provided an opportunity to compare this with the effects of mask configuration in complete arrays. In particular, Experiment 2 examined if the reduction in the magnitude of the exterior-

[3] The gap between the remaining interior letters in gapped arrays spanned approximately $1^{\circ}$ of visual angle, which exceeds the largest estimates for the limit of the spatial extend of lateral interference suggested in the literature (Wolford & Chambers, 1983).

[4] Nontarget letters were letters that were not used as target letters. Therefore, nontarget letters did not occur in any of the target positions, and nontarget letters could not be entered as a response. It was particularly important letters used to fill the three blank spaces in gapped arrays could not be entered as a response. If that had not been the case, these letters might have been entered as responses whereas that would not have been possible in gapped arrays, thereby making it impossible to properly assess the perceptual difference between interior letters in gapped and complete arrays.

letter advantage, when arrays were followed by W-masks, could also be observed in gapped arrays. The effects of mask configuration observed in Experiment 1 suggests that a difference in spatial uncertainty for exterior letters and interior letters may contribute to the exterior-letter advantage. If wide masks disrupt spatial anchors at the ends of arrays, it may be that spatial anchors are not available in gapped arrays. If that is the case, wide masks should not affect the exterior-letter advantage in gapped arrays.

Thus, subjects saw four different combinations of stimulus type and mask configuration. An example of a complete array and an example of an gapped array, together with examples of appropriate and wide masks are presented in Figure 3.4.

**Method**

*Subjects*. Sixteen subjects from the same population as Experiment 1 participated in two 1-hr sessions in Experiment 2.

*Stimuli*. Two stimulus groups were constructed from two overlapping sets of eight letters; b, q, x, z, d, g, p, t (stimulus group 1), and b, q, x, z, f, h, n, v (stimulus group 2). Both stimulus groups contained 4-letter and 7-letter stimuli constructed in the following way. Six different arrays of four letters were made up from the letters in one set, such that every letter occurred in three of the six arrays, but only once in a single array. Then 24 stimuli were constructed by varying the order of the letters in each of the six arrays such that each of the letters occurred once in each of the four positions. The same was done with the letters in the other set to construct the stimuli for stimulus group 2. The four letters were then arranged as if occupying positions 1, 2, 6, and 7 of a horizontally displayed, evenly spaced, 7-letter array, with three blank spaces in the middle positions. 7-letter stimuli were constructed by filling the three blank spaces using the letters of the other letter set, which were not common to both sets (d, g, p, t in set 1, and f, h, n, v in set 2). A list of all 4-letter and their corresponding 7-letter target arrays in stimulus groups 1 and 2 is presented in Appendix 1.

*Design*. Each of the 24 4-letter and 7-letter stimuli was shown 8 times during

**Figure 3.4.** An example of test stimuli and of pattern masks for each of the target arrays and mask configuration combinations used in Experiment 2. The example of target arrays is is taken from stimulus group 1. Note that middle letters of complete arrays were not used as target letters.

## EXPERIMENT 2


**COMPLETE ARRAY/ A-MASK**


**COMPLETE ARRAY/ W-MASK**


**GAPPED ARRAY/ A-MASK**


**GAPPED ARRAY/ W-MASK**

the experiment; of each stimulus each of the four positions was probed once in each of the two mask configurations during a total of 384 test trials.

Half of the subjects saw Stimulus Group 1, and half saw Stimulus Group 2; for each subject the same stimulus group was shown in both sessions. Each session was divided in three sections (one practice and two test sections), with no obvious transition from one section to the next. Half the stimuli were followed by A-masks, and half by W-masks in one session. This pairing was reversed in the second session. Assignment of stimuli to mask configurations in the first session was alternated between subjects. 4-letter stimuli and their corresponding 7-letter stimuli were presented in the same mask configuration in one session, but in different test sections. For every subject the order in which the target/mask stimuli were shown was re-randomised in both sessions, the only constraint being that every cycle of 16 trials was counterbalanced across both mask configurations, 7-letter and 4-letter stimuli, and target positions.

*Procedure.* All the letters in gapped arrays were tested, but only letters in positions 1, 2, 6, and 7 of complete arrays were probed for report.

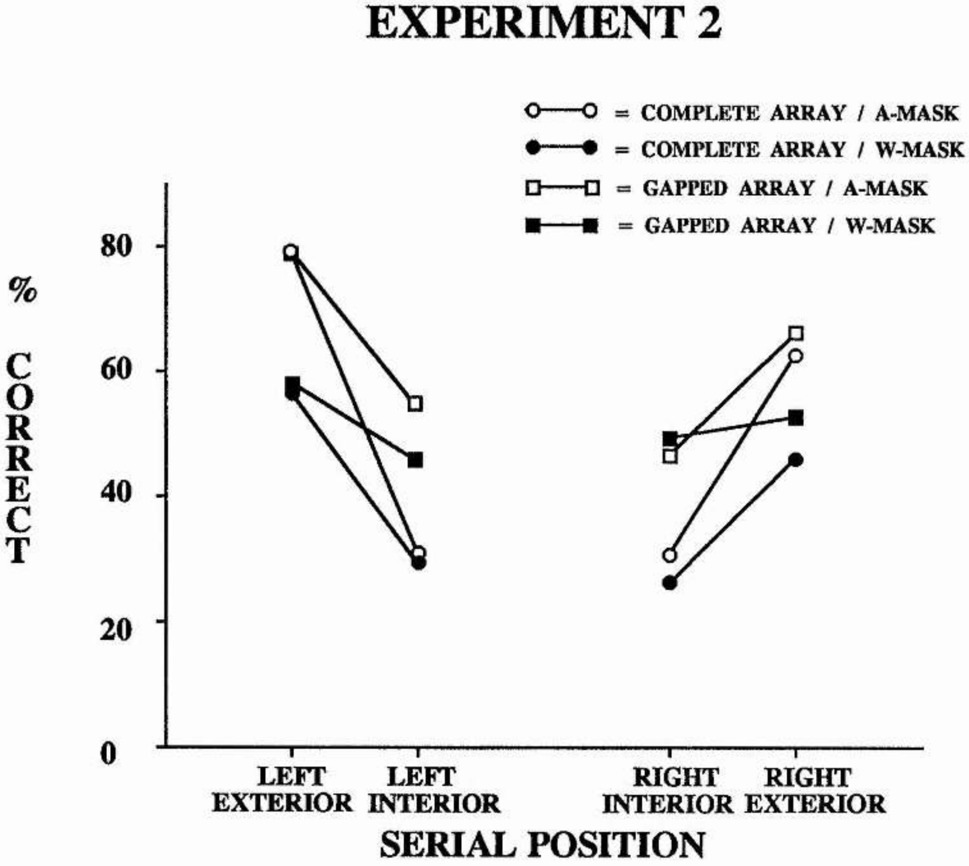
An average exposure duration was calculated for each of the subjects from the exposure durations set at the start of each of the 16-trial cycles in the test sections. The average exposure duration over all subjects was 37.2 ms. All remaining aspects of Experiment 2 were identical to those in Experiment 1.

## Results and discussion

### *Correct reports*

The data for correct reports in Experiment 2 are shown in Figure 3.5. Overall percentage correct report was 50.9%. The data for correct reports were submitted to an analysis of variance for mixed design, with one between-subjects factor (stimulus group), and three within-subjects factors (array type, mask configuration and serial position).

**Figure 3.5.** Mean percentage of targets correctly reported in each of the combinations of array type and mask configuration of Experiment 2.



Highly significant effects of array type, mask configuration and serial position were found [$F(1,18)=104.73$, $F(1,18)=45.51$, and $F(3,54)=11.45$ respectively, $ps<.001$]. The interactions between the effects of array type and serial position, and mask configuration and serial position were also highly significant [$F(3,54)=118.99$, and $F(3,54)=96.85$ respectively, $ps<.001$]. The three way interaction between stimulus group, mask configuration and serial position was marginally significant [$F(3,54)=2.98$, $p=0.039$]. No other effects reached significance. In particular, there was no evidence of a three way interaction between array type, mask configuration and serial position [$F(3,54)=1.888$, $p=.143$].

Newman-Keuls tests for paired comparisons examined the significant interactions more closely. Because there was no evidence for a three-way interaction between array type, mask configuration and serial position, the two-way interactions between array type and serial position, and between mask configuration and serial position can be considered independently.

*Array type by serial position.* The effect of array type was restricted to accuracy for interior letters; accuracy for interior letters was higher in gapped arrays than in 7-letters arrays ($ps<.05$) while there was no difference in accuracy for exterior letters between 4-letter and complete arrays ($ps>.05$). Exterior-letter advantages were observed for complete arrays ($ps<.05$). However, exterior-letter advantages were also observed in gapped arrays, even though exterior letters and interior letters were both immediately flanked by distractor letters on just one side and by blank spaces on the other ($ps<.05$).

*Mask Configuration by serial position.* The effects of mask configuration were restricted to accuracy for exterior letters. When the horizontal boundaries of masks matched the boundaries of the arrays accuracy for exterior letters was considerably higher than when the horizontal boundaries of masks extended beyond the boundaries of the arrays ($ps<.05$) whereas no such difference was observed for interior letters ($ps>.05$). Consequently, the exterior-letter advantage was smaller in the W-mask condition (21% at the left end and 11.7% at the right end) than in the A-mask condition (36.3% at the left end and 25.8% at the right end). However, exterior letters were reported more accurately than interior letters even when the horizontal boundaries of the masks exceeded those of the target arrays ($ps < .05$).

The significant three-way interaction between stimulus group, mask configuration and serial position reflects a difference between stimulus groups in the magnitude of the effect of mask configuration on the exterior-letter advantage left and right of the fixation point, rather than a qualitative difference. Indeed, there were no significant differences in the means for each mask configuration x serial position combination between stimulus groups ($ps > .05$).

The results of Experiment 2 indicate only a minor role for middle letters in the exterior-letter advantage. In particular, even though the exterior-letter advantage was smaller when middle letters were replaced with blank spaces, matching the number of immediately flanking letters for exterior letters and interior letters still produced a healthy exterior-letter advantage. Thus, even though the imbalance in the number of immediately flanking letters for interior letters and exterior letters may contribute to the exterior-letter advantage, other factors must be involved.

The results of Experiment 2 also show that the effects of mask configuration on accuracy of report were similar for complete arrays and gapped arrays. Furthermore, in both 4-letter and complete arrays, the effects of mask configuration were very similar to those observed in Experiment 1, which indicates that the effects of mask configuration on accuracy of report, apparent in Experiment 1, were not restricted to complete linear arrays. Before Experiment 2 was conducted, it was hypothesized that wide masks may have disrupted spatial anchors at the ends of arrays in Experiment 1, causing an increase in spatial uncertainty for exterior letters. If that is the case, the effect of mask configuration on accuracy of report for exterior letters of gapped arrays suggests that the exterior boundaries provided spatial anchors, even when middle letters were removed. An analysis of incorrect reports was conducted, to investigate the effect of mask configuration on spatial uncertainty for letters in the array.

*Error analysis*

As in Experiment 1, incorrect reports were classified as either location errors or intrusion errors. The data for location errors and intrusion errors in Experiment 2 are presented in Figure 3.6. Again, the majority of errors were location errors; 56.7% of errors made were location errors (28.0% of all responses), although intrusion errors were more frequent than in Experiment 1; 43.3% of errors made in Experiment 2 were intrusion errors (21.3% of all responses). Location errors and intrusion errors were each submitted to an analysis of variance with one between-subjects factor (stimulus group), and three within-subjects factors (array type, mask configuration and serial position).

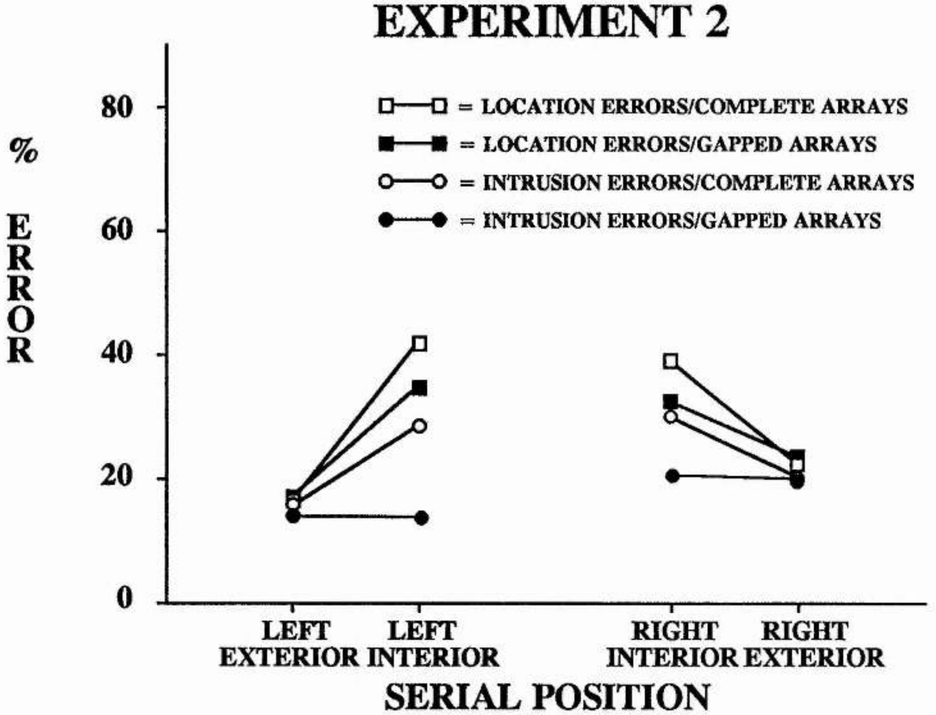
*Location errors.* The main effects of array type, mask configuration and serial position were all highly significant [$F(1,18)=12.78$, $F(1,18)=36.08$ and $F(3,54)=13.72$, $ps<.01$, respectively]. The two-way interactions between array type and serial position, and mask configuration and serial position were also significant [$F(3,54)=4.00$, $p=.012$, and $F(3,54)=3.16$, $p=.032$, respectively]. However, the three-way interactions between array type, mask configuration and serial position was not significant ($F<1$).

1) *Array type by serial position.* The data for location errors collapsed across mask configuration are shown in Figure 3.6a. Newman-Keuls tests for pairwise comparisons examined the interaction more closely. When interior letters were probed for report, location errors were more frequent in complete arrays than in gapped arrays ($ps<.05$). Furthermore, removing the middle letters had no effect on the number of location errors when exterior letters were probed for report ($ps>.05$).

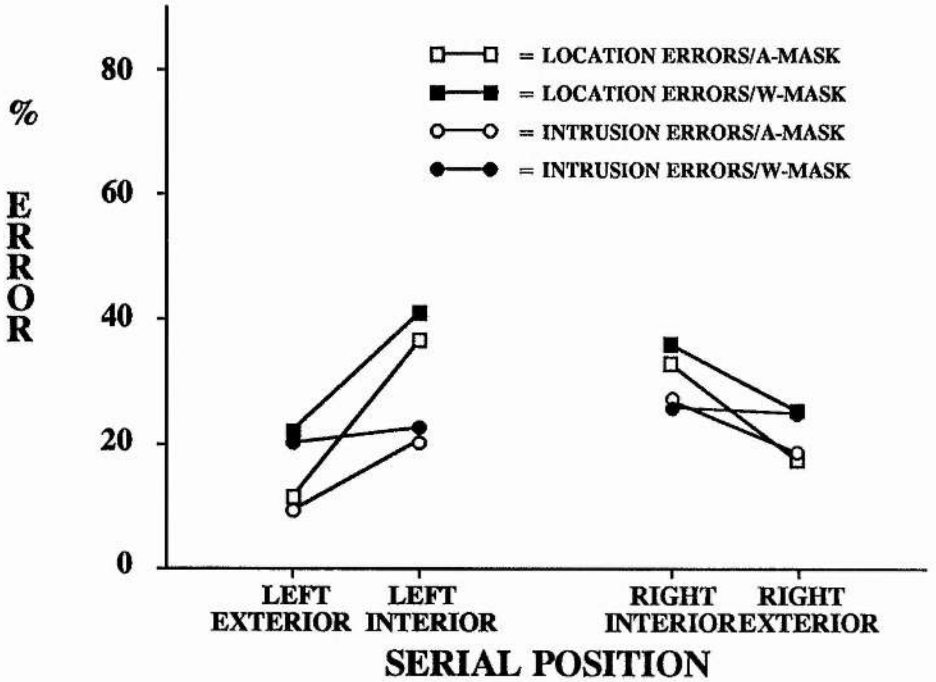
2) *Mask configuration by serial position.* The data for location errors collapsed across array type are shown in Figure 3.6b. Newman-Keuls tests for pairwise comparisons revealed that, when exterior letters were probed for report, location errors

**Figure 3.6.** Mean percentage of location errors and intrusion errors in each of the serial position in Experiment 2, (a) collapsed over mask configuration and (b) collapsed over array type.

(a)




(b)



were more frequent when arrays were followed by wide masks than when arrays were followed by appropriate masks ($ps < .05$). Furthermore, mask configuration had no effect on the number of location errors when interior letters were probed for report ($ps > .05$).

Thus, as for correct reports, the effects of array type on location errors were restricted to interior positions, while the effects of mask configurations on location errors were restricted to exterior positions.

*Intrusion errors*. The effects of array type, mask configuration and serial position were all highly significant [$F(1,18)=45.29$, $F(1,18)=28.00$ and $F(3,54)=5.76$, $ps < .01$, respectively]. The two-way interactions between array type and serial position, and mask configuration and serial position were also highly significant [$F(3,54)=8.07$ and $F(3,54)=8.63$, $ps < .001$, respectively]. In particular, the three-way interactions between array type, mask configuration and serial position was not significant ($F < 1$).

1) *Array type by serial position*. The data for intrusion errors collapsed across mask configuration are presented in Figure 3.6a. Newman-Keuls tests revealed that, when interior letters were probed for report, intrusion errors were more frequent in complete arrays than in gapped arrays ($ps < .05$). Furthermore, removing the middle letters had no effect on the number of intrusion errors when exterior letters were probed for report ($ps > .05$).

*Mask configuration by serial position*. The data for intrusion errors collapsed across array type are presented in Figure 3.6b. Newman-Keuls tests revealed that, when exterior letters were probed for report, intrusion errors were more frequent when arrays were followed by wide masks than when arrays were followed by appropriate masks ($ps < .05$). Furthermore, mask configuration had no effect on the number of intrusion errors when interior letters were probed for report ($ps > .05$).

Thus, as for correct reports and location errors, the effects of array type on intrusion errors were restricted to interior positions, while the effects of mask configurations on intrusion errors were restricted to exterior positions.

The pattern of intrusion errors was very similar to the pattern of location errors, which was in turn very similar to the pattern of correct reports. The only distinction appears to be that the effect of serial position was somewhat larger for location errors than for intrusion errors, and that, when interior letters were probed for report, removing middle letters perhaps lead to a slightly larger reduction in the number of intrusion errors than in the number of location errors. In particular, the effect of mask configuration appears to be very similar for location errors and intrusion errors.

The similarity in the effects of mask configuration on location errors and intrusion errors is surprising, considering that this factor affected mainly location errors in Experiment 1. If location errors correspond with failures in localisation and intrusion errors with failures in identification, the results of Experiment 1 indicate that mask configuration affected mainly the ability to correctly localise exterior letters, while the results of Experiment 2 would indicate that mask configuration affected the ability to correctly identify exterior letters to a similar extent as the ability to correctly localise exterior letters. However, while the cause for this discrepancy between the present experiment and Experiment 1 is not clear, it may indicate that a strict interpretation of location errors as failures to correctly localise the target letters is not justified. Indeed, in Chapter Two it was discussed how mechanisms other than failures to localise the target may give rise to location errors. In particular, (intentional or unintentional) false location errors (i.e., location errors caused by a misidentification of the target letter) may have been more frequent in Experiment 1 than in Experiment 2, which may explain why incorrect reports were almost exclusively location errors in Experiment 1, but not in Experiment 2.[5] That is, on each trial in Experiment 1, six

[5] Random guessing would almost certainly not have caused this difference between experiments. Although the chances that random guessing would lead to location errors or intrusion errors are slightly different between these two experiments (the chances that guessing results in location errors and intrusion errors are 50% and 41.7%, respectively, in Experiment 1 and 37.5% and 50%, respectively, in Experiment 2), this difference is too small to account for the difference in the proportion of intrusion errors found in these experiments. If all errors were the result

other letters could have been correctly identified and entered as a location error response, whereas in Experiment 2 only three other letters could have been correctly identified and entered as a location error response. Therefore, failures to identify the target letters may have resulted in location errors more often in Experiment 1 than in Experiment 2.

If failures to *identify* the target lead to more false location errors in Experiment 1 than in Experiment 2, it must be assumed that in Experiment 1 mask configuration affected identification of exterior letters more often than was suggested by the effect of mask configuration on intrusion errors. However, the effect of mask configuration on location errors in Experiment 2 may also have been caused by an increase in false location errors. Indeed, as Van der Heijden (1992, p.148) argued, from location errors no conclusions can be drawn regarding the ability to identify the target letter; "if the barmarker points at letter X, but subjects name an (adjacent) letter Y then the conclusion that there were no problems with the identification of Y is warranted, but not, however, the conclusion that there were no problems with the identification of X".

Thus, location errors may not provide an accurate measure of the degree of spatial uncertainty for letters in the target position. Therefore, an analysis of location errors in terms of the positions supplying the incorrectly reported letters might be more revealing. For example, Van der Heijden (1987) noted that, if location errors reflect spatial uncertainty for the letter indicated by the bar-probe, the letters in positions for which most location errors are made, should provide more location error responses than the letters in the positions for which least location errors are made, because position information for the latter would be most salient. In fact, the opposite relationship

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of random guessing, 41.7% of errors should have been intrusion errors in Experiment 1, whereas a proportion of only 21.1% was found. In Experiment 2 random guessing would predict that 50% of errors are intrusion errors, whereas a proportion of 43.3% was actually found. Thus, the proportion of intrusion errors deviated most from a prediction based on random guessing in Experiment 1, suggesting that other factors were more important for the ratio of location errors and intrusion errors in Experiment 1 than in Experiment 2.

between the number of location errors and the number of location error responses supplied by each serial position is actually found; positions in which the most location errors are made, only rarely provide location error responses (e.g., Hagenaar, 1990; Mewhort et al., 1981), suggesting that letters in these positions are least likely to be correctly *identified*.

Thus, location errors may not provide a particularly reliable measure for spatial uncertainty of target letters. However, one of the purposes of this study was to examine the effects of mask configuration on spatial uncertainty for letters in the target stimulus. In particular, it was suggested that when the horizontal boundaries of backward pattern masks extend beyond those of target arrays, spatial anchors provided by the exterior boundaries of linear arrays would be disrupted. For this purpose a measure of the effect of mask configuration on spatial uncertainty is essential.

The arguments of Van der Heijden (1987), about the relationship between spatial uncertainty for letters in particular positions and the frequency for letters in those positions supplying location error responses, can be extended for this purpose. If it is assumed that there exists a certain amount of uncertainty about the relative position of letters in the array, in addition to uncertainty about the identity of letters in the display, subjects may feel that reporting a letter which may have been the target, but may also not have been the target, gives them more chance on a correct report than guessing, if the target letter is not correctly identified. Thus, according to this line of reasoning, location errors may, to a certain degree, reflect spatial uncertainty for *nontarget* letters. Thus, if the number of location errors supplied by a particular position increases, it may be assumed that spatial uncertainty for letters in that position has increased, in particular, when accuracy of report for targets in that position decreases.

However, the number of location error responses supplied by each of the positions in the display alone, is not a sufficient measure of spatial uncertainty. That is, the number of location error responses supplied by a particular position in the display depends also on, for example, the perceptibility of letters in that position. Indeed, when letters in position A are more perceptible than letters in position B, it would be expected that position A supplies more location error responses than position B. Also, if position A is closer to the target position than position B, it would be expected that position A supplies more location error responses than position B, when a third position is probed for report (cf. Hagenaar, 1990). Nevertheless, if the distribution of location error responses over each of the positions in the display is compared between mask conditions, any changes in the number of location error responses supplied by a particular position relative to other positions, may be used as an indication that spatial uncertainty for letters that position was different in one mask condition compared to another. That is, if spatial uncertainty for letters in position A is higher in one condition than in another, it would be expected that, the distribution of location error responses changes, such that more location error responses are supplied by position A compared to the other nontarget positions.

The problem with this line of reasoning is that the circumstances under which an increase in spatial uncertainty for letters in position A would lead to a change in the distribution of location error responses is unknown. Nevertheless, an investigation of the effects of stimulus characteristics on the distribution of location errors may be informative, as it can be compared with predictions about the effect of stimulus characteristics on the distribution of location error responses. If these predictions are based on expectations about the effects of stimulus characteristics on spatial uncertainty for letters in target stimuli, these expectations may be confirmed if the predictions agree with the analysis of the distribution of location error responses.

When, for example, the left interior position is probed for report, it would be expected from the anticipated effect of mask configuration on spatial uncertainty, that spatial uncertainty for exterior letters immediately flanking the target position would be higher when arrays are followed by wide masks than when arrays are followed by appropriate masks. If a comparison between the A-mask condition and the W-mask condition shows that more location errors were supplied by immediately flanking exterior positions in the A-mask condition than in the W-mask condition, this could mean that spatial uncertainty for exterior letters is higher with wide masks than with appropriate masks. This conclusion would be strengthened if the results for accuracy of report show that exterior letters are reported less accurately with wide masks than with appropriate masks.

In summary, by comparing the distribution of location error responses in the wide mask condition with the distribution of location error responses in the appropriate mask condition, the prediction for the effect of mask configuration can be tested. If the difference in the distribution of location error responses between the wide mask condition and the appropriate mask condition corresponds with the prediction, it implies that the assumptions on which the prediction was based are justified.

Thus, according to the hypothesized effects of mask configuration and array type several predictions can be made for the position of location error responses in Experiment 2. The matter of interest was whether wide masks caused an increase in spatial uncertainty for exterior letters relative to appropriate masks, and if so, whether this was true for both complete arrays and gapped arrays. In addition, it was of interest to see whether spatial uncertainty for interior letters was higher in complete arrays than in gapped arrays. If wide masks increased spatial uncertainty for exterior letters relative to appropriate masks, it may seem reasonable to expected that, when interior letters are probed for report, immediately flanking exterior letters supply relatively more location error responses in the wide mask condition than in the appropriate mask condition (assuming that location errors are supplied by adjacent positions). Similarly, if spatial uncertainty is larger for interior letters of complete arrays than for interior letters of gapped arrays, it would be expected that, when exterior positions are tested, interior letters supply relatively more location error responses in complete arrays than in gapped arrays.

The frequencies of location error responses supplied by each position, are shown in Table 3.1. Array type had no effect on the position of location error responses when exterior positions were tested (chi-square$_{(2)}$=.15, $ps>.50$), which suggests that replacing middle letters with blank spaces did not affect spatial uncertainty for interior letters. Mask configuration did have an effect on the position of location error responses in both complete arrays and gapped arrays; when interior positions were tested, location error responses were supplied more often by flanking exterior positions in the wide mask conditions than in the appropriate mask conditions, which was matched by a decrease of location error responses supplied by the other interior position (chi-square$_{(2)}$=6.44, and chi-square$_{(2)}$=8.07, $ps<.05$, for complete and gapped arrays, respectively).

The effect of mask configuration on the position of location error responses suggests that spatial uncertainty for interior letters was not affected by the width of masks. However, the effect of mask configuration on the position of location error responses when interior positions were tested may have been caused by an increase in spatial uncertainty for exterior letters when the width of masks exceeded the boundaries of the target arrays, compared to when the boundaries matched those of target arrays, since there was no reason to expect that spatial uncertainty for interior letters across the gap would have been affected by a change in mask width. Furthermore, the effect of mask configuration on the position supplying location error responses was similar for complete arrays and gapped arrays, suggesting that spatial uncertainty for exterior letters may have been similarly affected by flanking mask contours in complete arrays and gapped arrays.

A comparison between the results for location errors and the results for the position of location error responses reveals that location errors do not necessarily reflect the degree of uncertainty about the relative position of letters in the array. For example, location errors were more frequent for interior positions in complete arrays than for interior positions in gapped arrays, even though the analysis of the position of location error responses reveals that the degree of spatial uncertainty for interior letters

**Table 3.1**. Frequencies of supplied location error responses for interior and exterior positions in Experiment 2. The frequencies of location errors for exterior positions are collapsed over mask configuration. Flanking response positions are the positions immediately adjacent to the target position, Interior (opposite side) and Exterior (opposite side) response positions are the interior and exterior positions, respectively, at the opposite side of the fixation point relative to the target position.

| *Test Position* | *Condition* | *Position of response letter Position (relative to test position)* | | |
|---|---|---|---|---|
| | | Flanking | Interior (opposite end) | Exterior (opposite end) |
| Exterior | complete arrays | 164 | 120 | 90 |
| | gapped arrays | 156 | 122 | 88 |
| Interior | complete arrays/A-masks | 125 | 143 | 108 |
| | complete arrays/W-masks | 173 | 130 | 118 |
| | gapped arrays/A-masks | 89 | 105 | 95 |
| | gapped arrays/W-masks | 135 | 92 | 103 |

was similar in complete arrays as in gapped arrays. Thus, this increase in location errors may not have been caused by an increase in spatial uncertainty, and it seems likely that the effect of array type on the ability to identify interior letters was larger than the number of intrusion errors would suggest. On the other hand, the analysis of the position of location error responses suggests that at least part of the effect of mask configuration on location errors may, reflect an increase of spatial uncertainty for exterior letters in the W-mask condition compared to the A-mask condition.

**Conclusions**

The two experiments in this chapter examined the role of backward pattern masks and lateral interference in the exterior-letter advantage. More specifically, Mewhort and Campbell (1978) suggested that the exterior-letter advantage is inspired by spatial anchors at the boundaries of linear multi-letter arrays, reducing spatial uncertainty for exterior letters compared to interior letters. Mewhort and Campbell further suggested that, when the width of masks exceeds the width of target arrays, the spatial anchors would be disrupted and the exterior-letter advantage would disappear. In addition, Estes (1978) suggested that the exterior-letter advantage is inspired by an imbalance in the number of immediately flanking distractors for interior letters and exterior letters; interior letters would suffer interference from immediately flanking letters on both sides, while exterior letters would suffer interference from immediately flanking letters on one side only.

Contrary to both these accounts, however, the experiments reported in this chapter show that the exterior-letter advantage cannot be explained by the effects of mask configuration or by an imbalance in the number of immediately flanking letters alone. More specifically, the exterior-letter advantage in the serial position curves for correct reports and location errors and the absence of an exterior-letter advantage in the serial position curve for intrusion errors apparent in Experiment 1 replicated previously reported findings in the bar-probe task using backward pattern masked linear multi-letter arrays (e.g., Mewhort & Campbell, 1978; Mewhort et al, 1981), suggesting that the same processes occurred. However, the results of Experiment 1 showed also that, when backward pattern masks extended beyond the horizontal boundaries of target stimuli, a sizable exterior-letter advantage remained, which was replicated in Experiment 2. In addition, the results of Experiment 2 showed that in gapped arrays, in which exterior letters and interior letters had immediately flanking distractor letters on one side only, exterior letters were still reported more accurately than interior letters.

Nevertheless, the exterior-letter advantage was larger when mask boundaries matched those of target stimuli than when mask boundaries exceeded those of target stimuli. These effects of mask configuration indicate that spatial anchors provided by the exterior boundaries of linear multi-letter arrays may have played some role in the exterior-letter advantage observed in the A-mask condition. Indeed, the analysis of the position of location error responses suggested that spatial uncertainty for exterior letters increases when mask boundaries extend beyond the boundaries of linear multi-letter arrays.

Furthermore, in complete arrays, in which interior letters had immediately flanking distractor letters on both sides, the exterior-letter advantage was larger than in gapped arrays, in which interior letters had immediately flanking letters on one side only. Thus, the effects of replacing middle letters with blank spaces indicate that the number of immediately flanking letters also played a role in the exterior-letter advantage in complete arrays. Furthermore, the most obvious explanation for this reduction in the size of the exterior-letter advantage is that lateral interference from middle letters reduced the perceptibility of interior letters. Indeed, the proportion of intrusion errors for interior positions was much higher for complete arrays than for gapped arrays, and the analysis of the position of location error responses provided no evidence for an decrease in spatial uncertainty for interior letters when middle letters were removed.

One further point should be made about the role of middle letters in the exterior letter advantage. If interior letters suffered lateral interference from middle letters in complete arrays, it may seem reasonable to assume that exterior letters should suffer lateral interference from middle letters as well. Yet, replacing middle letters with blank spaces in Experiment 2 did not affect performance for exterior letters. There at least three different reasons why lateral interference from middle letters may affect interior letters but not exterior letters. First, it may be the case that the spatial extent of lateral interference is not sufficient to overcome the distance between middle letters and exterior letters. Indeed, the edge-to-edge distance between exterior letters and the nearest middle letters were close to the upper limit of the spatial extent of lateral interference reported previously (Flom, Weymouth & Kahneman, 1963; Wolford & Chambers, 1984). Second, it may be the case that lateral interference is blocked by intervening letters, such that no lateral interference exists between letters with one or more intervening letters between them. That is, interior letters were positioned between exterior letters and middle letters, and, for example, any effects middle letters may have had on the perception of exterior letters would already have been achieved by interior letters. Third, a decrease in lateral interference caused by the removal of middle letters may have been compensated for by an increase in lateral interference provided by interior letters. That is, it has been suggested that lateral interference from distractors is related to the perceptibility of these distractors (Hagenzieker, Van der Heijden & Hagenaar, 1990; Van der Heijden, 1987, 1990). Thus, when middle letters were replaced with blank spaces, interior letters may have been perceived more accurately, providing more lateral interference for exterior letters, and substituting for the relief of lateral interference for exterior letters caused by the removal of middle letters. However, a link between the perceptibility of distractor and the amount of lateral interference suffered by targets lacks explanatory power because lateral interference has both negative and positive effect on the perceptibility of targets, and it may be possible to always find a balance between the two which agrees with the observed effects.

# Chapter Four



## The role of pattern masks in the exterior-letter advantage

The results of Experiments 1 and 2 showed that the exterior-letter advantage observed in linear 7-letter arrays followed by appropriate masks was considerably reduced when arrays were followed by wide masks. Furthermore, the results of Experiments 2 showed that the exterior-letter advantage observed in linear 7-letter arrays was considerably reduced when middle letters were replaced with blank spaces. Nevertheless, even in gapped arrays, and in arrays followed by wide masks, exterior letters were reported more accurately than interior letters. These findings promise to throw new light on the exterior-letter advantage in complete linear 7-letter arrays, because they suggest that factors other than lateral interference between immediately flanking letters and the availability of spatial anchors at the exterior boundaries of linear arrays might be contributing to the exterior-letter advantage in linear multi-letter arrays. However, before this can happen, the precise nature of the exterior-letter advantage in arrays without middle letters needs to be determined.

The three experiments reported in this chapter investigated further the role of mask configuration in the exterior-letter advantage. The analysis of the distribution of location error responses in Experiment 2 confirmed that wide masks may have increased spatial uncertainty for exterior letters compared to appropriate masks. If that is the case, it would indicate that spatial anchors, provided when blank spaces flank the peripheral side of exterior letters, were disrupted when mask boundaries extended beyond the exterior boundaries of target arrays. However, the effect of mask configuration on the distribution of location error responses was not restricted to complete 7-letter letter arrays, as it was also observed with gapped arrays. Therefore, if wide masks disrupted spatial anchors at the exterior boundaries of complete 7-letter arrays, wide masks may have similarly disrupted spatial anchors at the exterior boundaries of gapped arrays. To take this argument one step further, if exterior boundaries of gapped arrays function as spatial anchors for exterior letters, it may seem reasonable to expect that spatial anchors are not restricted to the exterior boundaries of arrays, but may occur wherever letters are flanked by blank spaces on one side. Thus, when interior letters are flanked by blank spaces on one side, these blank spaces may potentially function as spatial anchors, reducing spatial uncertainty for interior letters in gapped arrays compared to interior letters in complete arrays.

Nevertheless, no difference was apparent in the distribution of location error responses between complete and gapped arrays in Experiment 2, while such a difference would have been expected if spatial uncertainty for interior letters was reduced when middle letters were removed. However, the use of appropriate and wide masks in Experiment 2, may not have allowed a proper assessment of the effect of blank spaces flanking interior letters. That is, in both mask configurations used in Experiment 2, mask contours overlaid blank spaces flanking interior letters. If mask contours peripherally flanking exterior letters disrupted spatial anchors at the exterior boundaries of linear arrays, mask contours foveally flanking interior letters may have similarly disrupted spatial anchors at the interior boundaries of gapped arrays. Since both mask configurations, used in Experiment 2, presented mask contours overlaying blank spaces in the middle of gapped arrays, these may have prevented a decrease in spatial uncertainty for interior letters when middle letters were removed.

In addition, interior letters may have suffered lateral interference from mask contours overlaying blank spaces in the middle of gapped arrays. Indeed, when exterior positions were probed for report, more intrusion errors were made with wide masks than with appropriate masks, indicating that wide masks not only increased spatial uncertainty for exterior letters, but also decreased their perceptibility. This effect of mask configuration suggests that exterior letters may have suffered lateral interference from peripherally flanking mask contours.[1] Thus, interior letters may have similarly suffered lateral interference from foveally flanking mask contours, limiting their perceptibility relative to exterior letters in both mask conditions. This may have prevented the disappearance of the exterior-letter advantage when middle letters were replaced with blank spaces.

However, there is a second way in which mask contours overlaying blank spaces in the middle of gapped arrays may have played a crucial role in the exterior-letter advantage. It may be that the increase in spatial uncertainty for exterior letters in the W-mask condition in Experiment 2 was caused by the disruption of spatial anchors specific to the exterior boundaries of linear multi-letter arrays. If that is the case, mask contours overlaying the blank spaces between interior letters in gapped arrays may have filled the gap, providing information defining the position of exterior letters at the boundaries of linear multi-letter arrays, even when letters in the middle were not presented (Jordan, 1990, 1994). Thus, even in gapped arrays, spatial anchors may have been available in the A-mask condition, but not in the W-mask condition, in which they were disrupted by flanking mask contours.

To investigate these possibilities, the three experiments reported in this chapter used four different mask configurations. The appropriate and wide masks used in Experiment 2 were supplemented with appropriate and wide masks of which the mask contours overlaying blank spaces flanking interior letters were removed. Thus, four different types of mask were used; Appropriate masks (A-masks) and Wide masks (W-masks) were similar as in Experiment 2, Gapped Appropriate masks (GA-masks) and Gapped Wide masks (GW-masks) were similar as A-masks and W-masks, respectively, except that mask contours overlaying the blank spaces between interior letters were removed. Examples of all four mask configurations are shown in Figure 4.1.

[1] Flanking mask contours refer to portions of masks overlaying blank spaces flanking interior letters foveally or exterior letters peripherally. Even though, strictly speaking, mask contours overlaying adjacent letters are also flanking mask contours, the effects of these mask contours were not examined.

**Figure 4.1:** An example of test stimuli and of each of the mask configurations used in Experiment 3. See text for explanation.

## EXPERIMENT 3


**A-MASK**


**W-MASK**


**GA-MASK**


**GW-MASK**

**Experiment 3**

Experiment 3 examined the role of mask configuration in the exterior-letter advantage observed with gapped arrays in Experiment 2. The gapped arrays used in Experiment 2 were used in Experiment 3, followed by each of the four different mask configurations described above. If mask contours overlaying blank spaces in gapped arrays played a crucial role in the exterior-letter advantage in gapped arrays observed in Experiment 2, this exterior-letter advantage should disappear when arrays are followed by gapped masks.

In addition, more specific predictions can be derived about the nature of the role of mask contours overlaying the gap in the exterior-letter advantage. If spatial anchors are not specific to exterior boundaries of complete linear arrays, it may be expected that interior boundaries in gapped arrays provide spatial anchors for interior letters when arrays are followed by gapped masks. In the A-mask and W-mask conditions, however, mask contours overlaying blank spaces flanking interior letters may disrupt these spatial anchors, increasing spatial uncertainty for interior letters, just like mask contours overlaying blank spaces flanking exterior letters may disrupt spatial anchors at the exterior boundaries. On the other hand, if spatial anchors are specific to the exterior boundaries of complete linear multi-letter arrays, mask configuration should affect only spatial uncertainty for exterior letters, which should be less in the A-mask condition, in which spatial anchors are left intact, than in the W-mask, GA-mask and GW-mask conditions, in which spatial anchors for exterior letters are not present. Furthermore, there should be no difference in spatial uncertainty for exterior letters between the W-mask, GA-mask and GW-mask conditions because, in each of these conditions, exterior boundaries would not function as spatial anchors for exterior letters.

**Method**

*Subjects.* 16 subjects from the same population as Experiments 1 and 2 participated in two 1-hr sessions in Experiments 3.

*Stimuli.* The two groups of 24 gapped arrays used in Experiment 2 were used also in Experiment 3 (see Appendix 1). Only gapped arrays were used in Experiment 3.

A-masks and W-masks were constructed as in Experiment 1. GA-masks and GW-masks were constructed by removing the parts of A-masks and W-masks overlaying the blank spaces between interior letters (see Figure 4.1).[2]

*Design.* As in the previous experiments, subjects took part in two sessions, one on each of two separate days. Each session was divided in three sections (one practice and two test sections), with no obvious transition from one section to the next. In each session, half the stimuli were shown followed by A-masks and GA-masks, and half were shown followed by W-masks and GW-masks. In the second session, stimulus/mask pairings were reversed. Assignment of stimuli to particular mask configurations in the first session was alternated between subjects. In each session stimuli were shown followed by one mask configuration in the first test section and by another in the second test section. For every subject the order in which the target/mask stimuli were shown was re-randomised in both sessions, the only constraint being that every cycle of 16 trials was counterbalanced across mask configurations and target positions.

An average exposure duration was calculated for each of the subjects from the exposure durations set at the start of each of the 16-trial cycles in the test sections. The average exposure duration over all subjects in Experiment 3 was 28.8 ms. All remaining aspects of Experiment 3 were identical to those of Experiment 2.

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[2] The horizontal coordinates of the interior boundaries of gapped masks (i.e., GA-masks and GW-masks) (i.e., A-masks and W-masks) exactly matched the horizontal coordinates of the interior boundaries of gapped arrays.

**Results and discussion**

*Correct reports*

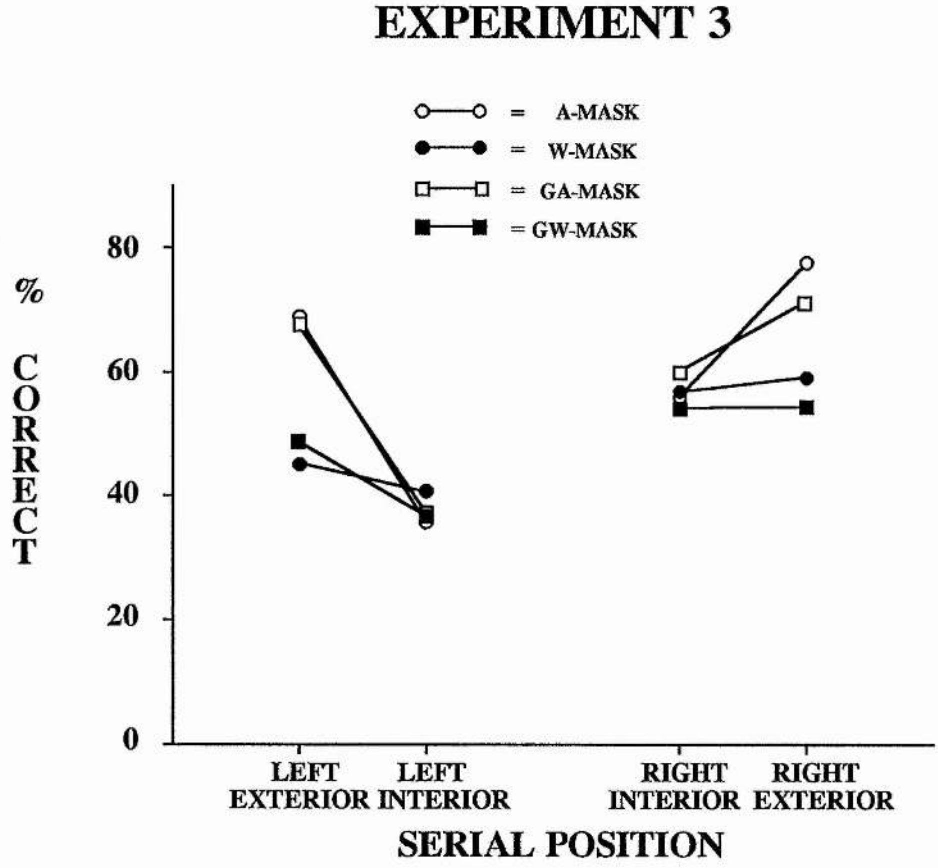
The data for correct reports in Experiment 3 are shown in Figure 4.2. Overall percentage correct reports in Experiment 3 was 54.3%. The data for correct reports were submitted to an analysis of variance for mixed design, with one between-subjects factor (stimulus group), and two within-subjects factors (mask configuration and serial position).

Highly significant effects of mask configuration and serial position were found [$F(3,42)=19.41$ and $F(3,42)=7.90$, $ps<.001$, respectively], together with a highly significant interaction between these two factors [$F(3,42)=9.55$, $p<.001$]. No other effects reached significance ($Fs<1$).

Newman-Keuls tests for pairwise comparisons examined the interaction between mask configuration and serial position more closely. As in Experiment 2, accuracy of report for exterior letters was severely affected by the width of the masks. That is, exterior letters were reported more accurately when target arrays were followed by appropriate masks (i.e., A-masks and GA-masks) than by wide masks (i.e., W-masks and GW-masks) ($ps<.05$). Accuracy for interior letters was not affected by the width of masks ($ps>.05$). Most importantly, however, removing mask contours overlaying blank spaces between interior letters had no effect on accuracy of report for either exterior letters or interior letters ($ps>.05$); exterior letters and interior letters were reported as accurately when target arrays were followed by gapped masks (i.e., GA-masks and GW-masks) (i.e., GA-masks and GW-masks) as when they were followed by complete masks (i.e., A-masks and W-masks). Moreover, exterior letters were reported as accurately in the gapped mask conditions (i.e., GA-masks and GW-masks) as in the complete mask conditions (i.e., A-masks and W-masks), and there was no difference in accuracy of report for interior letters between mask configurations.

A significant exterior-letter advantage was obtained in the A-mask condition

**Figure 4.2.** Mean percentage of interior-letters and exterior-letters correctly reported in each of the mask configurations of Experiment 3.



($ps < .05$), which replicates the exterior-letter advantage in gapped arrays observed in Experiment 2. In addition, exterior letters were reported more accurately than interior letters in the GA-mask condition ($ps < .05$). However, with wide masks (i.e., W-masks and GW-masks) the exterior-letter advantage almost disappeared; in the W-mask condition an exterior-letter advantage was observed on the left side of the fixation point only ($ps < .05$), while in the GW-mask condition no exterior-letter advantage was found on either side of the fixation point ($ps > .05$).

The results for accuracy of report indicate that the exterior-letter advantage apparent in gapped arrays in Experiment 2 was not caused by mask contours overlaying blank spaces flanking interior letters. In particular, in the GA-mask condition, in which masks overlaid only positions occupied by letters in the target stimulus, a considerable exterior-letter advantage was still apparent (30.2% and 11.2% left and right of the fixation point, respectively). Moreover, mask contours overlaying the gap between letters had no effect on accuracy of report for either interior letters or exterior letters. However, when wide masks (i.e., W-masks and GW-masks) were used, the exterior-letter advantage was severely disrupted.

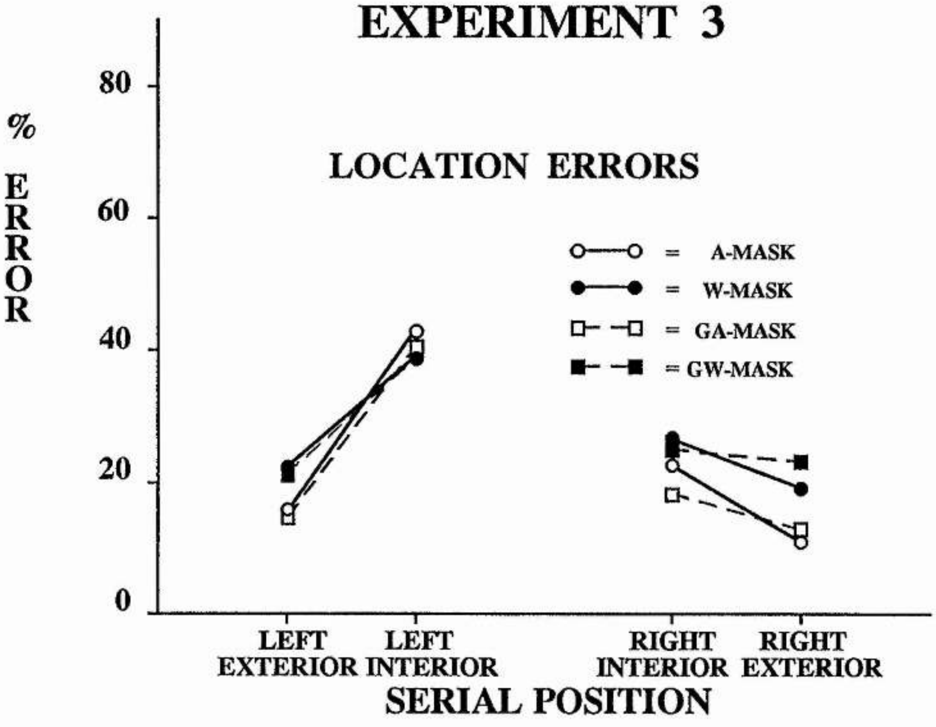
*Error Analysis*

The data for location errors and intrusion errors are shown in Figure 4.3. Location errors were slightly more frequent than intrusion errors; 54.2% of all errors made (24.7% of all responses) were location errors, 45.8% of all errors made (20.9% of all responses) were intrusion errors. The ratio of location errors and item errors was very similar to that of Experiment 2. The data for location errors and intrusion errors were each submitted to an analysis of variance for mixed design, with one between-subjects factor (stimulus group), and two within-subjects factors (mask configuration and serial position).

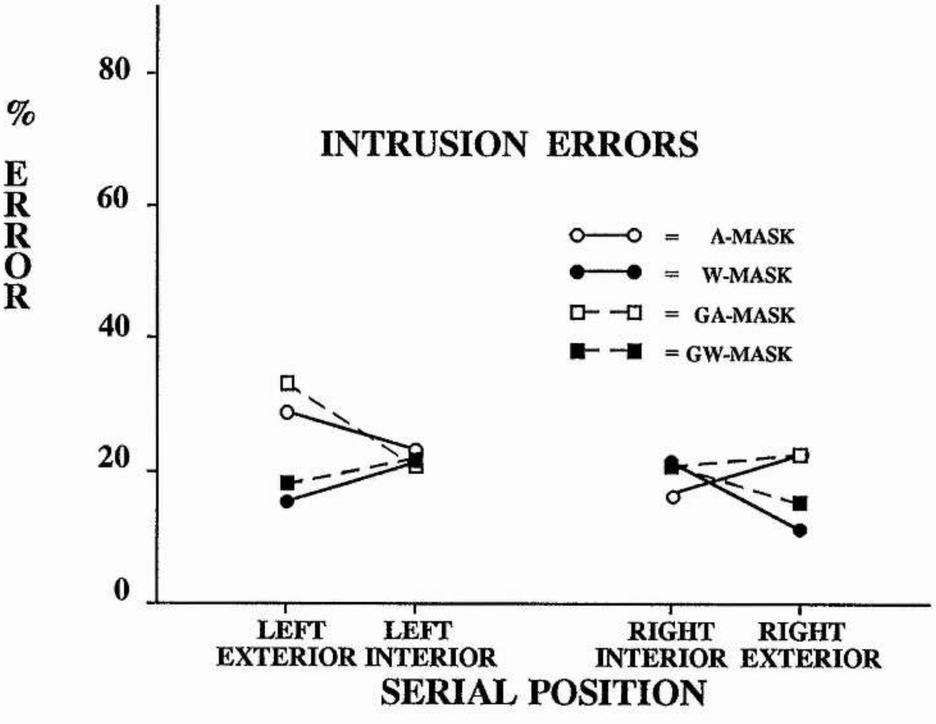
*Location errors*. For location errors the effects of mask configuration and serial position were highly significant [$F(3,42)=5.69$, $p=.002$, and $F(3,42)=25.42$,

**Figure 4.3.** Mean percentage of (a) location errors and (b) intrusion errors for interior and exterior positions in each of the mask configurations of Experiment 3.

(a)




(b)



$p < .001$, respectively], together with a highly significant interaction between these two factors [$F(9,126) = 3.47$, $p = .001$]. No other effects reached significance ($ps > .20$).

Newman-Keuls tests revealed that there was no difference between mask conditions in the frequency of location errors when interior letters were probed for report ($ps > .05$). When exterior letters were probed for report, however, location errors were more frequent with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks) ($ps < .05$), although no such difference was observed between complete masks and gapped masks ($ps > .05$). In addition, on the left of the fixation point, location errors were more frequent in interior positions than in exterior positions in all four mask conditions ($ps < .05$). On the right of the fixation point, however, location errors were more frequent in interior positions than in exterior positions only with appropriate masks (i.e., A-masks and GA-masks) ($ps < .05$); with wide masks (i.e., W-masks and GW-masks) there was no difference between interior and exterior positions on the right of the fixation point ($ps > .05$).

*Intrusion errors.* For intrusion errors the effect of mask configuration was highly significant [$F(3,42) = 11.80$, $p < .001$], together with a highly significant interaction between mask configuration and serial position [$F(9,126) = 6.61$, $p < .001$]. No other effects reached significance. In particular, the effect of serial position did not reach significance [$F(3,42) = 1.02$, $p = .392$].

Newman-Keuls tests revealed that there was no difference between mask conditions in the frequency of intrusion errors for interior positions ($ps > .05$). For exterior positions, however, wide masks (i.e., W-masks and GW-masks) produced more intrusion errors than appropriate masks (i.e., A-masks and GA-masks) ($ps < .05$), although no difference was observed between complete masks and gapped masks ($ps > .05$). On the right of the fixation point, the frequency of intrusion errors was higher for interior positions than for exterior positions, when arrays were followed by A-masks ($p < .05$). In the GW-mask condition, the frequency of location errors was less for interior positions than for exterior positions on the left of the fixation point

($p < .05$).

Thus, the analysis of location errors and intrusion errors confirms the lack of an effect of mask contours overlaying the gap on accuracy of report. Moreover, mask contours overlaying blank spaces in the middle of arrays had no effect on the frequency of location errors and intrusion errors for either interior or exterior positions. This general lack of effect of mask contours flanking interior letters offers no support for either of the hypotheses discussed in the introduction to this experiment.

In contrast to the absence of an effect of mask contours overlaying the gap, mask contours overlaying blank spaces next to exterior letters had a similar effect as apparent in Experiment 2. From the suggestion that intrusion errors reflect mainly misidentification of target letters it would follow that the effect on intrusion errors of mask contours overlaying blank spaces next to exterior letters indicates that wide masks (i.e., W-masks and GW-masks) caused an increase in lateral interference for exterior letters, limiting their perceptibility relative to exterior letters in arrays followed by appropriate masks (i.e., A-masks and GA-masks). Indeed, in the W-mask condition the exterior-letter advantage all but disappeared. Although for left serial positions a residual exterior-letter advantage remained in the W-mask and GW-mask conditions, this may be accounted for by a scanning bias. However, before any conclusions about the effects of mask configuration are drawn from the results of Experiment 3, the effects of mask configuration on the distribution of location error responses were examined.

As in Experiment 2, the matter of interest was whether wide masks (i.e., W-masks and GW-masks) caused an increase in location error responses for exterior positions relative to appropriate masks (i.e., A-masks and GA-masks), which would be expected if spatial anchors are disrupted when mask boundaries extend beyond array boundaries. However, an additional matter of interest was whether the effects of increasing mask size from A-masks to W-masks were the same as when mask size was increased from GA-masks to GW-masks. In addition, although mask contours overlaying blank spaces in the middle of arrays had no effect on the frequency of location errors for either interior or exterior positions, interior positions may have supplied more location error responses with complete masks than with gapped masks if spatial anchors are provided by interior boundaries.

To investigate the effects of mask contours overlaying blank spaces in the middle of target arrays, location errors in exterior positions were collapsed across complete mask conditions and across gapped mask conditions. If spatial anchors at the interior boundaries of arrays were disrupted by complete masks (i.e., A-masks and W-masks) but not by gapped masks (i.e., GA-masks and GW-masks), it would be expected that interior letters supplied relatively more location error responses when immediately flanking exterior positions were probed for report. To investigate the effects of mask width on spatial uncertainty for exterior letters, however, a separate analysis was conducted on the distribution of location error responses for gapped masks (i.e., GA-masks and GW-masks) and complete masks (i.e., A-masks and W-masks). Before the experiment was conducted, it was suggested that the effects of mask width might be different for gapped masks (i.e., GA-masks and GW-masks) (i.e., A-masks and W-masks) and complete masks (i.e., A-masks and W-masks). In particular, if spatial anchors are specific to the exterior boundaries of complete linear arrays, it may be that wide masks (i.e., W-masks and GW-masks) disrupt these spatial anchors only when mask contours overlay the gap between interior letters. If that is the case, when interior positions are tested, exterior positions immediately flanking the target position should supply more location error responses in the W-mask condition than in the A-mask condition, but a different pattern may be observed between GW-mask and GA-mask conditions. On the other hand, if spatial anchors are not specific to exterior boundaries of complete linear arrays, exterior positions should also supply more location errors responses in the GW-mask condition than in the GA-mask condition, when immediately flanking interior positions are tested (providing that adjacent positions supply location error responses).

The data for the position of location error responses are shown in Table 4.1. There was no difference in the distribution of location error responses between complete and gapped masks (i.e., GA-masks and GW-masks) (i.e., A-masks and W-masks) when exterior positions were tested ($\texttt{chi-square}_{(2)}$ =3.81, $p > .10$). When interior positions were tested, exterior positions supplied more location error responses in the GW-Mask condition than in the GA-Mask condition, which was matched by a decrease in the number of location error responses contributed by interior positions at the opposite side of the fixation point ($\texttt{chi-square}_{(2)}$ =8.05, $p < .05$). However, there was no difference in the position of location error responses between the A-mask condition and the W-mask condition when interior positions were tested ($\texttt{chi-square}_{(2)}$ =2.11, $p > .25$). No other comparisons showed an effect of mask configuration on the distribution of location error responses ($ps > .50$).

These effects of mask configuration on the position of supplied location errors suggest that wide masks (i.e., W-masks and GW-masks) did increase spatial uncertainty for exterior letters compared to appropriate masks (i.e., A-masks and GA-masks), but only when these masks were gapped. The absence of an effect of flanking mask contours on spatial uncertainty with complete masks (i.e., A-masks and W-masks) is surprising, considering that, in Experiment 2, evidence suggesting that spatial uncertainty for exterior letters in the W-mask condition increased compared to the A-mask condition was found in both complete and gapped arrays. However, it is not so important that there was no difference in the position of location error responses between the A-mask condition and the W-mask condition, considering that the difference between the GA-mask condition and the GW-mask condition clearly confirmed that mask contours overlaying the gap were not necessary for the effect of flanking mask contours on spatial uncertainty for exterior letters.

The first indication to emerge from the results of Experiment 3, is that mask contours overlaying the gap played no role in the exterior-letter advantage in gapped arrays. Second, the effects of flanking mask contours suggested that while exterior

**Table 4.1**. Frequencies of supplied location error responses for interior and exterior positions in Experiment 3. The frequencies of location error responses are collapsed over appropriate and wide masks for exterior target positions. Flanking response positions are the positions immediately adjacent to the target position, Interior (opposite side) and Exterior (opposite side) response positions are the interior and exterior positions, respectively, at the opposite side of the fixation point relative to the target position.

| *Test Position* | *Mask Configuration* | *Position of response letter (relative to test position)* | | |
|---|---|---|---|---|
| | | Flanking | Interior (opposite end) | Exterior (opposite end) |
| Exterior | connected masks | 126 | 69 | 64 |
| | gapped masks | 109 | 80 | 81 |
| Interior | A-masks | 67 | 96 | 86 |
| | W-masks | 79 | 82 | 88 |
| | GA-masks | 56 | 86 | 81 |
| | GW-masks | 85 | 67 | 92 |

boundaries may have provided spatial anchors in gapped arrays, no evidence was found to suggest that interior boundaries provided spatial anchors. Thus, the results of Experiment 3 indicate that there are still differences between interior letters and exterior letters in gapped arrays, even when mask contours overlaying the gap were removed.

Can something be said about the nature of this difference? The difference between interior positions and exterior positions for intrusion errors suggests that interior letters were slightly less perceptible than exterior letters, indicating that interior letters may have suffered more lateral interference than exterior letters. In addition, if spatial anchors are available for exterior letters but not for interior letters, spatial uncertainty may be less for exterior letters than for interior letters. Although it is as yet not clear why these differences exists between interior letters and exterior letters, this difference cannot be explained by an imbalance in the number of immediately flanking distractor letters for interior letters and exterior letters. However, the difference between interior letters and exterior letters was examined further in Experiment 4.

## Experiment 4

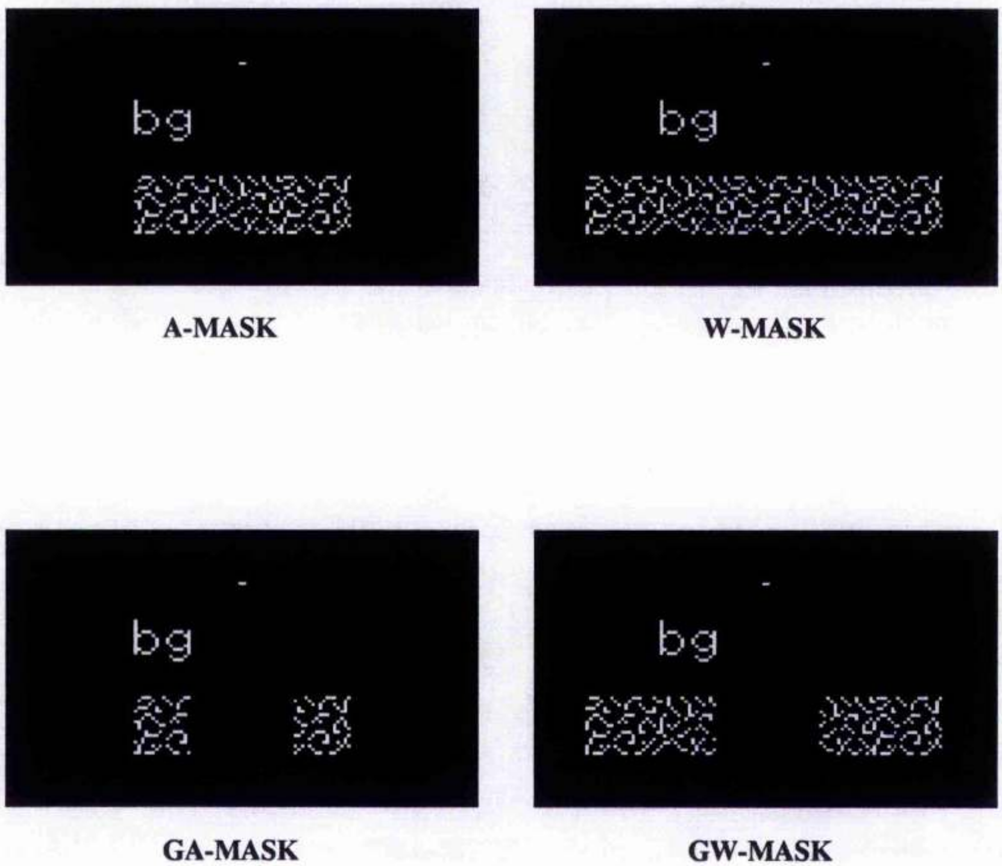
Although the results of Experiment 3 suggest that there is still a difference between interior letters and exterior letters in gapped arrays, even though both are flanked by blank spaces on one side, the nature of this difference is not clear. One possibility is that the exterior-letter advantage observed in gapped arrays in Experiments 2 and 3 was due to an asymmetry in the amount of lateral interference provided by letters in interior and exterior positions. Indeed, one of the properties of lateral interference is that letters presented in close proximity in locations more peripheral than the target letter disrupt the perceptibility of target letters more than letters presented in more foveal locations (Banks et al., 1977, 1979; Bouma, 1970; Chastain, 1982a, 1982b; Chastain & Lawson, 1979; Chambers & Wolford, 1983). This asymmetry in lateral interference might actually cause a violation of the visual acuity gradient, in that peripheral members of target pairs presented unilaterally are more perceptible than foveal members (Chastain, 1982a). Since exterior letters occupy more peripheral locations in the visual field than interior letters, it may seem reasonable to expect that the same asymmetry could have inspired an exterior-letter advantage, even though both interior letters and exterior letters are flanked by blank spaces on one side. If that is the case, the exterior-letter advantage apparent in the GA-mask condition in Experiment 3 may not be specific to letters in linear multi-letter arrays, but may be observed whenever two letters are presented unilateral to the fixation point.

Furthermore, this argument could be extended to account for the difference in the effects of flanking mask contours for interior letters and exterior letters. For example, complete masks (i.e., A-masks and W-masks) provided flanking mask contours for interior letters on the foveal side, while wide masks (i.e., W-masks and GW-masks) provided flanking mask contours for exterior letters on the peripheral side. Thus, mask contours flanking letters on the foveal side may have different effects than mask contours flanking letters on the peripheral side. If this is the case, the difference in the effects of flanking mask contours for interior letters and exterior letters may not be specific to letters in gapped arrays, but may reflect an asymmetry in the effects of peripherally flanking mask contours mask contours and foveally flanking mask contours.

Therefore, in Experiment 4, each trial consisted of only two letters presented on one side of the fixation point. Thus, the stimuli presented in this experiment were the same as the stimuli presented in Experiment 3, except that the letters on the opposite side of the fixation point relative to target letters were replaced with blank spaces. In addition, the same mask configurations as in Experiment 3 were used in Experiment 4. An example of each of the target/mask combinations is shown in Figure 4.4. When only two letters are presented unilateral to the fixation point, letters occupy positions which are different only in relation to each other, and not in relation to other letters.

**Figure 4.4.** An example of test stimuli and of each of the mask configurations used in Experiment 4. See text for explanation.

## EXPERIMENT 4



That is, both could be considered as exterior letters of a 2-letter array, except that one is the foveal exterior letter (i.e., closest to the fixation point) and the other is the peripheral exterior letter (i.e., furthest away from the fixation point). If the differences are specific to interior letters and exterior letters of linear arrays, the exterior-letter advantage and the difference between the effects of peripherally flanking mask contours on exterior letters and the effects of foveally flanking mask contours on interior-letters should not be observed with 2-letter arrays. On the other hand, if the exterior-letter advantage in gapped arrays and the effects of mask configuration observed in Experiment 3 reflects a difference between foveal letters and peripheral letters of single letter pairs, the differences between interior letters and exterior letters observed in Experiment 3 should also be apparent in Experiment 4.

## Method

*Subjects*. Sixteen subjects from the same population as Experiments 1-3 participated two 1-hr sessions in Experiment 4.

*Stimuli*. The same test stimuli used in Experiment 3 were used in Experiment 4, except that on each trial the two letters on the other side of the fixation point relative to the target position (*the nontarget letter-pair*) were replaced by blank spaces (see Figure 4.4).

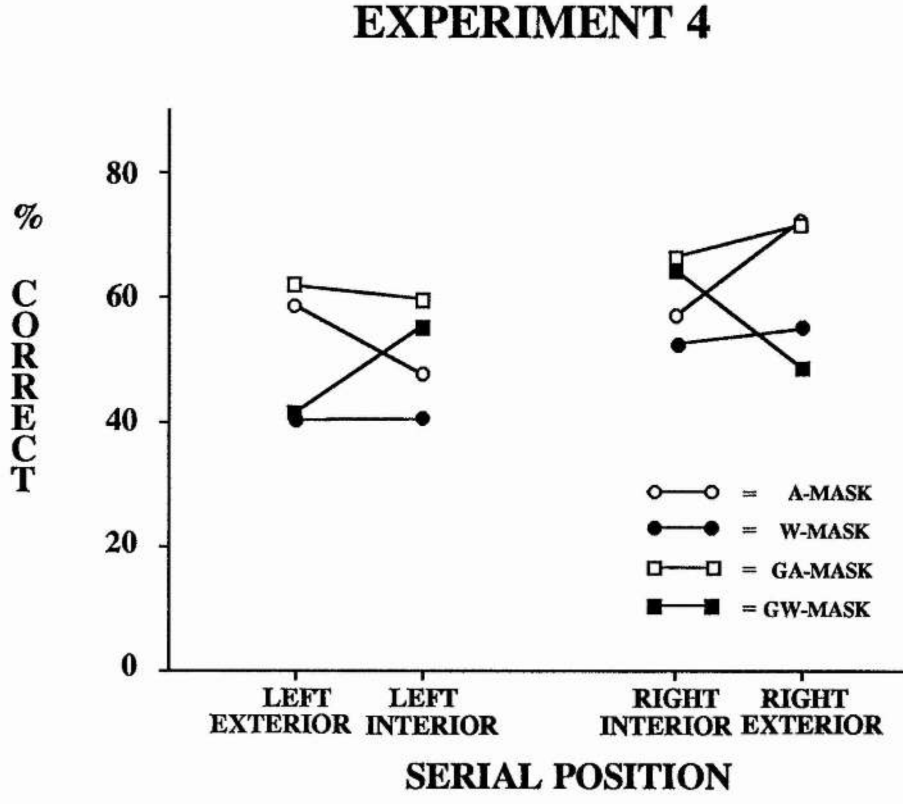
An average exposure duration was calculated for each of the subjects from the exposure durations set at the start of each of the 16-trial cycles in the test sections. Average exposure duration over all subjects was 21.8 ms. All remaining aspects of this experiment were identical to those of Experiment 3.

## Results and discussion

### *Correct reports*

The data for correct reports in Experiment 4 are shown in Figure 4.5. Overall

**Figure 4.5.** Mean percentage of interior-letters and exterior-letters correctly reported in each of the mask configurations of Experiment 4.



percentage correct reports in Experiment 4 was 55.9%. The data for correct reports were analysed in the same way as in Experiment 3.

Highly significant effects of mask configuration and serial position were found [$F(3,42)=39.75$ and $F(3,42)=6.41$, $ps<.001$, respectively], together with a highly significant interaction between these two factors [$F(3,42)=6.92$, $p<.001$]. No other effects reached significance. Newman-Keuls tests examined the interaction between mask configuration and serial position more closely. Accuracy of report for exterior letters was lower with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks) ($ps<.05$), but there was no difference between complete mask (i.e., A-mask and W-mask) and gapped mask (i.e., Ga-mask and GW-mask) conditions for exterior letters ($ps>.05$). Accuracy of report for left interior letters was higher in the GA-mask condition than in the W-mask and A-mask conditions ($ps<.05$), accuracy for right interior letters was higher in the GA-mask and GW-mask conditions than in the W-mask condition ($ps<.05$). No other comparisons between mask conditions reached significance for interior letters ($ps>.05$).

Only in the A-mask condition did exterior letters have an advantage over interior letters ($p<.05$); no advantage for exterior letters was observed in the W-mask and GA-mask conditions ($ps>.05$) while, in the GW-mask condition, accuracy for exterior letters was actually *worse* than for interior letters ($p<.05$).

The absence of an exterior-letter advantage in the GA-mask condition indicates that the asymmetry in lateral interference, which may have existed between members of unilaterally presented letter pairs, was not sufficient to account for the exterior-letter advantage in gapped arrays observed in Experiment 3. Therefore, the data for correct reports suggest that the presence of letters on the opposite side of the fixation point played a crucial role in the exterior-letter advantage in the GA-mask condition observed in Experiment 3.

Furthermore, letters on the opposite side of the fixation point relative to the target may have played a crucial role in the asymmetry of the effects of flanking mask contours for interior letters and exterior letters observed in Experiment 3. That is, when single letter pairs were presented, interior letters were reported less accurately with foveally flanking mask contours than without flanking mask contours and exterior letters were reported less accurately with peripherally flanking mask contours than without flanking mask contours. Thus, it may be that the differential effects of mask contours foveally flanking interior letters or peripherally flanking exterior letters observed in Experiment 3 are, indeed, specific linear arrays. Nevertheless, when both interior letters and exterior letters had flanking mask contours (i.e., in the W-mask condition), or they both had no flanking mask contours (i.e., in the GA-mask condition), accuracy of report was still slightly better for exterior letters, whereas the visual acuity gradient would predict better accuracy of report for interior letters. Thus, the asymmetry in lateral interference between interior letters and exterior letters may have been sufficient to cancel the effects of visual acuity. However, W-masks provided a larger amount of flanking mask contours for interior letters than for exterior letters, and GA-masks contained mask contours at the opposite side of the fixation point. Therefore, both types of mask may have disrupted the perceptibility of interior letters more than the perceptibility of exterior letters, and no conclusions can be drawn concerning the role of lateral interference between members of separate letter pairs. This matter is discussed further in Chapter Five.

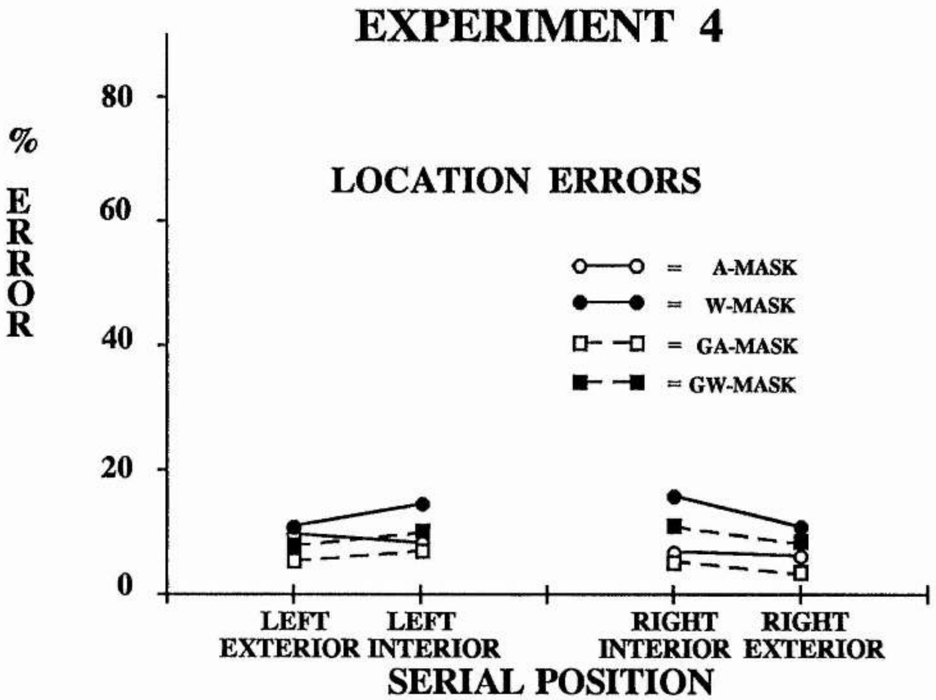
To compare the effects of flanking mask contours on performance in Experiment 4 with those observed in Experiment 3 in more detail, an analysis of incorrect reports was performed.

*Error Analysis*

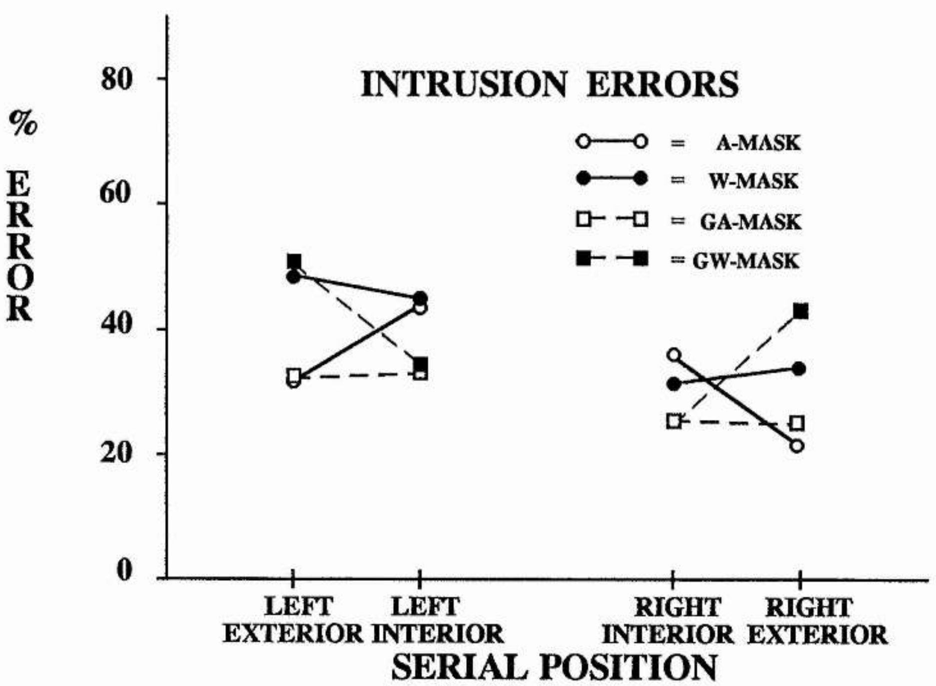
The data for location errors and intrusion errors in Experiment 4 are shown in Figure 4.6. Intrusion errors were much more frequent than location errors; only 20.0% of errors made (8.8% of all responses) were location errors, while 80.0% of errors

**Figure 4.6.** Mean percentage of (a) location errors and (b) intrusion errors for interior and exterior positions in each of the mask configurations of Experiment 4.

(a)




(b)



made (35.1% of all responses) were intrusion errors. The data for location errors and intrusion errors were each submitted to an analysis of variance for factorial design, with two within-subjects factors (mask configuration and serial position).

*Location errors.* Figure 4.6a shows the data for location errors in Experiment 4. The effect of mask configuration was highly significant [$F(3,45)=17.91$, $p<.001$], and the effect of serial position was marginally significant [$F(3,45)=2.96$, $p=.043$, respectively]. The interaction between these factors did not reach significance ($F<1$).

Newman-Keuls tests revealed that the proportion of location errors was smallest in the GA-mask condition, larger in the A-mask and GW-mask conditions, and largest in the W-mask condition ($ps<.05$). This effect of mask configuration on location errors suggests that the frequency of location errors depends primarily on the amount of flanking mask contours (either peripherally of foveally) provided by masks in each of the mask conditions; GA-masks presented no mask contours overlaying blank spaces next letters in either position, A-masks and GW-masks presented flanking mask contours for either interior letters or exterior letters but not for both, while W-masks presented flanking mask contours for both interior letters and exterior letters. While slightly more location errors were made when interior positions were probed for report than when exterior positions were probed for report in all four mask conditions, none of these comparisons reached significance ($ps>.05$).

*Intrusion errors.* Figure 4.6b shows the data for intrusion errors in Experiment 4. The effects of mask configuration and serial position were highly significant [$F(3,45)=18.50$, and $F(3,45)=7.75$, $ps<.001$, respectively], together with a highly significant interaction between these factors [$F(9,135)=9.35$, $p<.001$]. Newman-Keuls test revealed that the proportion of intrusion errors was higher when targets were flanked (either peripherally or foveally) by mask contours than when they had no flanking mask contours. That is, when exterior positions were probed for report, more intrusion errors were made with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks) ($ps < .05$) and, when the left interior position was probed for report, more intrusion errors were made with complete masks (i.e., A-masks and W-masks) than with gapped masks (i.e., GA-masks and GW-masks) (i.e., A-masks and W-masks) ($ps < .05$). When the right interior position was probed for report, however, there was no significant difference between mask conditions ($ps > .05$). In the A-mask condition more intrusion errors were made in interior positions than in exterior positions, whereas in the GW-mask condition more intrusion errors were made in exterior positions than in interior positions ($ps < .05$). There was no difference in the number of intrusion errors between interior and exterior positions in the GA-mask and W-mask conditions ($ps > .05$).

Thus, the analyses of incorrect reports revealed that no difference between interior positions and exterior positions for intrusion errors, but a small significant difference between interior positions and exterior positions remained for location errors. However, the effects of mask configuration on location errors and intrusion errors were similar for interior and exterior positions. Most importantly, the results for location errors and intrusion errors were very different from those observed in Experiment 3, suggesting once more that nontarget letter-pairs played a crucial role in performance for Experiment 3.

The effects of mask configuration on the pattern of intrusion errors were very similar as the effects of mask configuration on accuracy of report. Moreover, the effects of flanking mask contours on accuracy of report were matched almost entirely by intrusion errors. Following from the arguments presented in Chapter Two about the significance of intrusion errors, the effects of (either peripherally or foveally) flanking mask contours indicates that flanking mask contours disrupted mainly the perceptibility of letters in the display. However, the results of Experiments 2 and 3 suggested that mask contours overlaying blank spaces may have increased spatial uncertainty for letters flanking these contours. Therefore, in addition to the effects on the perceptibility of letters in the display, mask contours overlaying blank spaces may also have increased the spatial uncertainty for letters flanked by these contours in the present experiment. Indeed, the proportion of location errors in the GA-mask condition increased when mask contours peripherally flanked exterior letters and foveally flanked interior letters. Therefore, the effect of mask configuration on location errors may indicate that spatial anchors that exist when interior letters or exterior letters are flanked by a blank space, where disrupted when mask contours overlaid this blank space.

To investigate this possibility, location errors and intrusion errors were examined further. The analysis of the distribution of location error responses in Experiment 3 suggested that an increase in location errors supplied by a particular, nontarget, position may reflect an increase in spatial uncertainty for letters in that position. The same rational, underlying the analysis of the position of location error responses in Experiment 3, was used here. If spatial uncertainty for letters in position A is high it would be expected that these letters are more frequently given as a response, when position B is tested, than when spatial uncertainty for letters in position A is low. In addition, if the perceptibility of letters in position B does not change, the increase in location errors when position B was probed, caused by the increase of spatial uncertainty for letters in position A, should be matched by a decrease in the frequency of intrusion errors. Thus, when, for example, spatial uncertainty for exterior letters is higher in wide mask conditions than in appropriate mask conditions, it would seem reasonable to expect that when interior letters are tested, the proportion of location errors relative to intrusion errors should be higher with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks). Although some caution is appropriate, when conclusions are drawn about the effects of mask configuration on spatial uncertainty for letters in the display from a comparison of the relative frequency of location errors and intrusion errors, the link between backward pattern masks and spatial uncertainty was inspired by previous research (e.g., Jordan, 1990). Furthermore, a consistent confirmation of the predictions may provide a powerful indication that the assumptions underlying the link between spatial uncertainty and location errors and intrusion errors are justified.

The results of all pairwise comparisons of the ratio of location errors and intrusion errors between each of the mask configurations are shown in Table 4.2.

*Interior target position.* When interior letters were tested, location errors were more frequent in the wide mask (i.e., W-mask and GW-mask) conditions than in the appropriate mask (i.e., A-mask and GA-mask) conditions relative to intrusion errors. No difference was found between complete mask (i.e., A-mask and W-mask) conditions and gapped mask (i.e., GA-mask and GW-mask) conditions. These results agree with the prediction that spatial uncertainty for *exterior* letters would be larger when mask boundaries extend beyond the exterior boundaries of target arrays, compared to when mask boundaries match the exterior boundaries of target arrays.

*Exterior target position.* When exterior letters were tested, location errors were relatively more frequent in the complete mask (i.e., A-mask and W-mask) conditions than in the gapped mask (i.e., GA-mask and GW-mask) conditions. No difference was found between appropriate mask (i.e., A-mask and GA-mask) conditions and wide mask (i.e., W-mask and GW-mask) conditions. These results agree with the prediction that spatial uncertainty for *interior* letters would be larger when mask boundaries extend beyond the interior boundaries of target arrays, compared to when mask boundaries match the interior boundaries of target arrays.

The analysis of errors confirmed the pattern of correct reports by suggesting that there was, indeed, no difference in the effects of flanking mask contours on the report of interior and exterior letters. Accuracy of report was lower for letters with flanking mask contours than for letters without flanking mask contours. This was matched by an increase in intrusion errors, suggesting that letters with flanking mask contours were less perceptible than letters without flanking mask contours. Furthermore, it seems likely that spatial uncertainty for interior letters was affected by foveally flanking mask contours while spatial uncertainty for exterior letters was affected by peripherally flanking mask contours. Finally, there was no difference in accuracy of report between

**Table 4.2**. The frequency of location errors relative to intrusion errors compared between mask configurations of Experiment 4. The figures indicate the value of Pearson's Chi-square for differences in the relative frequency of location errors between mask conditions in two-by-two contingency tables of the frequencies of location errors and intrusion errors. (*=$p$<.05, **=$p$<.01.)

| *Test Position* | *Mask Configuration* | A-mask | W-mask | GA-mask | GW-mask |
|---|---|---|---|---|---|
| Interior | A-mask | - | 17.49** | 0.31 | 10.62** |
| | W-mask | | - | 11.15** | 0.50 |
| | GA-mask | | | - | 5.80** |
| | GW-mask | | | | - |
| | | A-mask | W-mask | GA-mask | GW-mask |
| Exterior | A-mask | - | 0.43 | 8.06** | 8.13** |
| | W-mask | | - | 5.96** | 5.93** |
| | GA-mask | | | - | 0.15 |
| | GW-mask | | | | - |

interior letters and exterior letters in single letters pairs. Taken together, the results of Experiment 4, indicate that there were no substantial differences in performance between interior letters and exterior letters of single letter pairs. Most importantly, however, the effects of mask configuration on exterior letters appeared to be similar to those observed in Experiment 3. Since the effects of mask configuration were similar for interior letters and exterior letters, the results of Experiment 4 indicate that nontarget letter-pairs played a crucial role in the differences in the pattern of performance observed between interior letters and exterior letters in Experiment 3.

## Experiment 5

Experiment 5 was conducted to examine the role of nontarget letter-pairs (the letters at the opposite side of the fixation point relative to the target letter) more closely. The results of Experiment 4 indicate that these letters play a crucial role in the exterior-letter advantage in gapped arrays and in the difference in the effect of flanking mask contours on exterior letters and interior letters apparent in Experiment 3. However, the nature of the role of nontarget letter-pairs is not clear. For example, it may be that the difference between interior letters and exterior letters observed in Experiment 3 is not restricted to 4-letter arrays, and the same difference may be found when nontarget letter-pairs are replaced with a pair of nonletter, "letter-like", characters. Indeed, one approach to investigating the exterior-letter advantage has concentrated on the fact that letters are a special subset of all possible shapes, which might also invoke a special subset of processes in visual recognition. Therefore, several investigator have compared the effect of serial position on the report of letters and other (letter-like) meaningless characters. For example, in a detection task with reaction time as the dependent variable, Mason and Katz (1976) found an exterior-letter advantage in linear multi-letter arrays, but no exterior-character advantage in an array of Greek characters (which are in effect meaningless for nonGreek readers). Reaction times for the detection of Greek characters were actually longer for characters appearing in the end positions than for characters appearing in the interior positions (see also Hammond & Green, 1982; Mason, 1982), indicating that characters appearing the exterior positions of nonletter arrays are processed least effectively. Therefore, to examine if the role of nontarget letter-pairs in the pattern of performance in Experiment 3 could also be played by pairs of nonletter characters, in Experiment 5 nontarget letter-pairs were replaced with pairs of ampersands (i.e., &'s), and the effects of mask configuration on performance was examined using the same mask configurations as in Experiments 3 and 4. An example of each of the target/mask combinations is shown in Figure 4.7. Ampersands were used as nonletter characters, because they are physically similar to letters, yet would not invoke processes specific for the visual recognition of letters.

**Method**

*Subjects.* Sixteen subjects from the same population as Experiment 1-4 participated in two 1-hr sessions in Experiment 5.

*Stimuli.* The test stimuli used in Experiment 3 were used in Experiment 5, except that on each trial the letters at the opposite side of the fixation point relative to the target were replaced by a pair of ampersands (see Figure 4.7).

An average exposure duration was calculated for each of the subjects from the exposure durations set at the start of each of the 16-trial cycles in the test sections. Average exposure duration over all subjects was 20.8 ms. All remaining aspects of this experiment were identical to those of Experiment 3.

**Results and discussion**

*Correct reports*

The data for correct reports in Experiment 5 are shown in Figure 4.8. Overall

**Figure 4.7:** An example of test stimuli and each of the mask configurations used in Experiment 5. See text for explanation.

# EXPERIMENT 5


**A-MASK**


**W-MASK**


**GA-MASK**


**GW-MASK**

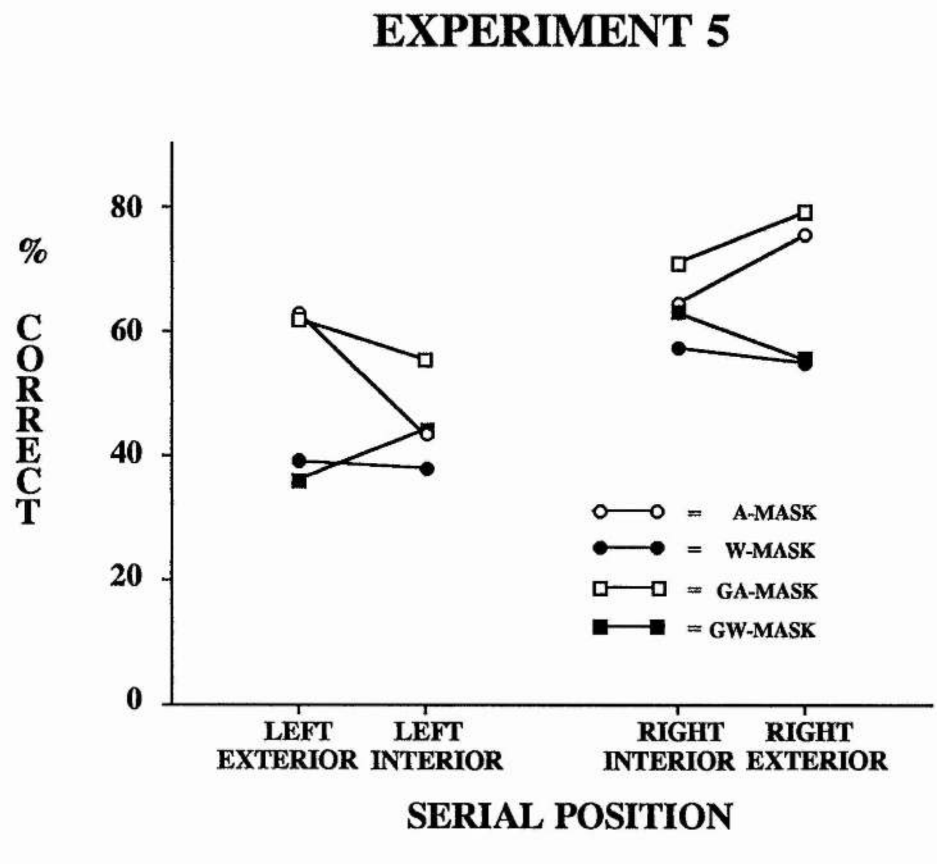
percentage correct reports in Experiment 5 was 56.4%. The data for correct reports were analysed in the same way as in Experiment 3.

Highly significant main effects of mask configuration and serial position were found [$F(3,42)=30.88$ and $F(3,42)=14.35$, $ps<.001$, respectively], together with a highly significant interaction between these two factors [$F(3,42)=5.93$, $p<.001$]. No other effects reached significance. Newman-Keuls tests revealed that accuracy of report for exterior letters was lower with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks) ($ps<.05$), but there was no difference between complete mask (i.e., A-mask and W-mask) and gapped mask (i.e., GA-mask and GW-mask) conditions ($ps>.05$). Accuracy of report for left interior letters was higher in the GA-mask condition than in all other mask conditions ($ps<.05$), while accuracy for right interior letters was higher in the GA-mask condition than in the W-mask mask condition ($p<.05$). No other comparisons between mask conditions reached significance for interior letters ($ps>.05$). In particular, the difference in accuracy for interior letters between the W-mask condition and the GA-mask and GW-mask conditions did not reach significance.

Only in the A-mask condition did exterior letters have an advantage over interior letters ($p<.05$; $ps>.05$ for all other masks). In particular, although, accuracy for exterior letters appeared to be *worse* than for interior letters in the GW-mask condition, this difference did not reach significance ($ps>.05$) nor did the apparent exterior-letter advantage in the GA-mask condition.

In some respects, the pattern of results for accuracy of report in Experiment 5 appears to be similar as in Experiment 4. Most importantly, no significant exterior-letter advantage was observed in the GA-mask condition and accuracy for interior letters was significantly higher in the GA-mask condition than in the W-mask condition in both experiments. However, there were also some differences between these experiments. For example, a negative exterior-letter advantage was apparent in the GW-mask condition in Experiment 4, but, although accuracy of report was higher for

**Figure 4.8.** Mean percentage of interior-letters and exterior-letters correctly reported in each of the mask configurations of Experiment 5.



interior letters than for exterior letters in the GW-mask condition in Experiment 5, this difference was not significant.

Thus, a comparison between Experiment 5 and Experiment 4 shows that ampersands did affect the processing of targets compared to blank spaces. However, most importantly, a comparison between Experiment 5 and Experiment 3 shows that ampersands did not have the same effect as a pair of letters presented at the opposite side of the fixation point. Indeed, although exterior letters were actually reported more accurately than interior letters in the GA-mask condition in Experiment 5, this difference was not significant, whereas in Experiment 3 a sizable exterior-letter advantage was observed. Furthermore, accuracy for interior letters was clearly affected by flanking mask contours in Experiment 5, while flanking mask contours had no effect on accuracy for interior letters in Experiment 3. This suggests that the difference in performance between interior letters and exterior letters apparent in Experiment 3 is specific to the use of letters in both exterior positions. However, to examine the effects of ampersands in more detail, an analysis of incorrect reports was conducted.

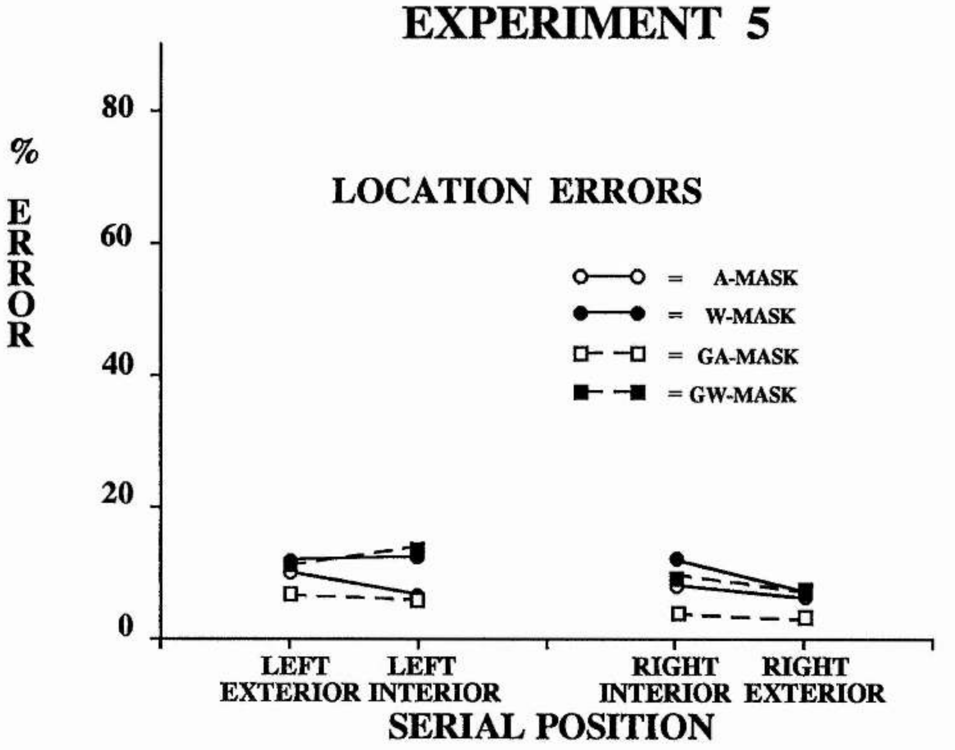
*Error Analysis*

The data for location errors and intrusion errors are shown in Figure 4.9. Intrusion errors were much more frequent than location errors; only 20.0% of all errors made were location errors (8.8% of all responses), while 80.0% of all errors made were intrusion errors (35.1% of all responses). The data for location errors and intrusion errors were each submitted to an analysis of variance for factorial design, with two within-subjects factors (mask configuration and serial position).

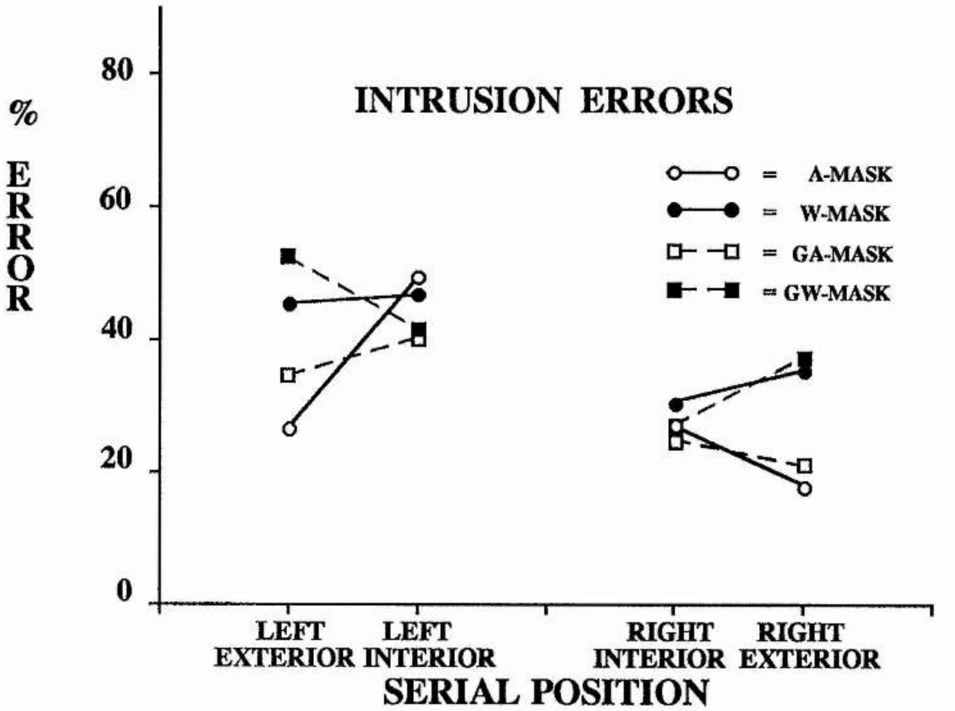
*Location errors.* For location errors the effects of mask configuration and serial position were both highly significant [$F(3,45)=17.91$, and $F(3,45)=2.96$, $ps<.001$, respectively]. The interaction between these factors was not significant [$F(9,135)=1.07$, $p=.390$]. Newman-Keuls tests revealed that the proportion of location errors was smallest in the GA-mask condition, larger in the A-mask and largest

**Figure 4.9.** Mean percentage of (a) location errors and (b) intrusion errors for interior and exterior positions in each of the mask configurations of Experiment 5.

(a)




(b)



in the GW-mask and W-mask conditions ($ps < .05$). Comparisons between serial positions showed that there was no difference in the proportion of location errors between interior and exterior positions ($ps > .05$).

*Intrusion errors*. For intrusion errors the effects of mask configuration and serial position were highly significant [$F(3,45)=8.47$, and $F(3,45)=14.98$, $ps < .001$, respectively], together with a highly significant interaction between these factors [$F(9,135)=6.75$, $p < .001$]. Newman-Keuls tests revealed that, when exterior positions were probed for report, more intrusion errors were made with wide masks (i.e., W-masks and GW-masks) than with appropriate masks (i.e., A-masks and GA-masks) ($ps < .05$). When interior positions were probed for report, however, there was no difference in the proportion of intrusion errors between mask conditions ($ps > .05$). On the left of the fixation point, the proportion of intrusion errors was higher in interior positions than in exterior positions in the A-mask condition, whereas in the GW-mask condition the proportion of intrusion errors was higher in exterior positions than in interior positions ($ps < .05$). On the right of the fixation point these differences did not reach significance ($ps > .05$).

As in Experiment 4, the effects of mask configuration on intrusions errors appears to match more or less the effects of mask configuration on accuracy of report. That is, flanking mask contours increased the proportion of intrusion errors for interior and exterior positions, although the effect appears to be somewhat smaller for interior positions. There was no difference between interior and exterior positions in the effect of effects of mask configuration on location errors.

To examine if the prediction that flanking mask contours increased spatial uncertainty for interior letters and exterior letters, the effect of mask configuration on the frequency of location errors relative to intrusion errors was investigated in the same way as in Experiment 4. The results of all pairwise comparisons of the ratio of location errors and intrusion errors between mask configuration are shown in Table 4.3.

*Interior target position*. When interior letters were tested, location errors were

**Table 4.3**. The frequency of location errors relative to intrusion errors compared between mask configurations of Experiment 5. The figures indicate the value of Pearson's Chi-square for differences in the relative fequency of location errors between mask conditions in two-by-two contingency tables of the frequencies of location errors and intrusion errors. (*=*p*<.05, **=*p*<.01.)

| *Test Position* | *Mask Configuration* | A-mask | W-mask | GA-mask | GW-mask |
|---|---|---|---|---|---|
| Interior | A-mask | - | 6.41** | 1.31 | 9.32** |
| | W-mask | | - | 12.46** | 0.35 |
| | GA-mask | | | - | 15.90** |
| | GW-mask | | | | - |
| | | A-mask | W-mask | GA-mask | GW-mask |
| Exterior | A-mask | - | 10.9** | 11.57** | 4.72* |
| | W-mask | | - | 1.80 | 0.08 |
| | GA-mask | | | - | 2.45 |
| | GW-mask | | | | - |

relatively more frequent in the wide mask conditions than in the appropriate mask conditions. No difference was found between complete and gapped mask conditions. These results agree with the prediction that spatial uncertainty for *exterior* letters would be larger when mask boundaries extent beyond the exterior boundaries of target arrays, compared to when mask boundaries matched the exterior boundaries of target arrays.

*Exterior target position*. When exterior letters were tested, the predictions about the effects of mask configuration on the relative frequency of location errors were not entirely confirmed. More specifically, location errors were not consistently more frequent in gapped mask conditions than in complete mask conditions. Thus, the analysis of the relative frequency of location errors confirmed the predictions about the effects of mask contours overlaying blank spaces next to exterior letters, but was indecisive about the effects of mask contours overlaying blank spaces next to interior letters.

**Conclusions**

The differences between performance for interior letters and exterior letters observed in Experiment 3 were not observed when letters at the opposite side of the fixation point were replaced with either blank spaces or a pair of ampersands. This indicates that nontarget letter-pairs played a crucial role in the difference between performance for interior letters and exterior letters in letter arrays. Furthermore, the role of nontarget letter-pairs in the pattern of performance apparent in Experiment 3 may have been specific to letters as it was not observed for nonletters (i.e., ampersands). Indeed, the effects of serial position and of mask configuration on performance were different when target letter-pairs were presented with nontarget letter-pairs, compared to when target letter-pairs were presented with ampersands. However, it is as yet not clear why the effects of pairs of ampersands were different from the effects of nontarget letter-pairs. Indeed, when the pattern of performance was compared between Experiments 4 and 5, the effects of pairs of ampersands were not entirely similar as the effects of blank spaces either. In particular, when interior positions were probed for report, the effects of mask configuration were slightly different between these two experiments. Therefore, ampersands may have exerted some of the effects of nontarget letter-pairs.

However, the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays is not immediately obvious. Nontarget letter-pairs appeared to play a crucial role in the exterior-letter advantage in gapped arrays, as no exterior-letter advantage was observed for single letter-pairs presented unilateral to the fixation point. In addition, nontarget letter-pairs played a crucial role in the effects of mask contours foveally flanking interior letters. Indeed, the analysis of the position of location error responses in Experiments 3 and 4, indicates that mask contours foveally flanking interior letters may have increased spatial uncertainty for interior letters of single letter-pairs, while mask contours foveally flanking interior letters had no effect on spatial uncertainty for interior letters of gapped arrays. Thus, it may be that nontarget letter-pairs in gapped arrays exerted some of the effects exerted by mask contours foveally flanking interior letters of single letter-pairs. That is, nontarget letter-pairs may have disrupted spatial anchors provided by interior boundaries of single letter-pairs. Consequently, spatial uncertainty for interior letters may have been higher in gapped arrays than in single letter-pairs irrespective of mask configuration.

Finally, although ampersands may have played a similar role in the effects of mask configuration on performance as played by nontarget letter-pairs in gapped arrays, apparently the presence of ampersands was not sufficient to produce an exterior-letter advantage. Therefore, either the disruption of spatial anchors at the interior boundaries was less severe when ampersands were presented across the gap than when nontarget letter-pairs were presented across the gap or the disruption of spatial anchors at the interior boundaries of gapped arrays alone may not have been sufficient to produce an exterior-letter advantage. This matter is examined further in Chapter Five.

**Exposure durations**

In addition to a difference in target stimulus characteristics between experiments, exposure durations were also different. In each of the experiments discussed in this chapter, exposure duration was adjusted for each subject individually in order to ensure that performance was in the midrange of the performance scale (56.25% correct). However, ensuring that the overall level of performance was the same between experiments, meant that average exposure durations were not necessarily the same between experiments. To examine this, mean exposure durations were compared between experiments, together with a comparison of overall levels of accuracy.

A Kruskal-Wallis one-way analysis of variance by ranks showed that there was no difference in overall percentage of correct report between the three experiments ($H=1.61$, $p>.30$). Thus, comparisons between these experiments were not confounded by scaling effects. A Kruskal-Wallis one-way analysis of variance by ranks showed that there was no significant difference between mean exposure durations in Experiments 3-5 ($H=5.19$, $p>.05$), indicating that the differences in the pattern of performance between experiments was not confounded with differences in mean exposure duration either.

## The role of lateral interference in arrays without middle letters

The results of Experiments 1 and 2 showed that when middle letters were replaced with blank spaces, or when mask boundaries extended beyond the boundaries of target arrays, the exterior-letter advantage did not disappear. Thus, neither the imbalance in the number of immediately flanking distractors for interior letters and exterior letters, nor the effects of mask configuration could account for the exterior-letter advantage in complete 7-letter arrays. Nevertheless, the exterior-letter advantage was larger in complete target arrays than in gapped target arrays, and the exterior-letter advantage was larger with A-masks than with W-masks. Thus, the number of flanking distractors for interior letters and exterior letters, and the width of masks relative to the width of target arrays did have an effect on the exterior-letter advantage.

The exterior-letter advantage was investigated further in Experiments 3-5, which were discussed in Chapter Four. In particular, the results of Experiment 4 indicated that nontarget letter-pairs, presented on the opposite side of the fixation point relative to the target, played a crucial role in the exterior-letter advantage in gapped arrays. More specifically, when nontarget letter-pairs were replaced with blank spaces no exterior-letter advantage was observed that could not be accounted for by the effects of flanking mask contours. However, the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays is still not clear. Therefore, Experiments 6 and 7 investigated the role of nontarget letter-pairs in this version of the exterior-letter advantage further.

In addition, even though there was no significant exterior-letter advantage when nontarget letter-pairs were replaced with blank spaces, exterior letters were still reported slightly more accurately than interior letters. In the absence of any other factors determining performance, the visual acuity gradient would predict that exterior letters are reported less accurately than interior letters, because they occupy more eccentric locations in the visual field. Thus, even for single letter-pairs, presented unilateral to the fixation point, other factors than the visual acuity gradient may have played a role in the relative perceptibility of interior letters and exterior letters. Therefore, relative perceptibility of interior letters and exterior letters in 2-letter arrays was examined more closely in Experiment 8.

## Experiment 6

Even though the results of Experiment 4 indicate a crucial role for letters on the opposite side of the fixation point relative to the target for the exterior-letter advantage in gapped arrays, the precise nature of this role is not clear. However, in previous discussions of the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays, the possibility that interior letters suffered more lateral interference from nontarget letter-pairs than exterior letters was thought to be unlikely. Indeed, if lateral interference from nontarget letter-pairs caused the exterior-letter advantage, the spatial extent of this interference far exceeds the limits for the spatial extent of lateral interference suggested by previous research (e.g., Bouma, 1970; Strangert & Brännström, 1975; Wolford & Chambers, 1983). For example, Bouma (1970) suggested that lateral interference should no longer affect performance if target letters and distractor letters are separated by more than half the visual angle that exists between the point of fixation and the position of the target letter. In the present study the position of left and right interior letters fell approximately $0.58^{o}$ of visual angle adjacent to the fixation point, which means that, according to Bouma's rule, no effects of lateral interference should have been observed when the distance between targets and distractors exceeded approximately $0.29^{o}$ of visual angle. In fact, the distance between interior letters on either side of the fixation point was approximately $0.94^{o}$ of visual angle. Other investigators have reported effects of lateral interference with separations of up to $1^{o}$ of visual angle (e.g., Eriksen & Hoffman, 1972), but these effects were obtained with target stimuli presented further away from the fixation point than in the present study. As it has often been demonstrated that the spatial extent of lateral interference increases with increasing eccentricity of the target stimuli (Banks, Bachrach & Larson, 1977; Banks & White, 1984; Bouma, 1970; Wolford & Chambers, 1984), estimates obtained with more eccentric stimuli may not predict the spatial extent of lateral interference present in the type of stimuli used here.

However, even though the possibility that interior letters suffered more lateral interference from nontarget letter-pairs than exterior letters seems unlikely, it cannot be excluded beforehand either. Indeed, even though interior letters and exterior letters of gapped arrays were both immediately flanked by blank spaces, interior letters were still closer to nontarget letter-pairs than exterior letters. Thus, if letters on one side of the gap suffered lateral interference from letters on the other side of the gap, it would seem likely that interior letters would be affected more by this interference than exterior letters. Therefore, it is appropriate to investigate the possibility that the exterior-letter advantage may have been caused by lateral interference from nontarget letter-pairs.

In order to investigate the role of lateral interference in the exterior-letter advantage in gapped arrays, the size of the gap between letter pairs on either side of the fixation point was varied between two and five letter-spaces (i.e., between approximately $0.65^{o}$ and $1.52^{o}$ of visual angle). If lateral interference between letter pairs was a factor in arrays with three blank letter-spaces (i.e., $0.94^{o}$ of visual angle) in the middle, it may seem reasonable to assume that varying gap size between two and five letter-spaces should have an effect on performance, as lateral interference from nontarget letter-pairs should be stronger with narrow gaps than with wide gaps. Furthermore, from previous findings concerning the effects of lateral interference from middle letters on performance for interior letters and exterior letters, it seems likely to expect that, if the exterior-letter advantage in gapped arrays was caused because interior letters suffered more lateral interference from nontarget letter-pairs than exterior letters, the exterior-letter advantage should be larger with narrow gaps than with wide gaps. That is, when middle letters of complete arrays were replaced with blank spaces, accuracy of report for interior letters was higher in gapped arrays than in complete arrays, but no difference in accuracy of report for exterior letters was observed. When these results were discussed, it was suggested that middle letters provided lateral interference for interior letters, but not for exterior letters. When middle letters were replaced with blank spaces, the amount of lateral interference suffered by interior letters would have dropped, which may explain the difference in the size of the exterior-letter advantage in complete and gapped arrays.

When this finding was discussed in Chapter Three, it was suggested that exterior letters did not suffer lateral interference from middle letters either because the spatial extent of lateral interference was less than the distance between middle letters and exterior letters, or because lateral interference was blocked by interior letters. However, if lateral interference from nontarget letter-pairs played a role in the exterior-letter advantage in gapped arrays, the first possibility seems unlikely. That is, if lateral interference from nontarget letter-pairs played a role in the exterior-letter advantage in gapped arrays, the spatial extent of this lateral interference should have been at least $0.94^{\circ}$. The distance between exterior letters and the nearest middle letter in complete arrays was only $0.34^{\circ}$. Therefore, if interior letters suffered lateral interference from nontarget letter-pairs, the second possibility seems the more likely. Furthermore, if interior letters blocked lateral interference from middle letters, such that exterior letters wee not affected when middle letters were removed, it would be expected that interior letters would also block lateral interference from nontarget letter-pairs, such that exterior letters are not affected by gap size.

In summary, if lateral interference from nontarget letter-pairs played a role in the exterior-letter advantage when gaps were three letter spaces wide, it would be expected that the exterior letter advantage is larger in arrays with narrow gaps than in arrays with wide gaps. Furthermore, this increase in accuracy of report should be matched mainly by a decrease in the number of intrusion errors, as a release of interference should increase the perceptibility of letters in the array (see previous discussion in Chapter Two).

To test this prediction about the effect of lateral interference from nontarget letter-pairs, the effects of gap size were examined by varying the distance between letters on either side of the fixation point. To avoid any effects of the retinal position, only the position of nontarget letter-pairs was varied, while the position of target letter-pairs was held constant. Thus, while target letter-pairs were presented in the same positions as in the previous experiments, the size of the gap between letters on either side of the fixation point varied according to the position of nontarget letter-pairs. Taking the gapped arrays used in the previous experiments as a starting point, nontarget letter-pairs were either moved one letter space position towards the fixation point, held in the same position, or moved one or two letter spaces towards the periphery. Thus, four different gap sizes were produced: gaps between letters on either side of the fixation point spanned two, three, four and five letter-spaces (approximately $0.65^{o}$, $0.94^{o}$, $1.23^{o}$ and $1.52^{o}$ of visual angle). An example of arrays in each of the gap size conditions is presented in Figure 5.1.

However, varying the position of nontarget letter-pairs, while keeping the position of target letter-pairs fixed may introduce another potentially confounding factor. That is, from the position of letter pairs in the visual field, subjects may deduce which pair contains the target letter before the bar-probe is presented. The position of letter pairs may be a particularly obvious cue in the largest gap size condition, in which the offset of nontarget letter-pairs is largest, while, in contrast, the offset of nontarget letter-pairs was less in the other gap size conditions. This would mean that in one condition a decision can be made about the relevance of letters in the display for

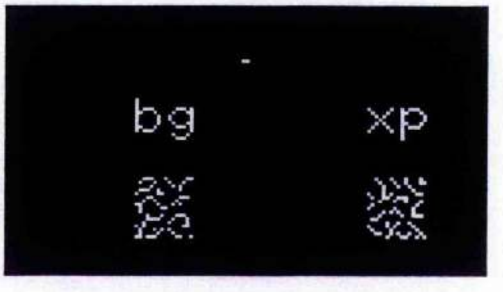
**Figure 5.1a.** An example of target stimuli for each of the gap size conditions in Expriment 6. Letters left of the fixation point are tested in test trials, while letters right of the fixation point are tested in filler trials.

## EXPERIMENT 6


**2-LETTER GAP**


**3-LETTER GAP**


**4-LETTER GAP**




**5-LETTER GAP**

**Figure 5.1b.** An example of target stimuli for each of the gap size conditions in Expriment 6. Letters right of the fixation point are tested in test trials, while letters left of the fixation point are tested in filler trials.

## EXPERIMENT 6


**2-LETTER GAP**


**3-LETTER GAP**


**4-LETTER GAP**


**5-LETTER GAP**

performance in the task on the basis of its position only, while in another condition such a decision can only be made on the basis of the bar-probe presented in the response display. Therefore, test trials were randomly interspersed with filler trials, in which members of the shifted letter pairs were probed for report. Thus, on any particular trial, all the letters in the target stimulus could potentially be tested, and as subjects were not informed about the difference between test trials and filler trials, the possibility that the position of letter pairs, relative to the fixation point, could function as a simultaneous cue towards the position of the target, may have been avoided.

Finally, if lateral interference between letters on either side of the fixation point plays a role in the exterior-letter advantage, the effect of lateral interference should be strongest in the 2-letter gap condition and weakest in the 5-letter gap condition. Therefore, the effects of lateral interference should be most apparent if performance in the two most extreme gap conditions is compared. Therefore, only the data for the 2-letter and 5-letter gap size conditions were analysed. The two intermediate gap size conditions were included to make the difference in the appearance of target arrays between arrays with 2-letter gaps and arrays with 5-letter gaps more gradual. That is, nontarget letter-pairs were presented slightly closer to the fixation point than target letter-pairs in the 2-letter gap size condition while nontarget letter-pairs were presented substantially further away from the fixation point than target letter-pairs. Conceivably, this difference between arrays in the most extreme gap size condition may induce different processing strategies. By including the intermediate gap size conditions the difference between the most extreme gap size conditions may have been less striking.

**Method**

*Subjects.* 16 subjects from the same population as Experiment 1-5 participated in two 1-hr sessions in Experiment 6.

*Stimuli.* Stimuli were constructed by randomly selecting four letters from the same letter set used in Experiment 1 (i.e., b, d, f, g, h, n, p, q, t, v, x, z), the only constraints being that letters did not occur twice in any one test stimulus, and that each of the letters occurred in each of the positions an equal number of times. For each subject a different stimulus set was constructed. Each stimulus set contained 48 test stimuli.

A preliminary experiment showed that near perfect scores could not be avoided when unmasked displays were used. Therefore, to avoid ceiling effects, for each trial a different mask was constructed. Only one mask configuration was used in this experiment; all target displays were followed by GA-masks which covered the location of each letter pair (see Figure 5.1).

*Visual Conditions.* The stimuli were presented in essentially the same way as in Experiment 3. That is, two letters on each side of the fixation point. However, four different gap sizes were produced by varying the position of nontarget letter-pairs, while keeping the position of target letter-pairs fixed. Four different separations between target letter-pairs and nontarget letter-pairs were used; gaps were either two, three, four, or five letter spaces wide. Consequently, distance between letter pairs was $0.65^{o}$, $0.94^{o}$, $1.23^{o}$ and $1.52^{o}$ of visual angle for gaps of two, three, four and five letter-spaces, respectively.

Masks were adjusted according to the size of the gap between the letter pairs, such that mask contours always overlaid the positions of the letters in the target (see Figure 5.1).

As in all the experiments reported previously in this thesis, dashes indicated the position of each letter in the target display, including the positions of the letters in the nontarget letter-pairs. The position of dashes marking the position of members of nontarget letter-pairs was adjusted according to the position of nontarget letter-pairs in the display.

*Design.* Each of the stimuli were shown 4 times in the test trials, and 4 times in the filler trials in a total of 384 trials divided over two sessions. Each session was divided into two sections (practice and test) with no obvious transition between the two.

Each letter of the target stimuli was tested once in a test trial and once in a filler trial.

*Procedure*. Throughout the practice and experimental sections exposure durations were re-assessed after each cycle of 32 trials (including each combination of target position, gap size in test trials and filler trials), and were adjusted if performance in the *test trials* differed substantially from 56.25% correct. For each of the subjects an average exposure duration of the test stimulus was calculated from the exposure durations set at the start of each 32-trial cycle in the test section. Average exposure duration over all subjects was 24.8 ms. All remaining aspects of this experiment were identical to those of Experiment 3.

**Results and discussion**

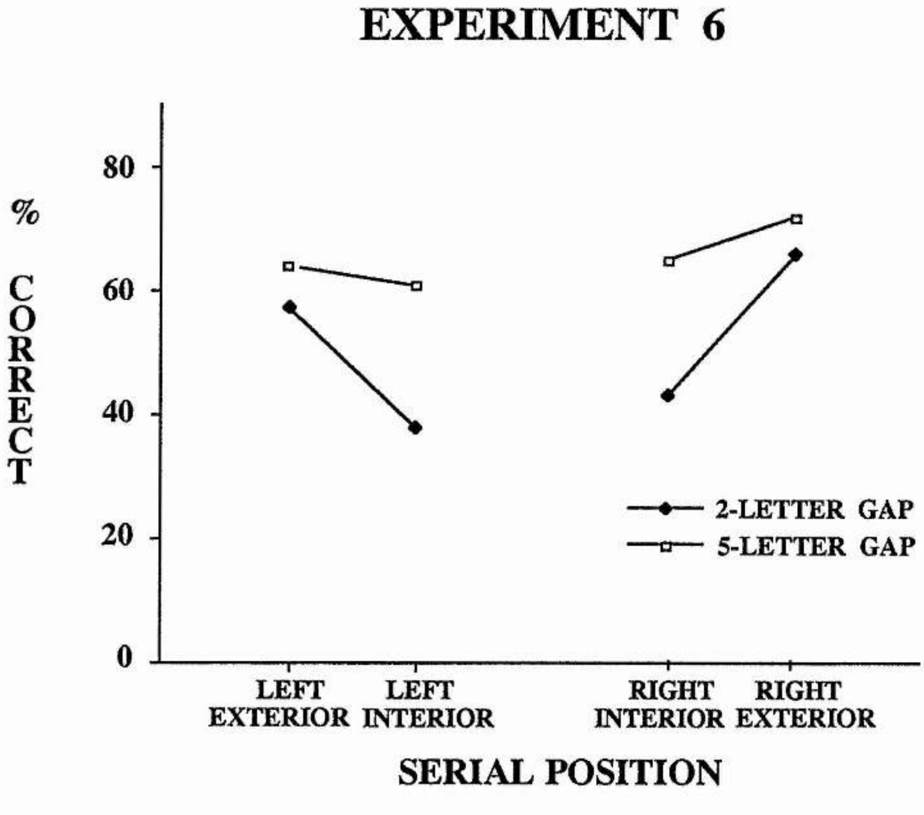
The purpose of Experiment 6 was to examine the importance of the size of the gap between letters on either side of the fixation point on the perceptibility of interior and exterior letters in arrays without middle letters. Conclusions about the role of gap size can be drawn only from data obtained in test trials, in which the location of targets in the visual field was independent of the size of the gap. Therefore, only the data obtained in those trials will be considered here. Nevertheless, the data from filler trials will be discussed briefly in the introduction to Experiment 8.

*Correct reports*

The data for correct reports in Experiment 6 are presented in Figure 5.2. Percentage correct reports overall gap size conditions was 57.8%. The data for correct reports were submitted to an analysis of variance for factorial design with two within-subjects factors (gap size and serial position).

The effect of gap size was highly significant [$F(1,15)=25.64$, $p<.001$], but the effect of serial position just failed to reach significance [$F(1,15)=2.57$, $p=.066$]. In addition, the interaction between these two factors was significant [$F(3,45)=4.69$, $p=.006$].

**Figure 5.2.** Mean percentage of targets correctly reported in 2-letter gap condition and 5-letter gap condition of Experiment 6.



Newman-Keuls tests revealed that accuracy of report for interior letters was significantly better with 5-letter gaps than with 2-letter gaps ($ps < .05$). Thus, when accuracy of report for interior letters was compared between the two most extreme gap size conditions, it is clear that gap size had a considerable effect on accuracy for interior letters. There was no significant difference, however, in accuracy of report for exterior letters in arrays with 2-letter gaps and arrays with 5-letter gaps ($ps > .05$). A closer look at Figure 5.2 reveals, however, that accuracy of report for exterior letters was actually slightly lower in the 2-letter gap condition than in the 5-letter gap condition. Maybe these negative findings were induced by the fact that the percentage correct reports in each condition was based on only half the number of observations compared to previous experiments reported in this thesis. Therefore, to conclude that gap size had no effect on accuracy of report for exterior letters may be too strong. Nevertheless, gap size had a much stronger effect on accuracy of report for interior letters than on accuracy of report for exterior letters, again suggesting that the distance between targets and nontarget letter-pairs is not the only factor to determine the amount of lateral interference suffered by each letter in the array (see Chapter Three).

*The exterior-letter advantage.* As a consequence of the differential effect of gap size on accuracy of report for interior letters and exterior letters, the exterior-letter advantage was affected also by gap size. Newman-Keuls tests revealed that exterior letters were reported more accurately than interior letters in the 2-letter gap condition ($ps < .01$), but in the 5-letter gap condition no difference in accuracy of report between interior and exterior letters was observed ($p < .05$). Thus, the exterior-letter advantage observed in arrays with 2-letter gaps almost entirely disappeared when gap size was increased. Thus, the exterior-letter advantage in arrays without middle letters, observed in previous experiments, was not caused merely by the presence of nontarget letter-pairs in the target display, but depended almost entirely on the distance between targets and nontarget letter-pairs. Before any conclusion can be drawn from these effects of gap size on accuracy of report, however, the effect of gap size on location errors and intrusion errors needs to be considered.

*Error analysis*

The data for location errors and intrusion errors are shown in Figure 5.3. Only 37.9% of errors made were location errors (16.0% of all responses), while 62.1% of errors made were intrusion errors (37.9% of all responses), which suggests that performance was limited mainly by the perceptibility of letters in the array and not so much by problems of localisation.

*Location errors*. The data for location errors were submitted to an analysis of variance for factorial design with two within-subjects factors (gap size and serial position). The main effect of gap size and serial position were significant [$F(3,15)=11.52$, $p=.004$, and $F(3,45)=3.52$, $p=.022$, respectively], but the interaction between these two factors was not significant ($F<1$).

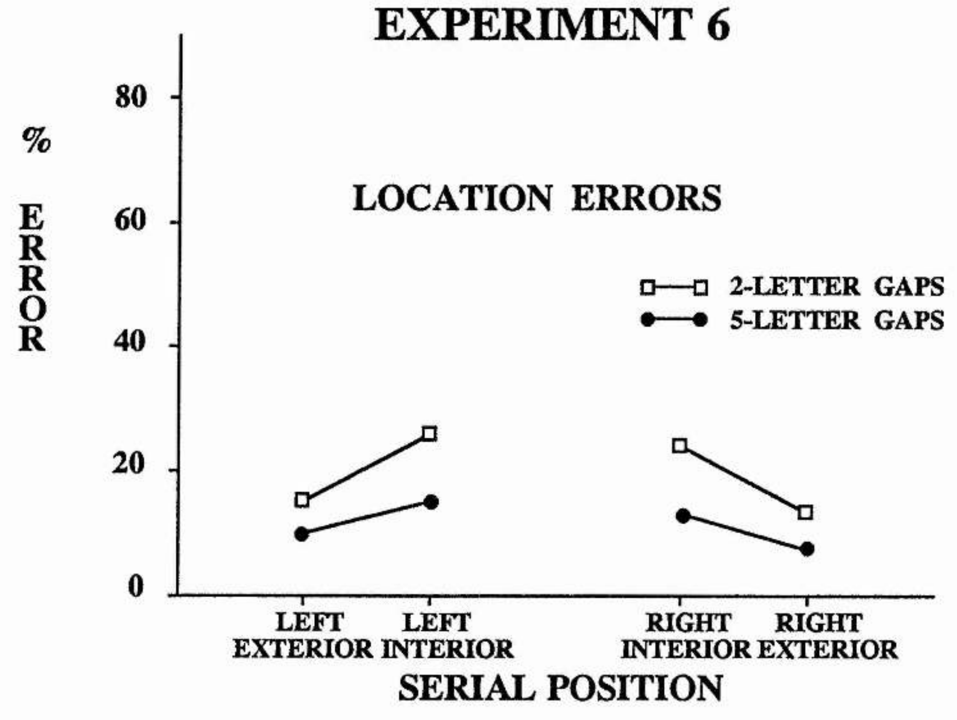
Newman-Keuls tests showed that location errors were more frequent in the 2-letter gap condition than in the 5-letter gap condition ($ps<05$), and location errors were more frequent for interior than for exterior target positions ($ps<05$).

*Intrusion errors*. The data for intrusion errors were submitted to an analysis of variance for factorial design with two within-subjects factors (gap size and serial position). The effect of gap size was significant [$F(3,15)=5.28$, $p=.003$], but the effect of serial position was not significant ($F<1$). The interaction between these two factors also reached significance [$F(3,45)=3.00$, $p=.041$]. Newman-Keuls tests showed that no relevant comparisons reached significance ($ps>05$).

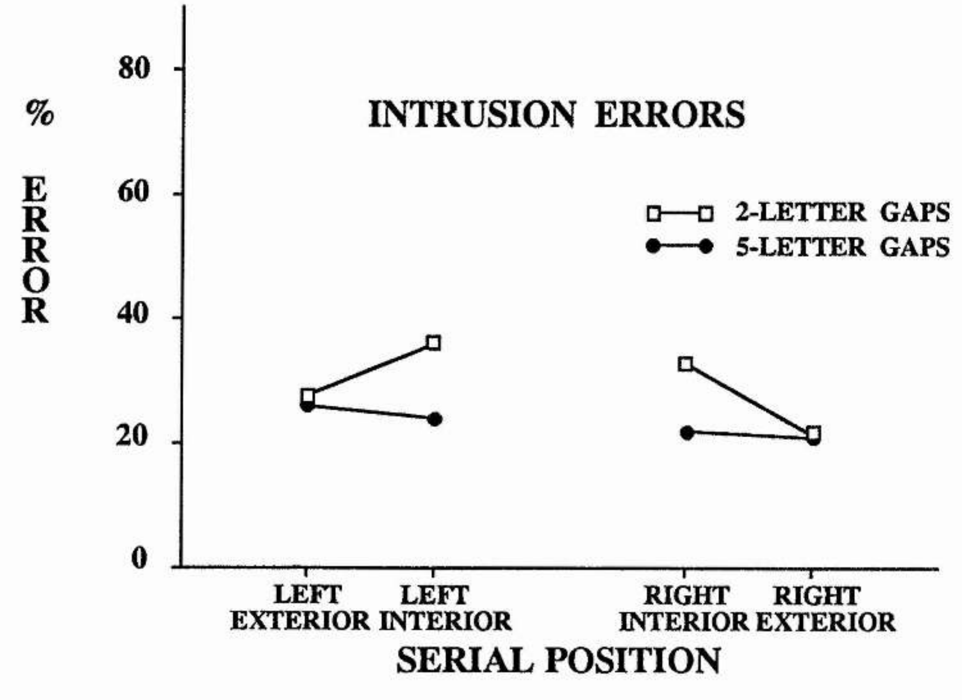
Thus, while the number of location errors varied almost equally for interior and exterior positions as gap size was varied, gap size affected the frequency of intrusion errors for interior positions but not for exterior positions. Moreover, the small difference in accuracy of report for exterior letters was matched almost entirely by location errors and not by intrusion errors. Although it is not clear what this difference in the effects of gap size on location errors and intrusion errors signifies, it may be that

**Figure 5.3.** Mean percentages of (a) location errors and (b) intrusion errors for interior and exterior positions in the widest and narrowest gap size condition of Experiment 6.

(a)




(b)



positional uncertainty for interior letters was slightly larger in arrays with 2-letter gaps than in arrays with 5-letter gaps. Therefore, interior letters may have supplied more location error responses in the 2-letter gap condition than in the 5-letter gap condition in cases when exterior letters were not correctly identified. Nevertheless, the effect of gap size on intrusion errors supports the conclusion that interior letters suffered more lateral interference than exterior letters because it suggests that interior letters were less perceptible in arrays with small gaps than in arrays with 5-letter gaps.

The frequencies of location error responses provided by each of the nontarget positions, in arrays with 2-letter gaps and arrays with 5-letter gaps, are listed in Table 5.1. When exterior positions were probed for report, gap size did not affect the position of location error responses ($\text{chi-square}_{(2)}=5.05$, $p>.05$). When interior positions were probed for report, however, exterior members of nontarget letter-pairs supplied relatively more location error responses in the 5-letter gap condition than in the 2-letter gap condition ($\text{chi-square}_{(2)}=8.38$, $p<.05$). Thus, the results of the analysis provide no indication that gap size had an effect on spatial uncertainty for interior or exterior members of target letter-pairs. The effect of gap size on the frequency of location error responses for exterior members of nontarget letter-pairs is surprising, but could be explained if it is considered that nontarget letter pairs occupied more eccentric locations in the 5-letter gap condition than in the 2-letter gap condition. This difference in the location in the visual field of nontarget letter-pairs may have increased positional uncertainty for both interior members and exterior members of nontarget letter-pairs. When interior letters of target letter-pairs were not correctly identified, exterior members of nontarget letter pairs may have been given as a response rather than interior members, since the position of target letters and supplied response letters was the same relative to the other member of the pair. That is, interior members of target letter-pairs and exterior members of nontarget letter-pairs were both positioned on the same side of the letter pair of which they are a member. Indeed, when exterior letters were tested, a similar increase in the relative frequency that interior members of

**Table 5.1**. Frequencies of location error responses supplied by each of the serial positions in Experiment 6. Flanking response positions are the positions immediately adjacent to the target position, Interior (opposite side) and Exterior (opposite side) response positions are the interior and exterior positions, respectively, at the opposite side of the fixation point relative to the target position. Note that only 16% of the total number of responses were location errors.

| *Test Position* | *Gap Width* | *Response Position (relative to test position)* | | |
|---|---|---|---|---|
| | | Flanking | Interior (opposite end) | Exterior (opposite end) |
| Interior | 2-letter gaps | 41 | 23 | 28 |
| | 5-letter gaps | 16 | 7 | 28 |
| Exterior | 2-letter gaps | 25 | 23 | 6 |
| | 5-letter gaps | 7 | 22 | 4 |

nontarget letter-pairs supplied location errors was apparent, although this difference between gap size conditions did not reach significance. Thus, it may be that confusions about the position of letters in the display are facilitated if the position relative to the other member of the letter pair is the same for the true position and the confused position (cf. Allport, 1977; Duncan, 1987; Mozer, 1983; Treisman & Schmidt, 1982; Treisman & Souther, 1986).

Three conclusions about the role of nontarget letter-pairs in the exterior-letter advantage may be drawn from the results of Experiment 6. First, before this experiment was conducted, it was suggested that, if lateral interference from nontarget letter-pairs affected accuracy of report for interior letters of gapped arrays in Experiments 2 and 3, it would be expected that accuracy of report for interior letters should be affected by changes in the size of gaps in gapped arrays. The results of Experiment 6 show that this was indeed the case, indicating that interior letters in gapped arrays suffer lateral interference from nontarget letter-pairs. More specifically, the effect of gap size on accuracy of report for interior letters indicates that interior letters suffered more lateral interference when gaps were narrow than when gaps were wide. This was further supported by the effect of gap size on intrusion errors

The second indication is derived from the finding that the effect of gap size was observed mainly with interior letters. The finding that lateral interference from nontarget letter-pairs affected performance in gapped arrays would be sufficient to explain the exterior-letter advantage, just on the basis that the distance between interior letters and nontarget letter-pairs is smaller than the distance between exterior letters and nontarget letter-pairs. However, the difference in the effect of gap size for interior letters and exterior letters indicates that absolute distance between targets and nontarget letter-pairs is not the only factor deciding how letters are affected by lateral interference. More specifically, the position in the array appeared to be a crucial factor in deciding whether letters would suffer lateral interference from nontarget letter-pairs; interior letters suffered more lateral interference than exterior letters, even when the absolute distance from nontarget letter-pairs was equated for letters in each position.

In Chapter Three, and in the introduction to this experiment the importance of relative position was introduced as a possible explanation for the finding that middle letters had no effect on performance for exterior letters in Experiment 2. The possibility that lateral interference from distractors does not affect targets when intermediate letters are shown, was presented as an alternative to the suggestion that middle letters did not affect exterior letters because the spatial extent of lateral interference was less than one letter space. The finding that lateral interference from nontarget letter-pairs may affect interior letters across four letter spaces suggests that a limit in the spatial extent of lateral interference to less than one letter space in Experiment 2 is unlikely.

Nevertheless, even though the results of Experiment 6 suggest that the spatial extent of lateral interference from nontarget letter-pairs was not restricted to less than one letter space, they do not allow any conclusions about the role of intervening letters on the effect of lateral interference between targets and distractors. Indeed, it may be that exterior letters were not affected by lateral interference for the simple reason that they are the exterior letters positioned at the exterior boundaries of linear arrays. In that case it may be that lateral interference does stretch across intermediate letters if the target is a letter in the interior of a linear letter array. Unfortunately, however, on the basis of the available data do it is impossible to decide between these hypotheses.

Finally, the finding that the exterior-letter advantage in arrays with 4-letters gaps almost entirely disappeared when gap size was increased to five letter spaces, suggests that lateral interference from nontarget letter-pairs played a crucial role in the exterior-letter advantage. More specifically, if interior letters still suffered lateral interference from nontarget letter-pairs, this interference was not strong enough to create an exterior-letter advantage.

Thus, the results of Experiment 6 suggest that lateral interference from nontarget letter-pairs plays a crucial role in the exterior-letter advantage in gapped arrays. However, if that is the case, the spatial extent of this lateral interference is unusual. Indeed, in the introduction to this experiment it was argued that the size of the gap between letters on either side of the fixation point exceeds any estimations about the limits of the spatial extent of lateral interference suggested by previous research (see the introduction to Experiment 6). In particular, Bouma's rule for the relationship between eccentricity of the target and the spatial limit of lateral interference suggests that no interference should be found from distractors presented at a distance of more than $0.29^{o}$ of visual angle away from interior letters. Nevertheless, the results of Experiment 6 suggest that interior letters still suffered lateral interference from nontarget letter-pairs when the distance between interior letters and nontarget letter-pairs was $0.94^{o}$ (the distance between letter pairs in gapped arrays used in Experiments 2 and 3). How then could this apparent discrepancy in the observed spatial extent of lateral interference between the present study and Bouma's (1970) study be explained? To answer this question we have to look at the type of displays that have been used to derive these estimates, and, in particular, at the arrangement of the letters in these displays. Bouma (1970) derived his estimate for the spatial extent of lateral interference by presenting a target letter embedded in distractor letters which were separated from the target letter by various numbers of blank letter-spaces. The minimum distance between target and distractor letters at which the target letter was reported as accurately as targets presented alone was taken as the limit of the spatial extent of interference from distractor letters. Specifically, in Bouma's (1970) procedure, when the number of blank letter-spaces was increased between distractors and target, this was done simultaneously for both distractors, such that both distractors maintained the same distance from the target. In the present study, target letters were always immediately flanked by the other member of the target letter-pair, while only the distractor letters in the nontarget letter-pair were presented across a gap exceeding the size of the space between immediately flanking letters. This difference in the arrangement of distractor letters between Bouma's (1970) study and the present study may mean that Bouma's rule does not have much predictive value for the effects of lateral interference in the type of displays used in the present study.

However, even though the discrepancy between the estimate of the spatial extent of lateral interference suggested by Bouma (1970) and the distance over which effects of lateral interference have been found in the present study could be explained by differences in stimulus characteristics, this needs clarification. Therefore, the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays is investigated further in Experiment 7.

## Experiment 7

Experiment 7 investigated whether the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays, is restricted to pairs of letters. The results of Experiment 5 indicate that pairs of ampersands presented on the opposite side of the fixation point relative to the target did not have the same effect as pairs of letters. In particular, there was no significant difference between interior letters and exterior letters in accuracy of report, when ampersands were presented on the opposite side of the gap. Furthermore, although the effects of mask configuration on performance in Experiment 5 were not entirely similar as with displays containing single letter-pairs, they were not the same as in displays with both target letter-pairs and nontarget letter-pairs either. Thus, the exterior-letter advantage in gapped arrays and the effects of mask configuration observed in Experiment 3 may be specific to linear *letter* arrays.

The difference in the effects of nontarget letter-pairs and ampersands may indicate that the lateral interference from nontarget letter-pairs suffered by interior letters was not the result of interactions at the feature extraction stage of processing. According to the feature interaction account of lateral interference, the letter positions may be assumed to represent parallel input channels, leading to feature detectors signaling the presence of particular features for each letter in the display (see Chapter Two). These parallel input channels may interact, however, when letters are presented in close proximity to other letters, and these interactions may slow down the rate of processing of the letters involved (Estes, 1972, 1978; Wolford, 1975). Estes (1978, p.184) put it like this: "if a letter and another patterned stimulus occur either successively and in the same location or simultaneously and spatially close together ..., then the central processor has the additional problem of determining which of the contours should be encoded together to form a representation of the target, and which should be interpreted as constituents of another stimulus or dismissed as part of the background". According to this description of feature interactions, it would seem reasonable to assume that ampersands should exert the same effects of lateral interference as nontarget letter-pairs. Thus, the difference in the effects of ampersands and nontarget letter-pairs may indicate that the lateral interference created by nontarget letter-pairs in gapped arrays was not caused by feature interactions between letters on either side of the fixation point.

Indeed, it has already been noted in Chapter Three, that an advantage for characters in exterior positions over characters in interior positions appears to be specific to linear multi-letter arrays, as it has not been found in linear arrays of nonsense (letter-like) characters (e.g., Greek characters, or nonsense characters made up of letter features; Hammond & Green, 1980; Mason, 1982; Mason & Katz, 1976). However, Mason (1982) also found an advantage for digits in the end positions in linear arrays of digits, similar to the exterior-letter advantage in letter arrays. Mason (1982), therefore, suggested that the exterior-letter advantage might be due to processes unique for any type of linear multi-character arrays in which the individual characters can combine to form higher level units. "The initial and final elements of both letter and digit arrays are salient in that they indicate word length for letters and magnitude for digits" (Mason, 1982, p. 737). The processes suggested by Mason (1982) may have contributed to the exterior-letter advantage in gapped arrays. However, when nontarget letter-pairs were replaced with ampersands, these processes could not contribute to the exterior-letter advantage, which may explain the absence of an exterior-letter advantage in the GA-mask condition of Experiment 5.

However, the difference between nontarget letter-pairs and pairs of ampersands was not restricted to the possibility that in combination with target letter-pairs higher level units would be formed as suggested by Mason (1982). For example, ampersands may contain only a few features in common with letters, which would make them easily distinguishable from letter pairs (cf. Duncan & Humphreys, 1989). Furthermore, pairs of ampersands may form a perceptual group more readily than nontarget letter-pairs which contained different combinations of twelve different letters. These differences between nontarget letter-pairs and pairs of ampersands may account for the absence of an exterior-letter advantage in the GA-mask condition of Experiment 5.

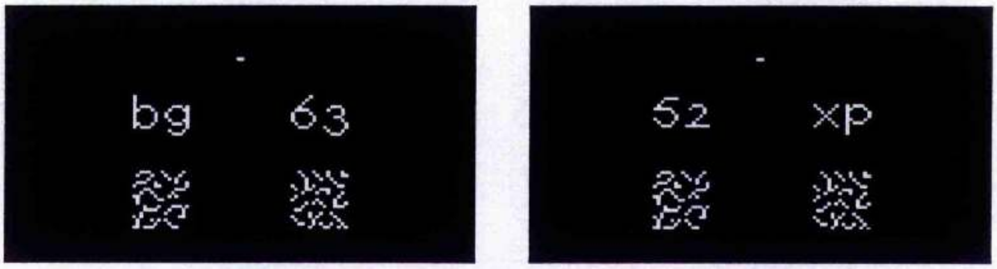
Therefore, a role of top down processes as suggested by Mason (1982) was examined further in Experiment 7. In Experiment 7, letters on one side of the fixation point of gapped arrays were replaced with a pair of digits. Such an array would have a letter in the exterior position on one end of the array, and a digit on the other end. If a letter pair on one side of the fixation point and a digit pair on the other side form a single unit, exterior characters would have no special significance in the sense of word length in words, or magnitude in numbers. Therefore, if the combination of exterior characters into a single higher level unit as suggested by Mason (1982) contributed to the exterior-letter advantage in gapped letter-arrays, no exterior-character advantage should be observed in arrays made up of letter pairs and digit pairs, as was the case in arrays with letters and ampersands. However, digits are probably more similar to letters than ampersands, digits, like letters but unlike ampersands, are often encountered in linear arrays, and digits are probably more familiar than ampersands. Furthermore, digit pairs contained different combinations of digits and, therefore, they are less likely to form a perceptual group than pairs of ampersands. If the differences between nontarget letter-pairs and pairs of ampersands listed above affected the exterior-letter advantage, it may be that these differences between character pairs on either side of the fixation point are overcome if pairs of digits were presented instead of pairs of ampersands. If that is the case, an exterior-letter advantage should be obtained in Experiment 7. Examples of arrays with letter-pairs on one side and digit-pairs on the opposite side of the fixation point are shown in Figure 5.4.

In addition to examining the influence of processes specific for higher level units as suggested by Mason (1982), Experiment 7 was conducted also to examine another hypothesis about the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays. In particular, Eriksen and Hoffman (1972; see also Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979) suggested that the amount of interference suffered by a single target from a distractor presented simultaneously in the target display depends on the amount of processing received by each of the distractors. Eriksen and Hoffman (1972) found that the amount of interference suffered by a target presented $2^{o}$ of visual angle from the fixation point decreased when distractor letters were moved away from the target, until no interference was found for targets with separations of more than $1^{o}$ of visual angle. Furthermore, they found a larger decrease in the amount of lateral interference suffered by targets, and a smaller spatial extent of lateral interference when black disks were used as distractors instead of letters. Eriksen and Hoffman explained this effect of spacing by arguing that, when the target is in the focus of attention, distractors receive less processing the further they are away from the target. In addition, according to this account of lateral interference, black disks would produce less interference because their physical dissimilarity with the target, and perhaps the lack of information content, would make it easier to exclude them from further processing after the initial processing stages.

This explanation, suggested by Eriksen and Hoffman (1972) to account for the difference in interference provided by letters and black disks, may also account for the role of nontarget letter-pairs in the exterior-letter advantage in gapped arrays. The difference in the effects of nontarget letter-pairs and ampersands could be explained

**Figure 5.4.** Examples of target stimuli and an example of the mask stimuli used in Experiment 7. Letters are tested in letter target trials, while digits are tested in digit target trials.

## EXPERIMENT 7



according to Eriksen and Hoffman's suggestion, if it is assumed that ampersands received less processing than nontarget letter-pairs, possibly because ampersands have less information value, they were never used as targets, or they were physically different to letters. In addition, the effect of spacing between target letter-pairs and nontarget letter-pairs may indicate that as nontarget letter-pairs were moved further away from the fixation point they received less processing and, therefore, produced less interference, which may explain the decrease in the exterior-letter advantage when nontarget letter-pairs were moved away from the fixation point.[1] Although it is not clear exactly why nontarget letter-pairs would receive less processing when they are presented further away from the fixation point, members of nontarget letter-pairs may have been less perceptible further away from the fixation point due to the visual acuity gradient. Therefore, subjects may have adopted a strategy which involved that letter pairs closer to the fixation point received more processing than letter pairs further away from the fixation point. Such a strategy would have particularly disadvantaged nontarget letter-pairs in the arrays with 5-letter gaps, as these were presented two letter spaces further away from the fixation point than target letter-pairs.[2]

To test the influence of processing requirements for target letter-pairs and nontarget letter-pairs in the exterior-letter advantage in gapped arrays, Experiment 7 included another manipulation in addition to the replacement of letter on one side of the fixation point with digits introduced above. There are indeed some indications to suggest that when digits are presented together with letters, either type of character may receive less processing when the other type of character is consistently probed for report, compared to when either type of character is probed for report unpredictably. For example, Merikle (1980) presented displays containing letters and digits, and

[1] Remember that nontarget letter-pairs were tested in the filler trials in Experiment 6. Therefore, the eccentricity of nontarget letter-pairs from the fixation point could not be used as a cue towards the relevance of letter pairs on either side of the fixation point in any particular trial.

[2] Remember that target letter-pairs kept their position relative to the fixation point throughout the experiment, while nontarget letter-pairs were moved closer or further away from the fixation point to achieve different gap sizes.

observed that accuracy of report was higher when subjects were instructed to report either only letters or only digits, compared to when no instruction was given. Van der Heijden (1992) argued that Merikle's results showed that an optimal expectation about relevant and irrelevant items allowed irrelevant items presented in the display to be successfully excluded from further processing after they had been categorised.

According to Eriksen and Hoffman's (1972) idea that the amount of lateral interference suffered by targets depends on the amount of processing received by distractors, digit distractors should provide less interference for letter targets in blocks of letter trials, if it is the case that in blocks of trials in which letters are tested, digits receive less processing. Similarly, letter distractors should provide less interference for digit targets in a block of digit target trials, if it is the case that in blocks of trials in which digits are tested, letters receive less processing. Unfortunately, Merikle (1980) did not use linear arrays of characters. Therefore, it is not clear whether the serial position curve, and in particular the exterior-letter advantage, was affected by the partial report instruction. However, in a bar-probe task, Styles and Allport (1986) found that the exterior-letter advantage observed in linear letter arrays, completely disappeared when single letter targets were embedded in arrays of digits. This finding of Styles and Allport (1986) suggests that lateral interference suffered by targets may indeed depend on the potential relevance of distractor characters for the task on hand.

To examine the role of predictability, subjects in Experiment 7 were divided into two groups. Subjects in one group received trials in which letters were probed for report mixed in with trials in which digits were probed for report (*mixed group*). Subjects in the other group received trials in which letters were probed for report in one block of trials, and trials in which digits were probed for report in separate block of trials (*blocked group*). Furthermore, subjects in the blocked group were informed before the start of each block of trials which type of character was going to be tested. If the exterior-letter advantage in gapped arrays is in some way related to the amount of processing received by nontarget letter-pairs, it would seem reasonable to assume that the exterior-letter advantage would depend on whether letter trials or digit trials are presented mixed or blocked, if in the blocked group, nontarget character pairs receive less processing than in the mixed group. Thus, it would be expected that in the blocked group interior characters suffer less lateral interference from nontarget character pairs in the blocked group than in the mixed group and, consequently, the exterior-character advantage should be reduced for the blocked group compared to the mixed group.

In sum, if the exterior-character advantage in gapped arrays is specific to arrays in which characters on one side of the fixation point are the same as characters on the other side of the fixation point, then an exterior-character advantage should not be observed for either the mixed group or the blocked group. On the other hand, if the exterior-character advantage in gapped arrays is caused by lateral interference related to the amount of processing received by nontarget character pairs, it may be expected that an exterior-character advantage is found in the blocked group, but not in the mixed group.

**Method**

*Subjects.* 16 subjects from the same population as Experiment 1-6 participated in Experiment 7.

*Stimuli.* For each of the subjects 48 4-character stimuli were constructed in a similar way as in Experiment 6, the only additional constraints being that each target stimulus contained two letters and two digits. Letters were selected from the letter set b,f,g,p,t, x (a subset of the letters used in Experiment 1); digits were selected from the digit set 2,3,4,5,6, 8.

*Visual Conditions.* For each trial a different postmask was constructed, but only one mask configuration was used through out the experiment; target stimuli were always immediately followed by GA-masks. Letters and digits in target stimuli were presented as if occupying positions 1, 2, 6 and 7 of a centrally presented 7-character linear array. Thus, they were similar to the arrays used in Experiment 3, except that letters were positioned together on one side of the fixation point and digits on the other side. Digits had the same horizontal and vertical dimensions as the letters (see Appendix 2).

*Design.* Of the 48 test strings, each position was probed for report once in 192 test trials; letters were tested in letter target trials and digits were tested in digit target trials. For half the subjects, digit targets trials were randomly mixed with letter target trials (mixed group) while, for the other subjects, digit target trials were presented in one half of the experiment and letter target trials in the other (blocked group). For the mixed group, the session was divided into two sections (practice and test), with letter target trials and digit target trials presented randomly in both sections. For the blocked group, the session was divided in 4 sections, such that a block of letter target test trials was preceded by a block of letter target practice trials, and a block of digit target test trials by a block of digit target practice trials. Thus, the four sections in a session for subjects in the blocked group were: letter target practice, letter target test, digit target practice, digit target test for subjects tested on letters in the first half of the experiment, and digit practice, digit test, letter practice, letter test for subjects tested on digits in the first half of the experiment. There was no obvious transition between practice sections and test sections. In the blocked group, half of the subjects started with letter target trials and the other half started with digit target trials. Assignment to digit targets or letter targets in the first section was alternated between subjects. In addition, subjects were alternately assigned to the mixed group or blocked group.

*Procedure.* At the start of each practice section in the blocked group, the words "digits" or "letters" were shown in the middle of the screen, in order to inform subjects about the type of character that was going to be tested in the block of trials that was going to follow. These words remained on the screen until the subjects pressed a key to continue with the experiment.

In both mixed and blocked targets conditions the exposure durations was adjusted separately for each type of target after 16 presentations of each.

Consequently, in the mixed group, exposure duration was adjusted after every cycle of 32 trials (16 letter target trials and 16 digit target trials), if performance for each type of target deviated substantially from 56.25% correct (see Experiment 1). In the blocked group, exposure duration was adjusted after every cycle of 16 trials (16 letter target trials or 16 digit target trials, depending on the type of character tested). All remaining aspects of Experiment 6 were identical to those in Experiment 3.

**Results and discussion**

*Correct report*

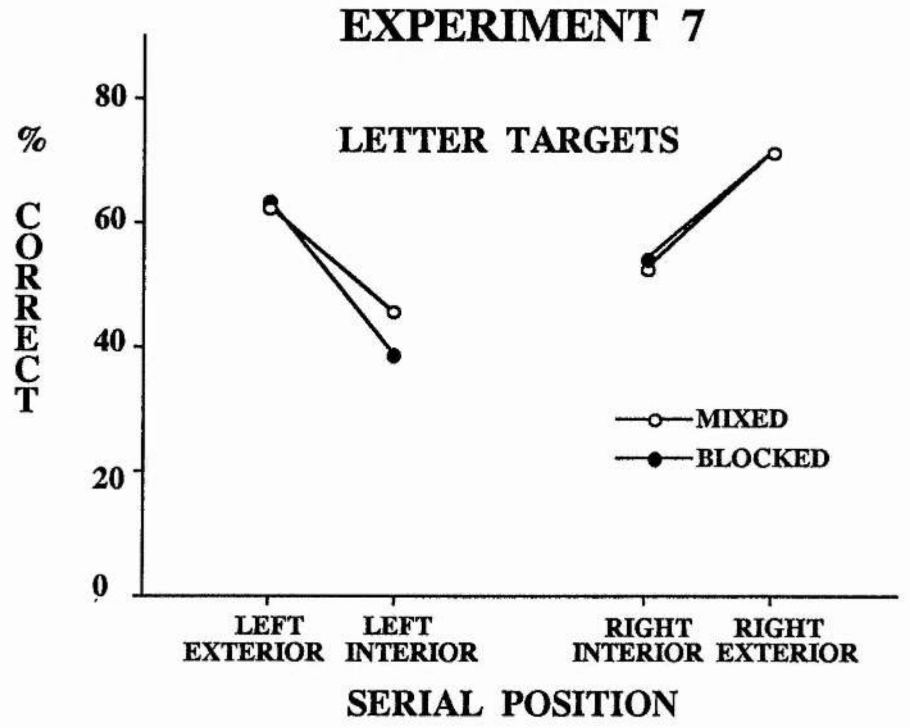
The data for accuracy of report in Experiment 7 are shown in Figure 5.5. Overall accuracy of report for letter targets was 57.4%, and for digit targets was 53.7%. The data for correct reports in Experiment 7 were submitted to an analysis of variance for mixed design, with one between-subjects factor (group; blocked or mixed), and two within-subjects factors (target type and serial position).

The effect of serial position was highly significant [$F(3,42)=11.0$, $p<.001$], and the effect of target type was marginally significant, [$F(1,14)=6.73$, $p=.021$]. None of the other effects reached significance ($p$s$>.10$). In particular the two-way interactions between group and serial position, and between target type and serial position were not significant ($F$s$<1$). Newman-Keuls tests revealed that at both sides of the fixation point characters were reported more accurately in the exterior position than in the interior position ($p$s$<.05$).

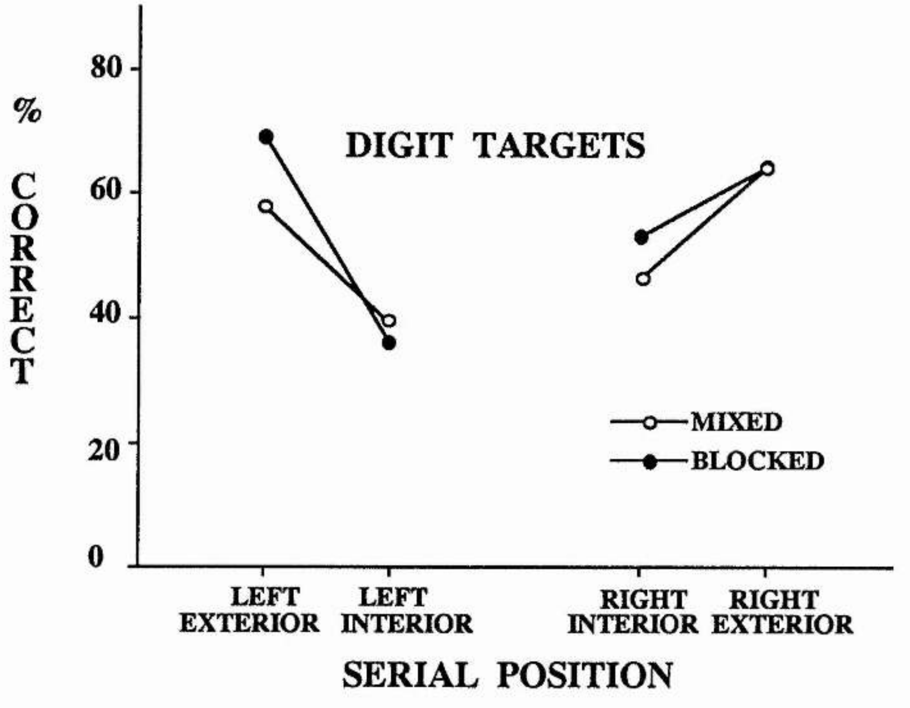
An exterior-character advantage observed with both nontarget letter-pairs and nontarget digit-pairs indicates that processes specific for single higher level unit as suggested by Mason (1982) played no crucial role in the exterior-letter advantage. Furthermore, an exterior-character advantage is not specific for letter pairs as exterior digits were reported also more accurately than interior digits. Finally, the finding that a similar exterior-character advantage was obtained in the mixed group as in the blocked group, suggests that lateral interference between characters on either side of the

**Figure 5.5.** Mean percentage of targets correctly reported for (a) letter targets and (b) digit targets in each of the serial position in the blocked and mixed presentation groups of Experiment 7.

(a)




(b)



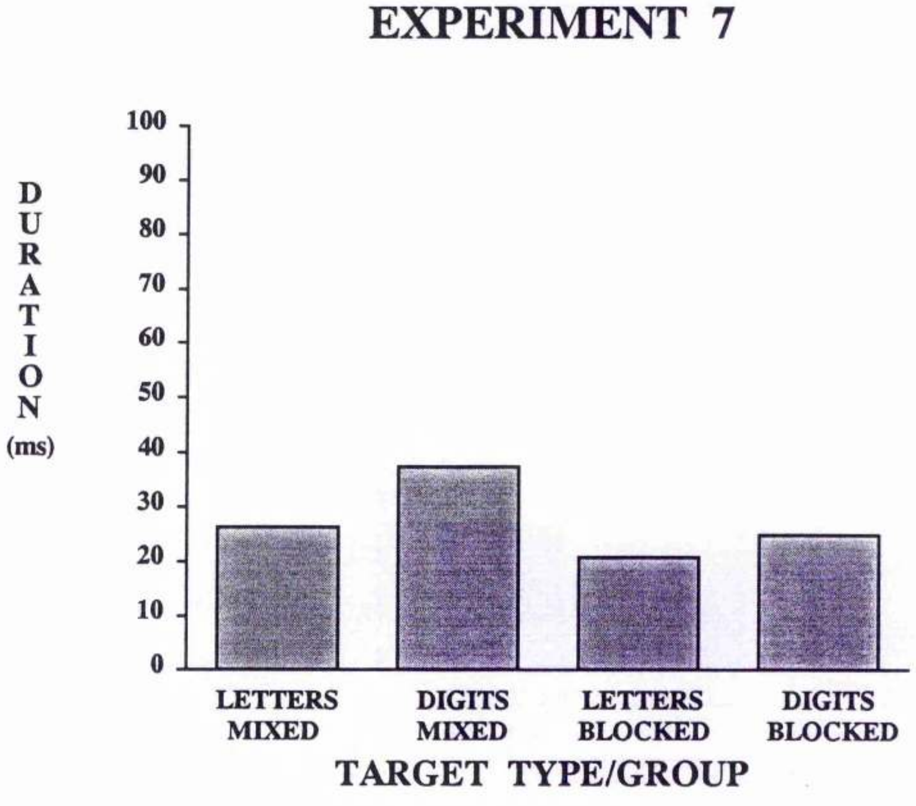
fixation point was not affected when the nontarget character pair could be excluded from processing as soon as it was categorised. However, to see if processing requirements were different for mixed presentations than for blocked presentations, the exposure durations for both groups needs to be compared.

*Exposure durations*

If the processing requirements with mixed presentations were higher than with blocked presentations, mixed letter and digit trials may have needed longer exposure durations than blocked presentations in order to maintain the desired level of accuracy. Furthermore, exposure durations were adjusted separately for letter trials and digit trials. Therefore, the data for exposure duration may reveal additional differences between groups and between target types. Average exposure durations in Experiment 7 are shown in Figure 5.6. The data for exposure duration were submitted to an analysis of variance for split-plot design, with one between-subjects factor (group) and one within-subjects factors (target type). The effect of target type was highly significant [$F(1,14)=11.51$, $p=.004$]. The effect of group and the interaction between group and target type did not reach significance [$F(1,14)=3.27$, $p=.092$, and $F(1,14)=2.34$, $p=.149$, respectively].

Figure 5.6 reveals that exposure durations were longer for digit targets than for letter targets indicating that digits were less perceptible than letters. Indeed, even though the average exposure duration was longer for digits than for letters, the analysis of accuracy of report showed that digits were still reported slightly less accurately than letters. This difference between letters and digits is easily explained, however, if it is considered that the font used for digits might have been less distinctive than the font used for letters. However, the important comparison is between average exposure duration for the blocked group and average exposure duration for the mixed group. The lack of a significant difference between these average exposure durations indicates that, although processing requirements may have been slightly higher in the mixed

**Figure 5.6.** Average exposure durations for each type of target for the mixed and blocked group.



group, blocking digit trials and letter trials had no real beneficial effect on processing requirements.

*Error analysis*

The data for location errors and intrusion errors in Experiment 7 are shown in Figure 5.7. 35.7% of errors made were location errors (15.9% of all responses), while 64.3% of errors made were intrusion errors (28.6% of all responses). The data for location errors and intrusion errors were each submitted to an analysis of variance for mixed design, with one between-subjects factor (group) and two within-subjects factors (target type and serial position).

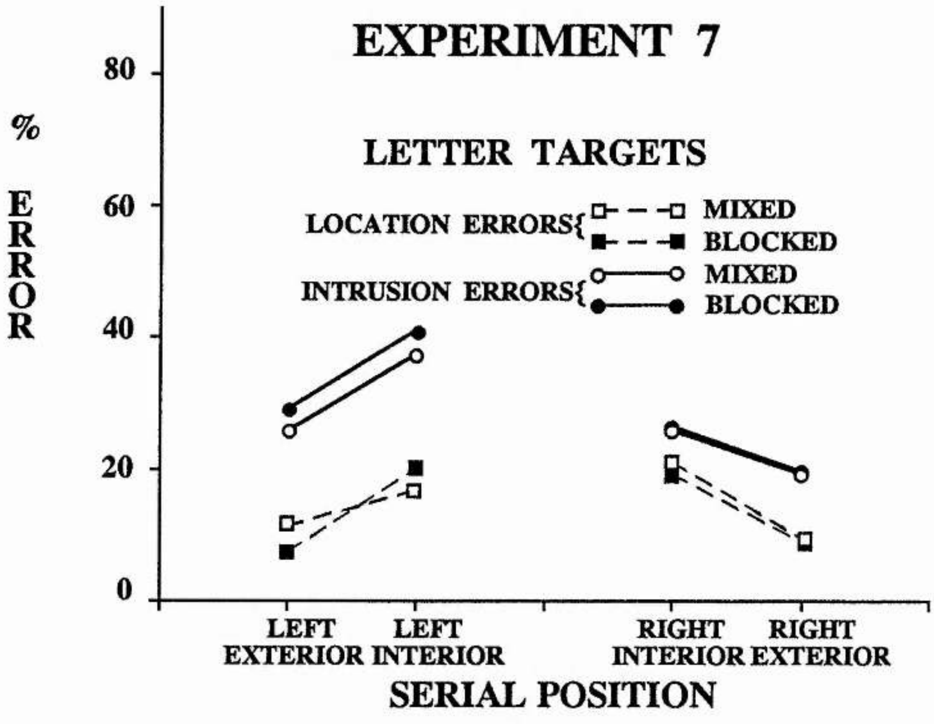
*Location errors.* The effect of serial position on the frequency of location errors was highly significant [$F(3,14)=22.73$, $p<.001$], and the effect of target type was also significant [$F(1,14)=5.55$, $p=.034$]. None of the other effects reached significance ($ps>.10$). In particular, the interaction between serial position and group was not significant [$F(1,14)=1.50$, $p=.242$]. Newman-Keuls tests for paired comparisons revealed that more location errors were made when interior positions were probed for report than when exterior positions were probed for report ($ps<.05$). Furthermore, slightly more location errors were made when the target was a digit than when it was a letter ($p<.05$).

*Intrusion errors.* The effect of serial position on the frequency of intrusion errors was highly significant [$F(3,14)=4.75$, $p=.006$]. The effect of target type was not significant ($F<1$), but the interaction between target type and serial position did reach significance [$F(3,42)=11.81$, $p=.036$]. None of the other effects reached significance ($ps>.10$). In particular, the interaction between serial position and group was not significant ($F<1$).

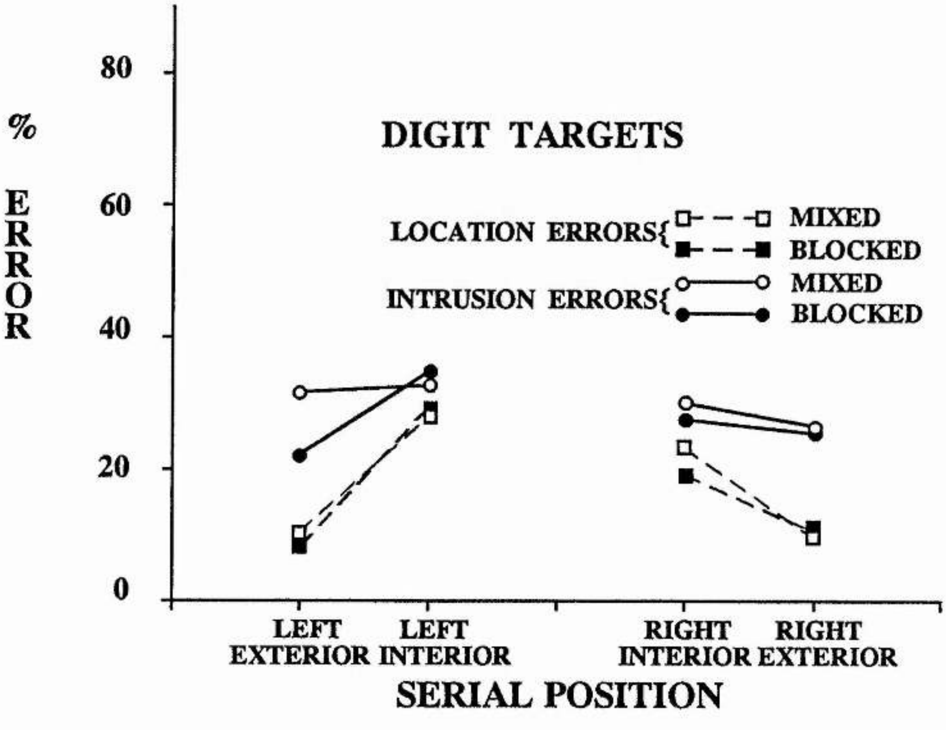
Newman-Keuls tests for paired comparisons examined the significant interaction between target type and serial position more closely. On the left of the fixation point fewer intrusion errors were made in exterior positions than in interior positions when

**Figure 5.7.** Mean percentages of (a) location errors and (b) intrusion errors for interior and exterior positions in the blocked and mixed presentation groups of Experiment 7.

(a)




(b)



letters were tested ($p < .05$), while no such difference was apparent when digits were tested. No other comparisons reached significance ($ps > .05$).

Thus, the pattern of location errors and intrusion errors was more or less the same as that for accuracy of report. That is, there was no difference in the number of location errors and intrusion errors for the mixed group and the blocked group, and for letter targets and digit targets. Location errors and intrusion errors were made when interior positions were tested than when exterior positions were tested on the left of the fixation point, although this difference between interior positions and exterior positions was less pronounced or almost nonexistent on the right of the fixation point.

Overall, the pattern of performance in Experiment 7 was very much the same as in the GA-Mask condition in Experiment 3, or the 3-letter gap condition in Experiment 6 (3-letter gaps between letter pairs and digit pairs existed in the displays used in Experiment 7). Moreover, performance appeared to be no different from what would have been expected from previous experiments reported in this paper for either mixed groups or blocked groups. From this similarity in performance, and in particular the similarity in the exterior-letter advantage, with blocked and mixed presentation and comparable conditions in previous experiments reported in this thesis, three conclusions may be drawn. First, the exterior-letter advantage is not specific to arrays with the same type of character on both sides of the fixation point. Thus, it seems that processes specific for the processing of letter arrays played no role in the exterior-letter advantage in gapped arrays. The second indication to emerge from the results of Experiment 7, is that nontarget character-pairs in the present experiment had a very different effect on performance than pairs of ampersands. More specifically, an exterior-letter advantage was obtained with nontarget letter-pairs and nontarget digit-pairs but not with pairs of ampersands. This difference in the effects of nontarget character-pairs and pairs of ampersands suggests that the physical similarity between target pairs and nontarget pairs, the familiarity of nontarget pairs, or the tendency of ampersands to form perceptual groups may have played an important role in the exterior-letter advantage in gapped arrays. Finally, the third indication to emerge from the findings of Experiment 7 is that there is no difference in performance when nontarget letter-pairs can potentially be ignored after category membership of its members is established compared to when the establishment of category membership does restrict the positions of the target character. In particular, the absence of a real difference in the average exposure duration of the mixed group and the blocked group suggests that, even with blocked presentation of letter and digit trials, nontarget character-pairs may not have been processed differently with blocked presentations than with mixed presentations of letter and digit trials. If nontarget character-pairs did not receive less processing with blocked presentation than with mixed presentation of letter and digit trials, no conclusions can be drawn concerning the importance of the amount of processing received by nontarget character pairs in the amount of interference suffered by interior characters.

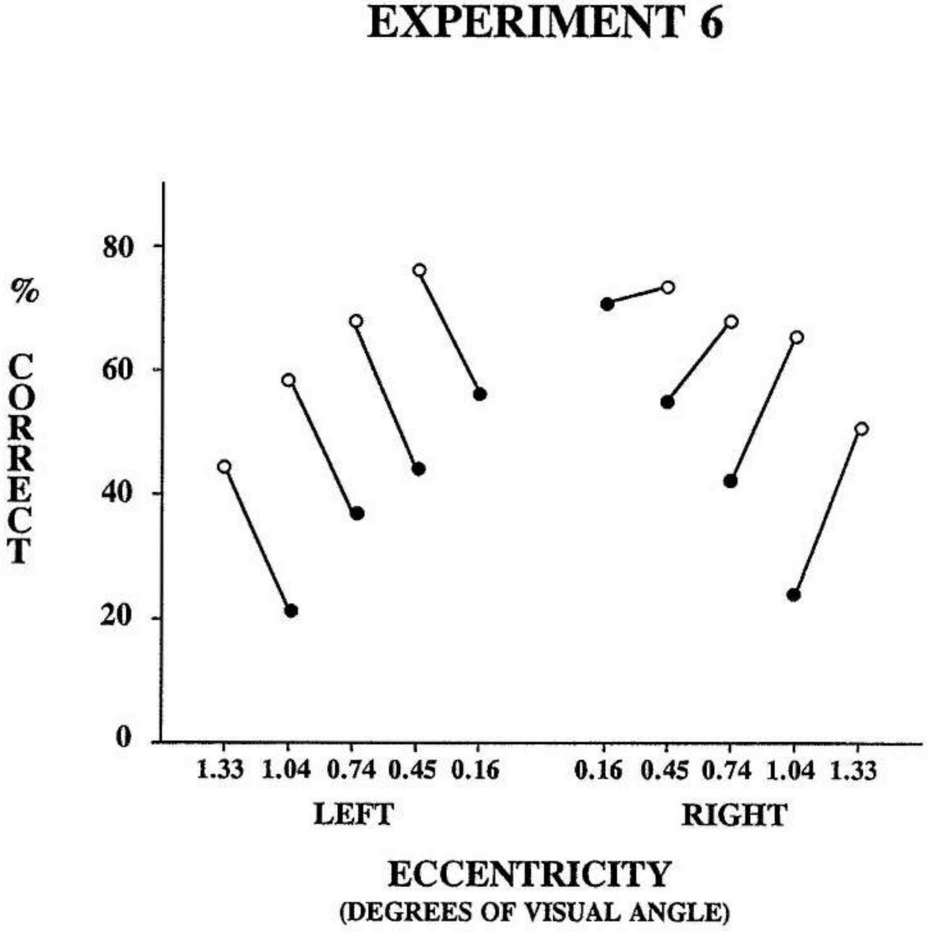
## Experiment 8

The results of Experiment 6 indicated that the exterior-letter advantage was due to interior letters suffering more lateral interference from nontarget letter-pairs than exterior letters. However, the results of Experiment 4 show that even when nontarget letter-pairs were replaced with blank spaces, exterior letters were still reported slightly more accurately than interior letters, a difference that just failed to reach significance. Nonetheless, the visual acuity gradient would predict that in the absence of other factors, the perceptibility of exterior letters is worse than the perceptibility of interior letters, because exterior letters fall into a region in the visual field where acuity is worse. Thus, the results of Experiment 4 indicate that even when single letter-pairs are presented unilateral to the fixation point, the visual acuity gradient is not the only factor determining the relative perceptibility of interior letters and exterior letters.

There are at least three possible factors that could have inspired this violation of the visual acuity gradient in unilaterally presented letter pairs. First, although each target stimulus used in Experiment 4 contained only two letters presented on one side of the fixation point, mask stimuli presented mask contours on both sides of the fixation point (see Figure 4.4). Therefore, interior letters may have suffered lateral interference from mask contours presented at the opposite side of the fixation point, disrupting, to a certain extent, the perceptibility of interior letters relative to exterior letters. The second possibility is that mask contours overlaying positions occupied by letters in the target stimulus may have disrupted the perceptibility of interior letters more than the perceptibility of exterior letters. Indeed, because temporal resolution may vary with the degree of visual angle from the centre of the visual field (e.g, Breitmeyer & Ganz, 1976), it is conceivable that mask contours overlaying more peripheral letters are more disruptive than mask contours overlaying more central letters, although it is not clear if this is the case. The third possibility is, that the slight difference in accuracy of report between interior letters and exterior letters in unilaterally presented single letter-pairs may indicate that interior letters suffered more lateral interference from exterior letters than exterior letters from interior letters. This last possibility becomes more likely, when it is considered that one of the properties of lateral interference is that targets suffer more interference from distractors flanking on the peripheral side than from distractors flanking on the foveal side (Banks et al., 1977, 1979; Bouma, 1970; Chastain, 1982a, 1982b; Chastain & Lawson, 1979; Chambers & Wolford, 1983). In addition, this asymmetry in the interference from foveally flanking distractors and peripherally flanking distractors increases as targets are presented further away from the fixation point (Banks, et al., 1977, 1979). Thus, interior letters, presented at the foveal side of exterior letters, may have suffered more interference from exterior letters than vice versa. This asymmetry in lateral interference may have offset the visual acuity gradient, because the perceptibility of exterior letters would have been disrupted less than the perceptibility of interior letters, even when no other letters were presented in the target display (cf., Chastain, 1982a; Chastain & Lawson, 1979).

Evidence supporting the possibility that an asymmetry in lateral interference between adjacent letters may have inspired the violation of the visual acuity gradient, was provided by the results for filler trials of Experiment 6. In Experiment 6, the size of the gap between letter pairs of gapped arrays was varied by presenting one letter pair at a fixed location in the visual field, while varying the location in the visual field for the other letter pair. Members of letter pairs at the fixed location were tested in test trials, while members of letter pairs in variable locations were tested in filler trials. The results of the test trials (discussed in more detail in the discussion of Experiment 6) showed that the exterior-letter advantage in gapped arrays with 2-letter gaps disappeared when gap size was increased to five letter-spaces. This result was taken to indicate that with 5-letter gaps lateral interference from nontarget letter-pairs was not sufficient to cause an advantage for exterior letters. The results of filler trials, however, showed that gap size had an altogether different effect when the location of targets in the visual field was varied as well. As Figure 5.8 reveals, when letters of letter pairs in variable locations were tested, the exterior-letter advantage remained the same when letter pairs on the left were moved away from the fixation point, and even seemed to increase when letter pairs on the right were moved away from the fixation point. If lateral interference between letters on either side of the fixation point, together with the visual acuity gradient were the only factors determining the relative perceptibility of interior letters and exterior letters, the difference between interior and exterior members of letter pairs in variable locations should have disappeared, as it did for letter pairs in the fixed location. Furthermore, if interior members of nontarget letter-pairs suffered no more interference from nontarget letter-pairs, accuracy of report should have been higher for interior letters then for exterior letters because interior letters occupy more favourable positions in the visual field. Thus, it seems that lateral interference from target letter-pairs and the visual acuity gradient may not be the only factors affecting the relative perceptibility of letters in the display.

**Figure 5.8.** Mean percentages of interior letters (solid disks) and exterior letters (open disks) correctly reported in the filler trials of Experiment 6. Connected interior letter and exterior letters were presented together in the displays.



These effects of gap size on the exterior-letter advantage in filler trials of Experiment 6 are not easily explained by the effects of overlaying mask contours. Even though overlaying mask contours may be more disrupting for targets presented peripherally than for targets presented foveally, it is not clear how this could explain that the effect of position in the visual field appears to be different for interior letters and exterior letters. However, the effects of gap size observed in the filler trials of Experiment 6 on the exterior-letter advantage in nontarget letter-pairs could be quite easily explained if asymmetry of lateral interference between members of unilaterally presented letter pairs is added to the equation. Indeed, it could be that, when letter-pairs were moved away from the fixation point, the decrease in lateral interference for interior members from letter-pairs on the opposite side of the fixation point was (more than) compensated for by an increase in the asymmetry of lateral interference between interior and exterior members. That is, with small gaps, the asymmetry may have been small, but interference from letters across the gap would have been strong, while with large gaps interior members of nontarget letter-pairs would have suffered little interference from letters across the gap, but the asymmetry between interior and exterior members of nontarget letter-pairs may have been large, because of the increase in eccentricity of their position in the visual field.

However, because the target stimuli used in Experiment 6 always contained letter pairs on both side of the fixation point, the results of the filler trials of Experiment 6 tell us little about the role of the asymmetry of lateral interference between interior letters and exterior letters of single, unilaterally presented, letter pairs. Therefore, Experiment 8 investigated the relative perceptibility of interior letters and exterior letters in single letter-pairs, presented unilaterally at four different distances from the fixation point. The locations occupied by letter pairs in Experiment 8 were the same as the locations occupied by nontarget letter-pairs in the test trials of Experiment 6. If the asymmetry in the lateral interference between interior letters and exterior letters is larger for letter pairs presented further out into the periphery of the visual field, it would be expected that the exterior-letter advantage increases as letters pairs are moved away from the fixation point. More specifically, although it is expected that both members are reported less accurately as letter pairs are presented in more eccentric locations due to a decrease in visual acuity further away from the fixation point (which was indeed the case for letter pairs in variable locations in Experiment 6), if asymmetry in lateral interference between interior letters and exterior letters increases as letter pairs are moved away from the fixation point, the decrease in accuracy of report for interior letters should be steeper than for exterior letters. In particular, a differential effect of eccentricity for interior letters and exterior letters may be revealed if exterior letters are reported more accurately than interior letters even when the distance from the fixation point of these letters is equated. That is to say, when a letter pair is moved one letter-space away from the fixation point, interior letters would occupy the same screen position as previously occupied by exterior letters.

Finally, although backward pattern masks were used, mask contours overlaid only the positions occupied by letter pairs in the preceding target stimulus. Therefore, if exterior letters were reported slightly more accurately than interior letters in Experiment 4, because mask contours were presented at both sides of the fixation point, no difference between interior letters and exterior letters of letter pairs, occupying the same positions as in Experiment 4, should be observed in Experiment 8. An example of target stimuli in each of the four distance conditions, and an example of mask stimuli is presented in Figure 5.9.

**Method**

*Subjects.* 16 subjects from the same population as previous experiments participated in a single 1-hr session in Experiment 8.

*Stimuli.* Stimuli were constructed by randomly selecting two letters from the letter set used in Experiment 1 (i.e., b, d, f, g, h, n, p, q, t, v, x z), the only constraints being that letters did not occur twice in any test stimulus, and that each of

**Figure 5.9a.** An example of target displays with letter-pairs presented at four eccentricities on the left of the fixation point Experiment 8. Gap sizes refer to the corresponding conditions in the filler trials of Experiment 6.

## EXPERIMENT 8

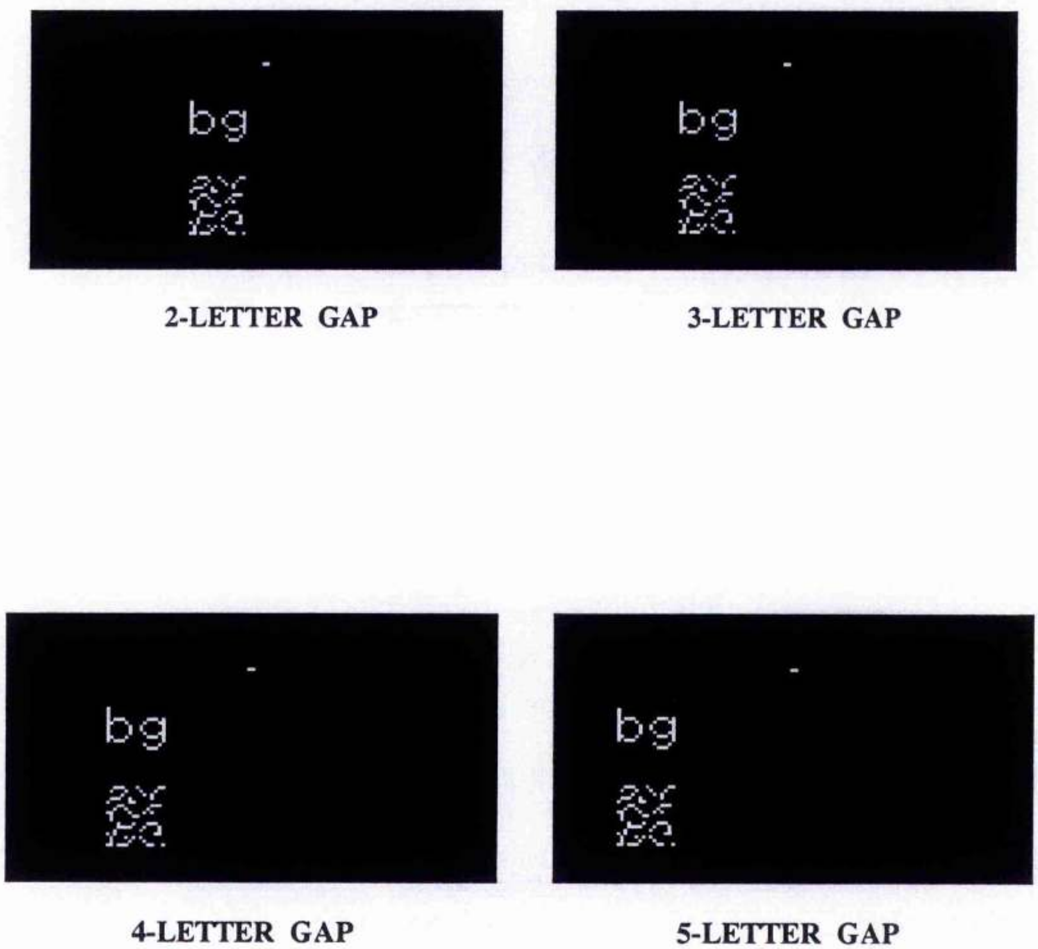
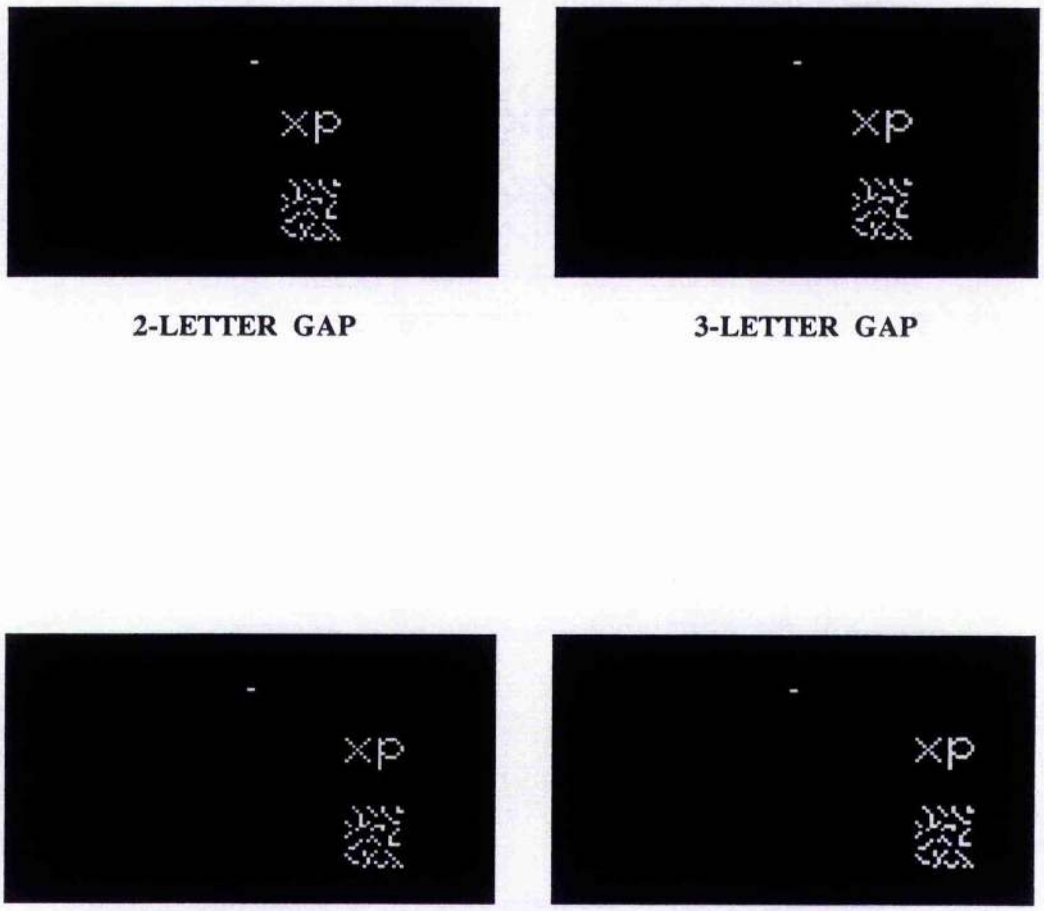


**Figure 5.9b.** An example of target displays with letter-pairs presented at four eccentricities on the right of the fixation point Experiment 8. Gap sizes refer to the corresponding conditions in the filler trials of Experiment 6.

## EXPERIMENT 8




**2-LETTER GAP** **3-LETTER GAP**

**4-LETTER GAP** **5-LETTER GAP**

the letters occurred in interior and exterior positions an equal number of times. For each subject a different stimulus set was constructed. Stimulus sets contained 48 test stimuli.

*Visual Conditions.* For each trial a different mask was constructed. Only one mask configuration was used in this experiment; mask contours overlaid only the positions occupied by the letters in the preceding display (see Figure 5.9). The stimuli were presented on one side of the fixation point in adjacent positions, at the same locations as the letters in variable locations in Experiment 6. Thus, letters were presented at four different distances from the fixation point: The eccentricity from the fixation point to the edge of interior letters was approximately $0.16^{o}$, $0.45^{o}$, $0.74^{o}$ and $1.04^{o}$, while the eccentricity from the fixation point to the edge of exterior letters was approximately $0.45^{o}$, $0.74^{o}$, $1.04^{o}$ and $1.33^{o}$ in the 2-letter, 3-letter, 4-letter and 5-letter gap conditions.

*Design.* Half the stimuli were presented at the left of the fixation point, and half were presented at the right of the fixation point. Each stimulus was shown 4 times; once in each of the four distance conditions. Average exposure duration over all subjects was 20.7 msec. All remaining aspects of Experiment 8 were identical to those of Experiment 6.

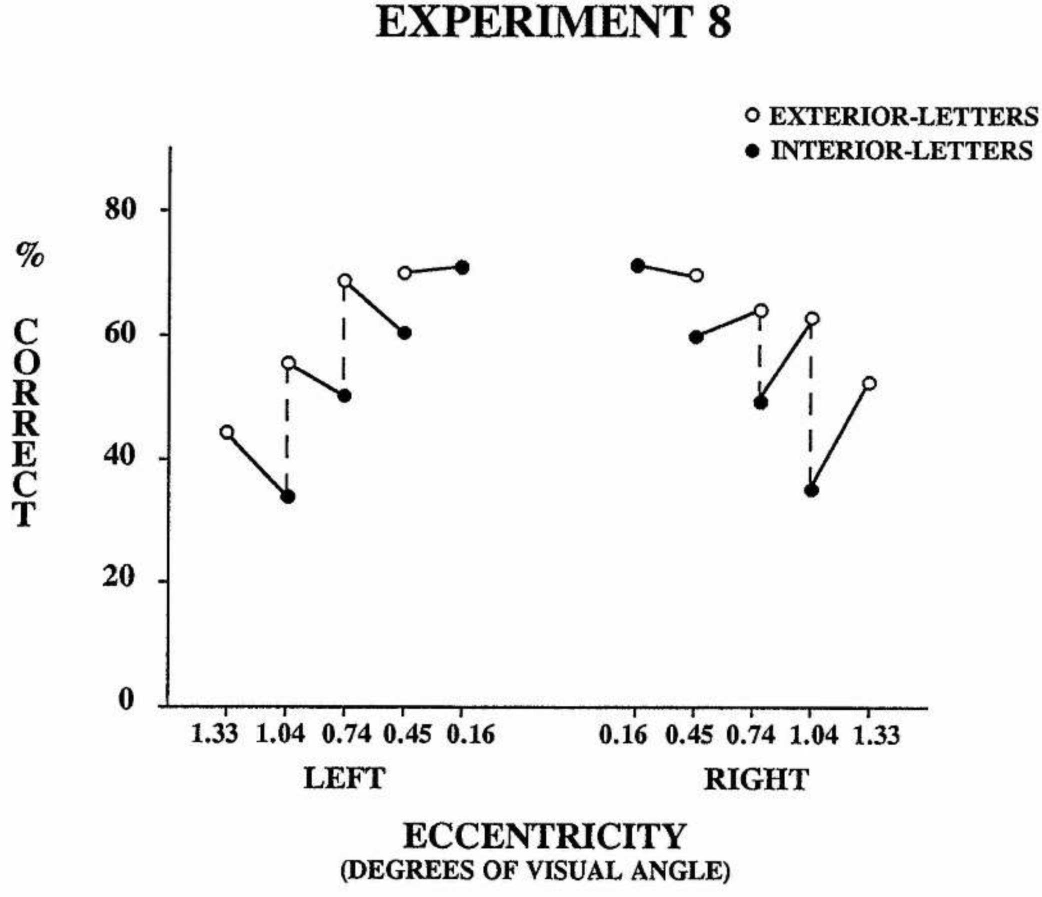
**Results and Discussion**

*Correct reports*

The data for accuracy of report in Experiment 8 are shown in Figure 5.10. The overall percentage correct report was 57.5%. The data for correct reports were submitted to an analysis of variance for factorial design, with two within-subjects factors (eccentricity and serial position). Eccentricity corresponds to the ten screen positions used to present letters; five positions on the left of the fixation point and five positions on the right.

The effect of eccentricity was highly significant [$F(3,45)=49.53$, $p<.001$], but

**Figure 5.10.** Mean percentage of interior-letters and exterior-letters correctly reported for letter-pairs presented at four different distances left and right from the fixation point in Experiment 8.



the effect of serial position failed to reach significance [$F(3,45)=2.29$, $p=.091$]. The interaction between these factors, however, was significant [$F(9,135)=2.13$, $p=.031$]. Because the levels of eccentricity were equally spaced, an analysis of trend could be conducted on the data for accuracy of report for interior letters and exterior letters as a function of eccentricity. Trend analysis showed highly significant quadratic trends in accuracy of report for interior letters and exterior letters as a function of eccentricity [$F(1,45)=95.2$ and $F(1,45)=42.27$, $ps<.001$, respectively], indicating inverted U-shaped curves for accuracy of report across the visual field for letters in both positions. Quadratic trends accounted for 97.7% and 88.8% of the variance for interior letters and exterior letters, respectively.

Newman-Keuls tests revealed that although there was no exterior-letter advantage in letter pairs presented closest to the fixation point, a significant exterior-letter advantage was observed in letter pairs presented furthest away from the fixation point ($ps<.05$). The exterior-letter advantages apparent for letter pairs presented at all intermediate eccentricities from the fixation point failed to reach significance ($ps>.05$). Finally, exterior letters with eccentricity of $0.74^{o}$ and $1.04^{o}$ of visual angle were reported more accurately than interior letters with the same eccentricity ($ps<.05$), indicated by the dashed lines in Figure 5.10.

The decrease in accuracy of report for interior letters and exterior letters as letter pairs were presented further away from the fixation point indicates that the perceptibility of letters pairs was, to a certain extent, determined by a decrease in visual acuity as stimuli were presented further into the periphery. However, the decrease in accuracy as a function of eccentricity from the fixation point was steeper for interior letters than for exterior letters. This was most clearly demonstrated by the finding that interior letters were reported less accurately than exterior letters presented at the same eccentricity from the fixation point. If the visual acuity gradient was the only factor affecting accuracy of report, it would be expected that the effects of eccentricity are similar for interior letters and exterior letters.

*Error analysis*

The data for location errors and intrusion errors are shown in Figure 5.11. 29.6% of errors made were location errors (12.6% of all responses), while 70.4% of errors made were intrusion errors (29.9% of all responses). The data for location errors and intrusion errors were each submitted to an analysis of variance for factorial design, with two within-subjects factors (eccentricity and serial position).

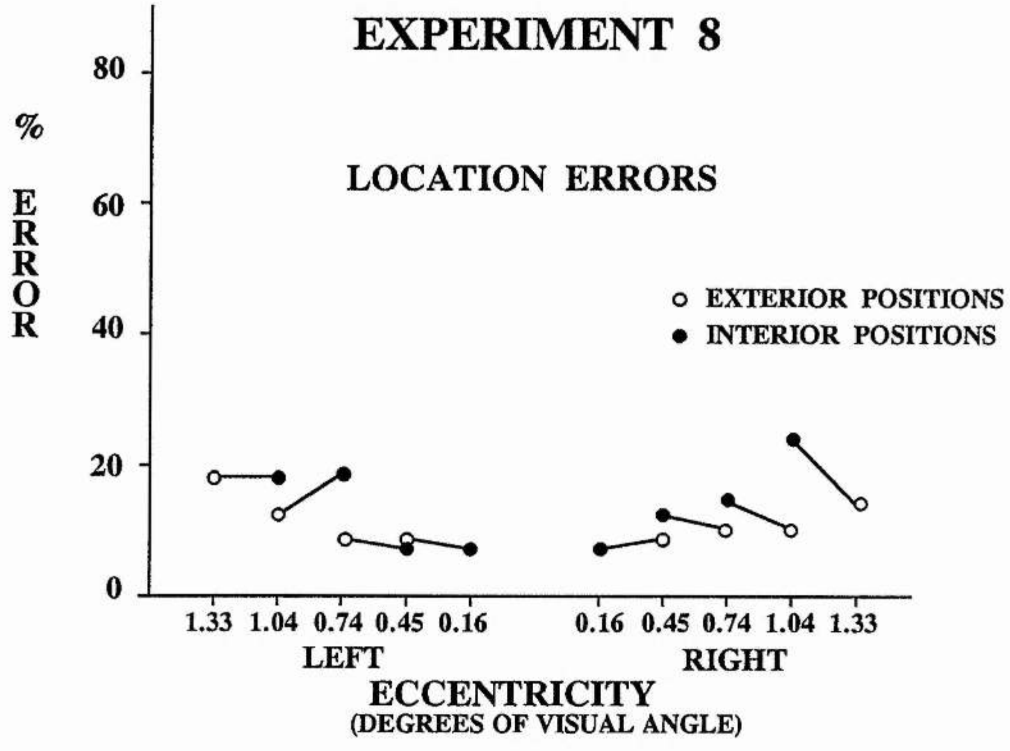
*Location errors.* For location errors, the effect of eccentricity was highly significant [$F(3,45)=17.71$, $p<.001$]. The effect of serial position and the interaction between eccentricity and serial position did not reach significance [$F(3,45)=1.42$, $p=.250$, and $F(9,135)=1.72$, $p=.091$]. Trend analysis showed highly significant quadratic trends in the frequency of location errors as a function of eccentricity for both interior and exterior positions [$F(1,45)=39.27$ and $F(1,45)=13.80$, $ps<.001$, respectively]. Quadratic trends accounted for 82.9% and 82.3% of the variance for interior letters and exterior positions, respectively.

*Intrusion errors.* For intrusion errors, the effect of eccentricity was highly significant [$F(3,45)=16.48$, $p<.001$]. The effect of serial position and the interaction between eccentricity and serial position did not reach significance [$F(3,45)=1.76$, $p=.168$, and $F(9,135)=1.30$, $p=.242$]. Trend analysis showed highly significant quadratic trends in the frequency of intrusion errors as a function of eccentricity for interior and exterior positions[$F(1,45)=40.60$ and $F(1,45)=22.20$, $ps<.001$, respectively]. Quadratic trends accounted for 87.6% and 89.8% of the variance for interior letters and exterior letters, respectively.

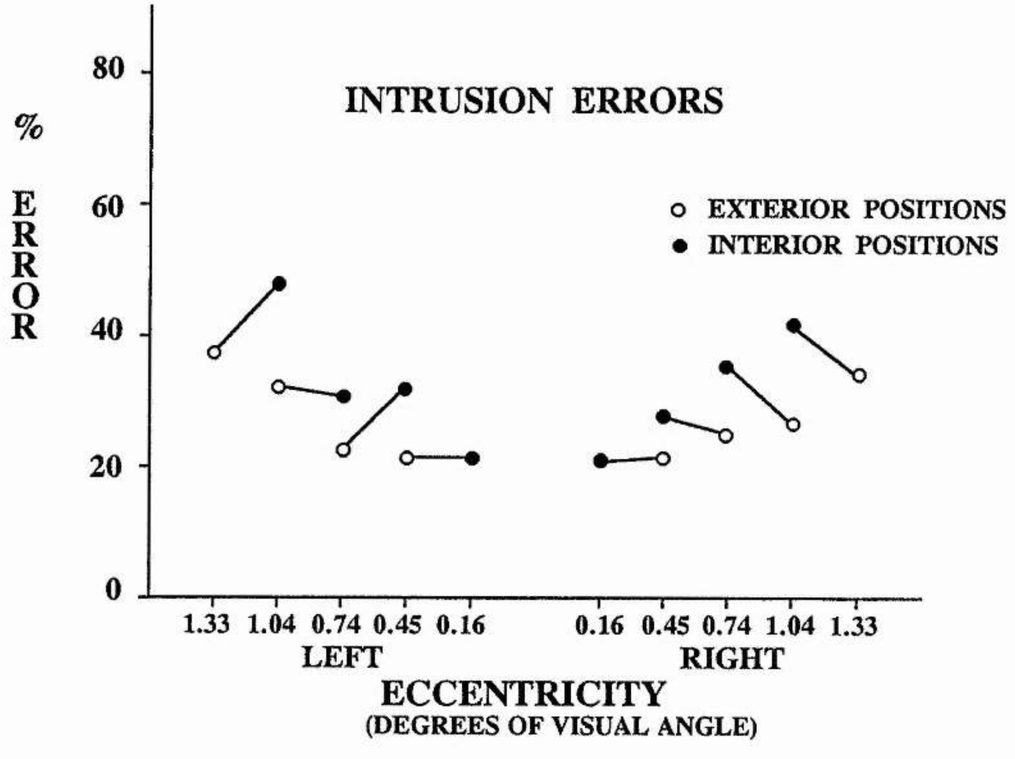
The curves for location errors and intrusion errors as a function of eccentricity are quite similar; both types of error increased as letter pairs were presented further away from the fixation point, although the effect of eccentricity was somewhat more pronounced for intrusion errors. Furthermore, it appears that the effect of eccentricity was somewhat larger for interior letters than for exterior letters, although not significantly so. The absence of significant interactions between eccentricity and

**Figure 5.11.** Mean percentages of (a) location errors and (b) intrusion errors for interior and exterior positions in each of the distance conditions of Experiment 8.

(a)




(b)



position for location errors and intrusion errors indicates that the differential effect of eccentricity on accuracy of report for interior letters and exterior letters was not reflected in just one type of error.

The results of Experiment 8 show that, even in single letter-pairs, the visual acuity gradient is not the only factor determining the relative perceptibility of interior letters and exterior letters. Most importantly, however, this factor becomes stronger, and the offset of the visual acuity gradient becomes larger, as the eccentricity of letter pairs increases. This clearly indicates that, rather than the visual acuity gradient, the asymmetry of lateral interference between interior letters and exterior letters was the important factor determining the relative perceptibility of interior letters and exterior letters.

Obviously, the possibility that pattern masks affected the relative perceptibility of interior letters and exterior letters cannot be excluded, since mask contours overlaid letter positions at every eccentricity. For example, it could be that mask contours overlaying exterior letters caused more lateral interference for interior letters than the interference for exterior letters caused by mask contours overlaying interior letters. However, since this would have to assume an asymmetry in lateral interference, it only strengthens the case for the role of asymmetry of lateral interference between interior letters and exterior letters. Furthermore, although eccentricity may have weakened the effects of overlaying mask contours, such that masking was progressively weaker for exterior letters than for interior letters, a difference in the effectiveness of overlaying mask contours at different eccentricities could not explain the difference in accuracy of report between interior and exterior letters presented at the same eccentricity. Finally, the slight advantage for exterior letters over interior letters, when letter pairs occupied the same location in the visual field as letter pairs presented in Experiment 4, indicates that a similar difference between interior letters and exterior letters in Experiment 4, was not caused by mask contours presented at the opposite side of the fixation point.

**Conclusions**

The first indication to emerge from the results of the experiments reported in this chapter is that the exterior-letter advantage in gapped arrays reflects a difference in the amount of lateral interference suffered by interior letters and exterior letters. Two possible sources of interference contributing to this difference have been identified. First, the perceptibility of interior letters relative to exterior letters may be limited by lateral interference from letters across the gap. Second, the asymmetry in lateral interference between interior letters and exterior letters may contribute to the exterior-letter advantage when the asymmetry is large enough to offset the visual acuity gradient. However, the role of asymmetry of lateral interference in the exterior-letter advantage is probably more important when interior letters and exterior letters occupy more eccentric locations in the visual field than in letter pairs of arrays with 3-letter gaps centred across the fixation point. Therefore, the first source of interference contributing to the exterior-letter advantage will be discussed in more detail.

The results of Experiment 6 indicated that interior letters suffered more lateral interference from letters across the gap than exterior letters. At first, this was assumed to occur because the distance between interior letters and nontarget letter-pairs is smaller than the distance between exterior letters and nontarget letter-pairs. However, the effect of gap size also indicated that the absolute distance between the target and distractors across the gap was not the dominant factor in the amount of lateral interference suffered by interior letters relative to exterior letters. Indeed, interior letters still suffered more lateral interference than exterior letters when the distance to nontarget letter-pairs was equated for letters in either position. Rather, the position of letters relative to each other and to letters across the gap appeared to be the dominant factor in determining the amount of lateral interference suffered by letters in gapped arrays. Furthermore, the relative position of letters in gapped arrays appeared to be so important that performance for exterior letters was no different in arrays with 5-letter gaps than in arrays with 2-letter gaps. Although it is not clear how this difference between interior letters and exterior letters occurs, it may be that spatial anchors provided by exterior boundaries were available for exterior letters, while no, or less useful, spatial anchors were provided by interior boundaries for interior letters (see Chapter Four).

However, even though interior letters may have suffered lateral interference from letters on the opposite side of the fixation point, the nature of this interference is not clear. The distance between letters on either side of the fixation point appears to exclude the possibility that feature interactions across the gap decreased the perceptibility of interior letters relative to exterior letters. Furthermore, interior letters may have suffered lateral interference from nontarget letter-pairs and nontarget digit-pairs but not from pairs of ampersands, suggesting that the physical similarity between letters and digits, the fact that letters and digit both frequently occur in linear arrays, or the familiarity of letters and digits played a crucial role in the exterior-letter advantage in gapped arrays.

In Chapter Three and in the discussion of Experiment 6, it was suggested that the availability of spatial anchors for exterior letters may have been part of the explanation for the absence of an effect of middle letters on performance for exterior letters. That is, interior letters in complete arrays may have suffered lateral interference from middle letters, which can explain the increase in accuracy of report for interior letters when middle letters were removed. However, exterior letters did not appear to suffer lateral interference from middle letters, as removing middle letters did not affect performance for exterior letters. Therefore, it was suggested that exterior letters may have been 'shielded' from lateral interference produced by middle letters. In particular, the effects of mask configuration observed in Experiments 3-5, indicated that this may, indeed, have been the case.

However, before any conclusions are drawn about the role of spatial anchors in the exterior-letter advantage, the nature of lateral interference between letters on either side of the fixation point in gapped arrays, and between middle letters and interior letters in complete arrays, was examined in Experiments 9-11, reported in Chapter Six.

# The Exterior-letter Advantage in a Forced-Choice Paradigm

The experiments reported in the previous chapter suggest that the exterior-letter advantage reflects a difference in the amount of lateral interference suffered by interior letters and exterior letters. In particular, while interior letters suffer lateral interference from middle letters in complete arrays, or from nontarget letter-pairs in gapped arrays, exterior letters appear to suffer (almost) no lateral interference from any of these letters. In particular, it was argued in the previous chapter that the finding that interior letters of gapped arrays suffer lateral interference from letters on the other side of the fixation point across a three letter space gap is hard to reconcile with a feature interaction account of lateral interference. More specifically, the gap between letters on either side of the fixation point was thought to be too wide to allow letters on either side to interact on a feature level of processing. Therefore, an alternative account of lateral interference was tested in Experiment 7, but the results failed to produce any evidence suggesting that lateral interference between letters on either side of the gap was not due to feature interactions. Nevertheless, this failure does not necessarily suggest that feature interactions across the gap do occur. Indeed, the argument that the distance between letters on either side of the gap is too large for feature interactions to occur is still valid.

To investigate the role of lateral interference and mask configuration in the exterior-letter advantage, the approach adopted in most of the experiments reported up to now in this thesis (Experiment 7 was an exception) has been to vary the characteristics of stimulus displays and measure the effects of these manipulations on performance in the bar-probe task. In particular, performance was measured by distinguishing between three types of response; correct report, location errors and intrusion errors. On the basis of these response types, a distinction was made between the ability to identify letters in target displays and the ability to localise letters in target displays. Traditionally, this distinction has been conflated with the distinction between intrusion errors and location errors (Butler, 1981; Mewhort & Campbell, 1978; Townsend, 1973). But, as argued by Van der Heijden (1987, 1992; also Hagenaar, 1990; see also Chapters Two and Three), and as demonstrated in Chapters Three and Four, there is not necessarily a one-to-one relationship between error type and type of processing. Therefore, based on the pattern of intrusion errors and location errors, conclusions about the effects of stimulus characteristics on the ability to identify and localise letters in linear arrays may be limited.

Given the uncertain nature of the relationship between the type of error made and failures in either, or both, localisation and identification of letters in multi-letter arrays, several investigators have suggested less ambiguous indicators to monitor these processes (Chow, 1986; Hagenaar, 1990; Mewhort, Huntley & Duff-Fraser, 1993; Van der Heijden, 1984, 1986). For example, Hagenaar (1990) argued that by imposing restrictions on the set of letters used to construct stimulus arrays, localisation processes and identification processes could be monitored more reliably than in arrays of randomly selected letters. Because Hagenaar's (1990) method is relevant to the method used in the experiments reported in this chapter, it will be discussed in more detail.

Hagenaar (1990) selected seven pairs of letters, such that the confusability within pairs was high, but confusability between pairs was low. Each letter pair was assigned to a position in a 7-letter array, such that each target stimulus contained one letter of each pair in its assigned position. Each subject was required to learn the position to which each letter pair was assigned. In all other respects, the procedure used by Hagenaar (1990) was similar to an ordinary bar-probe task, in that a bar-probe was presented on each trial, indicating the position of the target letter which had to be reported. Hagenaar imposed these restrictions on the composition of target arrays for two purposes. First, limiting confusability between members of letter pairs assigned to different positions was done to ensure that letters in one position could not easily be mistaken for letters in another position, thereby preventing (unintentional) false location errors (location errors resulting from misidentifications). Second, by tying each letter pair to a particular position, subjects were able to guess the correct position of correctly identified letters, thereby preventing (intentional) false location errors. Hagenaar (1990) argued that these restrictions ensured that all misidentifications were indeed scored as incorrect identifications; if not as a misidentification of the target letter, then as a misidentification of another letter in the display. Furthermore, because letter pairs were tied to a particular position in the array, each response could also be linked to a particular position. Thus, it would be possible to link an incorrect report to the misidentifications of a particular letter in the array (see Hagenaar, 1990, for more details).

Hagenaar (1990) was primarily interested in showing that errors were not only caused by mislocalisations, as was suggested by Mewhort and colleagues (discussed in Chapter Two), but also by misidentifications. However, Hagenaar (1990) was not interested in why misidentifications occurred, as no conclusions could be drawn from her data about the mechanisms underlying misidentifications. Nevertheless, Hagenaar (1990) discussed this problem, and suggested that misidentifications could reflect two basic situations; (a) only partial information about the identity of a letter in the array is available, in which case it may be confused with the nonexposed, highly confusable, member of the letter pair of which the target was a member (this is called a *genuine confusion*), or (b) no information is available about the identity of a letter in the array, in which case there is a 50% chance that the target letter is reported, based on a guess between either member of the letter pair assigned to a particular position.

For the present study, it is crucial to distinguish between these two situations, as such a distinction may provide information about the type of process underlying the exterior-letter advantage. For example, according to the feature interaction account of lateral interference, interactions between the features of two letters presented close together limit the amount of feature information for either, or both, of these letters. If such a situation is translated into Hagenaar's task, the effect of feature interactions on the perceptibility of target letters would mean that their identity needs to be derived from partial information, in which case they may easily be confused with the, highly confusable, nonexposed member of the letter pair of which they are a member. Thus, in Hagenaar's (1990) bar-probe task it would be expected that, if a reasonable level of performance is maintained, targets suffering more lateral interference are more often confused with the other member of the letter pair, than targets suffering less lateral interference.

Here we have arrived at a crucial point in the argument underlying the experiments reported in this chapter. According to the feature interaction account of lateral interference, more genuine confusions would be expected for targets suffering more lateral interference, and less genuine confusions would be expected for targets suffering less lateral interference. However, in order to test the effect of lateral interference on the likelihood that target letters are confused with nonexposed letters, a second condition needs to be included. That is, it may seem reasonable to assume that confusions are more likely to occur when the choice is between two letters with high confusability than when the choice is between to letters with low confusability. Consequently, it may be argued that the same amount of lateral interference suffered by targets should lead to genuine confusions more often if the choice is restricted to two letters with high confusability than when the choice is restricted to two letters with low confusability. Thus, the feature interaction account of lateral interference may be tested if the effects of lateral interference are compared in a two-alternative forced-choice task (which Hagenaar's task effectively is), by comparing between a condition in which the confusability between alternatives is high and a condition in which the confusability between alternatives is low.

In Hagenaar's (1990) task, however, the choice of response was always restricted to two high confusability alternatives. Therefore, to investigate the nature of lateral interference, the method used by Hagenaar (1990) was extended. Since the same method is used in all three experiments reported in this chapter, it will be discussed before turning to Experiment 9.

In the three experiments reported in this chapter, accuracy of report for interior and exterior letters was compared in a two-alternative forced-choice paradigm. That is, after presentation of a target array, two letters were presented in the response display (*choice letters*). One of the choice letters was actually presented in the array (*the target letter*) while the other choice letter was not (*the alternative response letter*). In this task, subjects had to decide on each trial which of the choice letters was the target letter presented in the target array. As in Hagenaar's (1990) study, target letters and alternative response letters were selected to be highly distinctive from all other letters in the array. The confusability between choice letters and nontarget letters (letters presented in the array other than the target letter) was controlled in this way to prevent decisions based on a nontarget letter when a choice letter is confused with one of the nontarget letters. In which case, it may be assumed that an incorrect response reflects a misidentification of the target letter, and not of another letter presented in the target stimulus (cf. Hagenaar, 1990). Furthermore, the forced-choice paradigm also minimised the effects of inversions in the perceived order of the letters in the array on performance. That is, even if the target letter was correctly identified, but not correctly localised, subjects should still have been able to enter the correct response, since the choice was restricted between the target letter and a letter not presented in the display. Thus, the forced-choice paradigm ensures, as far as possible, that performance reflects ability to identify the target letter.

To investigate the mechanisms underlying lateral interference between letters in the array, two different relationships between target letters and alternative choice letters were used in two different conditions. The confusability of alternative choice letters with target letters was much higher in the *high confusability* condition than in the *low confusability* condition. However, to stress this point once more, the confusability of both choice letters with nontarget letters presented in the array was low. Given these restrictions imposed on the composition of the arrays and the alternative response letters, it may be possible to find evidence that lateral interference affects the amount of feature information needed to decide correctly which of the choice letters is the target letter. That is, if on a proportion of trials the amount of feature information is limited by lateral interference, it would be expected that more genuine confusions are made in the high confusability condition than in the low confusability condition. If that is the case, accuracy of report would be higher in the low confusability condition than in the high confusability condition.

To explain, what is meant by the confusability of letter A with letter B is that, when letter B is presented but the features of letter B are not always correctly extracted, the proportion of trials on which letter A is reported should be high if letter A is confusable with letter B, but the proportion of trials on which letter A is reported should be low if letter A is not confusable with letter B. That is, incomplete information about letter B may sometimes be accepted as evidence for the presentation of letter A if the confusability of letter A with letter B is high. This is what was called a *genuine confusion*. The confusability of alternative letters with target letters was established in a separate experiment in which single targets were briefly presented followed by pattern masks. Brief presentations and backward pattern masks were used to degrade the target stimulus, such that information about the target could not always be fully extracted from the display. Confusability between letter A and B was defined as the proportion of errors in which letter A was reported when letter B was presented (see Table A3.2). This notion of confusability can be extended to the forced-choice experiments dealt with in this chapter. Suppose that, on a particular trial, only the amount of available feature information of the target letter is limited. In that case, if the confusability of the alternative response letter with the target letter is low, the feature information available may be sufficient to distinguish between the target letter and the alternative response letter, and the target letter should be reported correctly.

However, if the confusability between choice letters is high, the same amount of feature information available may not be sufficient to distinguish between the choice letters, and a genuine confusion may be the result. Thus, if a certain amount of feature information of the target letter is available, genuine confusions may less often lead to a correct report in the high confusability condition than in the low confusability condition. This need not always be the case. For example, the amount of feature information for the target letter may be insufficient to influence the decision between the choice letters, in which case guessing should lead equally often to a correct report as to an incorrect report, regardless of the relationship between choice letters. Nevertheless, if a reasonable level of performance is maintained (e.g., in the midrange of the performance scale), it may be assumed that over a series of trials the amount of information about the target letter will vary, such that on some trials incorrect reports reflect genuine confusions, while on other trials incorrect reports may reflect guessing. Most importantly, however, if on a substantial number of trials information about the target letters is such that guessing is not necessary, it would be expected that genuine confusions are less frequent in the low confusability condition than in the high confusability condition.

Alternatively, however, it may be the case that on any particular trial, either full information or no information is available about the identity of the target letter. In the first case no genuine confusions would be expected, as the target letter would always be identified correctly. In the second case, no genuine confusions would be expected either, since responses necessarily have to be based on guessing. Consequently, no difference in accuracy of report between the high confusability condition and the low confusability condition is expected, since in the first case the target letter is always reported correctly, and in the second case the chance that a correct response is given is independent of the relationship between the choice letters.

In sum, therefore, the three experiments reported in this chapter used the method described above to investigate the role of lateral interference in the exterior-letter advantage in linear arrays. In particular, in the previous chapter it was suggested that the gap between letters on either side of the fixation point in gapped arrays was too large for feature interactions to occur between these letters. When it is assumed that feature interactions would limit the amount of feature information about letters in the array, it may be expected that letters suffering lateral interference are more often genuinely confused with alternative response letters than letters suffering no, or less, lateral interference. Consequently, according to the feature interaction account of lateral interference more genuine confusions would be expected in the high confusability condition than in the low confusability condition for target letters suffering lateral interference. Thus, letters suffering lateral interference should be reported correctly more often in the low confusability condition than in the high confusability condition.

## Experiment 9

Experiment 9 investigated the role of lateral interference in the exterior-letter advantage in gapped arrays using the two alternative forced-choice paradigm described above. In particular, the results of Experiment 5 indicate that the exterior-letter advantage in gapped arrays reflects a difference in the amount of lateral interference suffered by interior letters and exterior letters. More specifically, interior letters may have suffered lateral interference from nontarget letters across the gap, while exterior letters did not. However, in the introduction to Experiment 7, it was suggested that if interior letters suffered lateral interference from letters on the other side of the gap, this lateral interference was difficult to reconcile with a feature interaction account of lateral interference. Although the results of Experiment 7 failed to support an alternative account of lateral interference between letters on either side of the gap, no indications have emerged to suggest that feature interactions between letters on either side of the fixation point occurred. Therefore, Experiment 9 was conducted to see if evidence for feature interactions between letters on either side of the gap could be obtained.

If interior letters suffered more lateral interference from letters across the gap than exterior letters, then, according to the feature interaction account of lateral interference, this would mean that feature information may be extracted less accurately for interior letters than for exterior letters. Furthermore, it was suggested in the introduction to this chapter that if less information is available about the features of the target letter, genuine confusions between target letter and alternative response letters should be expected. If that is the case, more genuine confusions would be expected in the high confusability condition than in the low confusability condition, and, consequently, accuracy of report for interior letters in the forced-choice task, should be higher in the low confusability condition than in the high confusability condition. Therefore, according to the feature interaction account of lateral interference, the exterior-letter advantage should be larger in the high confusability condition than in the low confusability condition.

Thus, to investigate the role of lateral interference in the exterior-letter advantage in gapped arrays, arrays similar to those used in Experiment 3 were presented and performance in the forced-choice task was measured. An example of high confusability stimuli and an example low confusability stimuli are presented in Figure 6.1.

**Method**

*Subjects*. 20 subjects from the same population as previous experiment participated in one 1-hr session in Experiments 9.

*Stimuli*. Four pairs of letters were selected according to the following two criteria: (a) the confusability between letters of different pairs was as low as possible, while (b) within-letter-pairs confusability was asymmetric, such that one member of each pair was often confused with the other, but not the other way around.

**Figure 6.1.** An example of target and mask display in the high confusability and low confusability condition of Experiment 9.

## EXPERIMENT 9


**HIGH CONFUSABILITY** **LOW CONFUSABILITY**

Confusability measures were obtained in a separate experiment reported in Appendix 3. The selected letter pairs were; *p-b*, *e-c*, *w-m*, *y-g*. Thus, for example, in the letter pair *p-b* the *p* (the high confusability member) is more easily confused with the *b* (the low confusability member) than the *b* with the *p*, but neither the *b* nor the *p* are confusable with members of any of the other pairs. The same could be said for each of the other letter pairs. The confusability measures for letters within pairs and between pairs are presented in Table A3.2. The confusability of high confusability members with low confusability members, averaged over all four pairs, was 22.8, while the confusability of low confusability members with high confusability members, averaged over all four pairs, was 7.5. The confusability for high confusability members with letters in all other pairs was 1.94, while the confusability for low confusability members with letters in all other pairs was 2.25. Thus, "general" confusability was low and matched for high confusability and low confusability letters while "specific" confusability between members of pairs was different by approximately 300%.

The selected letters where used to construct 96 pairs of 4-letter arrays (stimulus pairs), with the restriction that only one letter of each letter pair was presented in any particular stimulus (see Appendix 4). The members of each stimulus pair differed by just the target letter, with target letters occurring equally often at each of the four letter positions. The target letter in one member of each stimulus pair was provided by the high confusability member of a letter pair (*high confusability stimulus*), while the target letter in the other member of the stimulus pair was provided by the low confusability member of a letter pair (*low confusability stimuli*). For example, if the right exterior position in the target stimulus contained the target letter, a typical high confusability stimulus would be '*mpcy*', in which *y* is the high confusability member of the letter pair *y-g*, while the corresponding low confusability stimulus would be '*mpcg*', in which *g* is the low confusability member of the letter pair *y-g*. The choice would be between *y* and *g* in both cases. When the high confusability stimulus was presented the target letter is more easily confused with the alternative response letter than when the low confusability stimulus is presented. An additional 40 high confusability and 40 low confusability stimuli were constructed to provide 80 practice stimuli for the practice section of the experiment (see design). The four letters in each target stimulus were arranged as in Experiment 3. That is, presented across the fixation point, the four letters appeared as two-by-two on either side of the fixation point with three blank letter-spaces in the middle (see Figure 6.1).

For each trial a pattern mask was constructed as in Experiment 1. Mask width was determined by the width of the letters in the target display, which were not equally wide (see Appendix 2). For each target display, the left and right boundaries of letter pairs on either side of the fixation point were matched exactly by the boundaries of the masks, such that mask contours overlaid only the positions of the letters, like the GA-Masks used in Experiment 3 (see Figure 6.1).

*Design.* High confusability and low confusability members of each stimulus pair were presented once during the experiment. The experiment was divided into three sections (practice, A, B) with no obvious transition from one section to the next. One member of each stimulus pair was presented in section A, and the other in section B. The allocation of stimuli to Sections A and B was re-randomized for each subject, with the constraint that each section contained an equal number of each type of stimulus (48 high confusability stimuli and 48 low confusability stimuli). Stimuli were presented in cycles of 16 trials, counterbalanced across stimulus type and target-letter position.

*Procedure.* The response display used in Experiment 9 were a little different from those used in previous experiments. That is, immediately after mask offset, four dashes were shown, corresponding to the four letter positions in each stimulus, and at one of these dashes (corresponding to the target-letter position) two letters were shown, one above the dash and one below, and subjects had to decide which of these two letters had been shown at the position indicated by the dash (see Figure 6.1). The dashes and the two alternatives remained on the screen until subjects made their choice by pressing one of two keys to select either the upper or the lower alternative. One of the two letters was always the target letter, and it was presented randomly above or below the dash. The alternative response letter was always the other member of the same letter pair as the target letter.

Throughout the practice and experimental sections, exposure durations were reassessed for each subject after each cycle of 16 trials. Exposure duration was increased (by 4.5 msec) if the number of correct responses in a cycle was below 11 (68.75%) and was increased (by 4.5 msec) if the number of correct responses in a cycle was above 13 (81.25%). This adjustment procedure ensured that overall performance fell in the midrange of the performance scale and that each condition was represented at the same exposure duration and equal number of times. Average exposure duration for high confusability stimuli and low confusability stimuli was 42 msec. All remaining aspects of Experiment 9 were identical to those of Experiment 1.

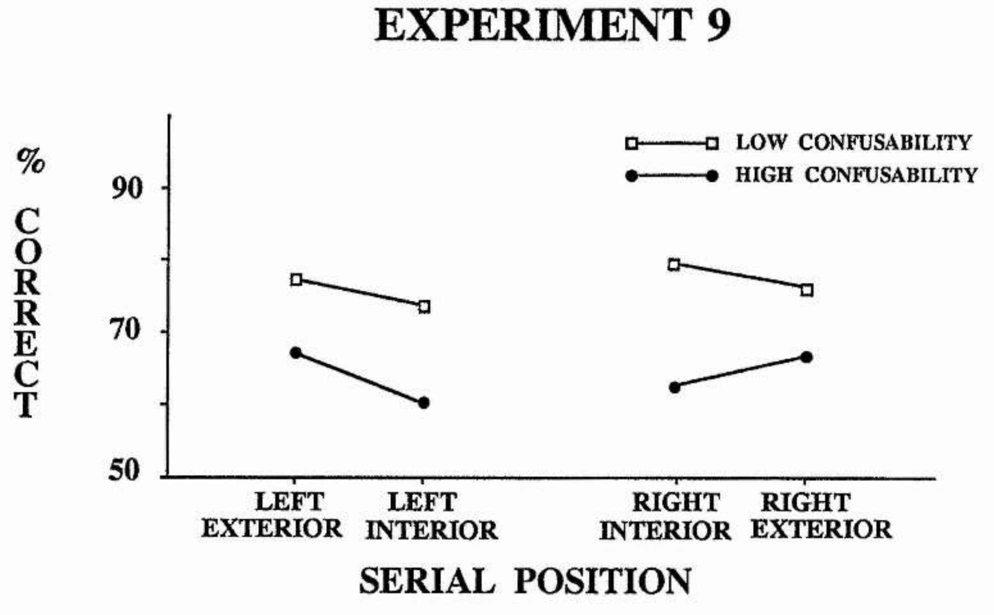
**Results and Discussion**

The results of Experiment 9 are shown in Figure 6.2. Overall percentage correct reports in Experiment 9 was 70.4%. The data were converted to proportions correct, and submitted to an analysis of variance for factorial design, with two within-subjects variables [confusability (high, low), target position].

The effect of confusability was highly significant [$F(1,19)=18.69$, $p<.001$]. The percentage correct reports was 64.2% in the high confusability condition and 76.7% in the low confusability condition. There was no evidence of an effect of target position ($F<1$), or of an interaction between these two variables [$F(3,57)=1.12$, $p=.347$].

The findings of Experiment 9 do not suggest that decisions about the identity of target letters were based more often on a limited amount of feature information for target letters when interior positions were tested than when exterior positions were tested. If that had been the case, an interaction between confusability and target position would have been expected, but no such interaction was observed. More

**Figure 6.2.** Mean percentage of critical-letters correctly reported in the low confusability condition and high confusability condition in Experiment 9.



specifically, no exterior-letter advantage was observed in either confusability condition. Although this absence of an exterior-letter advantage in gapped arrays is surprising, considering that it has been found repeatedly in previous experiments reported in this thesis, it may indicate that there was no difference in the amount of lateral interference suffered by interior letters and exterior letters, and, if that is the case, no interaction between confusability and target position would have been expected regardless of the effect of lateral interference on the quality of feature information.

Thus, the results of Experiment 9 do not provide information about the nature of lateral interference. The absence of an exterior-letter advantage may indicate, however, performance in the forced-choice task may not be sufficiently sensitive to reveal the processes that caused an exterior-letter advantage in the bar-probe task. For example, when the target letter was provided in the response display, it should have been correctly reported even when it was not perceived in its correct position. In the bar-probe task such a situation would probably have led to an incorrect report. Thus, if a certain amount of spatial uncertainty existed for letters in the target array, this may not have affected performance in the forced-choice task although it would have affected performance in the bar-probe task. Therefore, Experiment 10 was conducted in order to see if an exterior-letter advantage could be obtained in the forced-choice task used in Experiment 9.

## Experiment 10

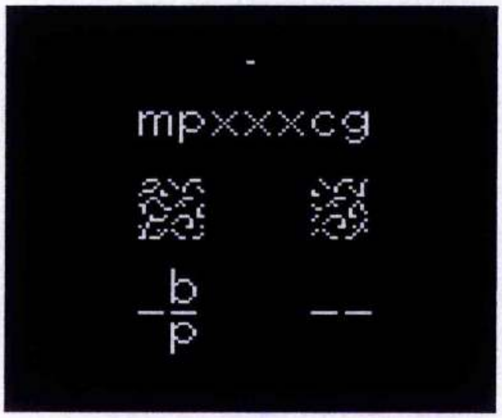
Experiment 10 built on the results of Experiment 2, which showed that the exterior-letter advantage was larger in complete arrays than in gapped arrays. Furthermore, this difference in the extent of the exterior-letter advantage between gapped arrays and complete arrays observed in Experiment 2 appears to have been caused by lateral interference from middle letters, which affected the perceptibility of interior letters but not the perceptibility of exterior letters. Thus, the difference in the amount of lateral interference suffered by interior letters and exterior letters may have been larger in complete arrays than in gapped arrays. If this is the case, an exterior-letter advantage may be obtained in the forced-choice task using complete arrays, although it was not obtained using gapped arrays.

Therefore, the three blank spaces in the middle of the gapped arrays used in Experiment 9 were replaced with three letters in Experiment 10. If these letters caused a larger difference in the amount of interference suffered by interior letters and exterior letters, an exterior-letter advantage may be obtained in the forced-choice task used previously in Experiment 9. In addition, if interior letters suffer more lateral interference than exterior letters in complete arrays, it may be that more genuine confusions occur when interior positions are tested than when exterior positions are tested. If that is the case, the exterior-letter advantage should be larger in the high confusability condition than in the low confusability condition.

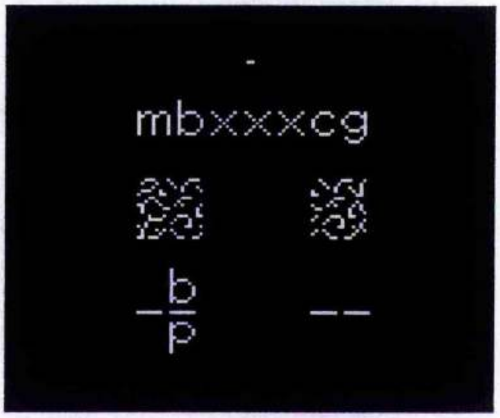
In order to keep the chance that nontarget letters were confused with choice letter as low as possible, three x's were used, rather than three different letters. If the effect on performance of lateral interference is less in the forced choice paradigm than in the bar-probe task, it may be that the same difference in the amount of lateral interference suffered by interior letters and exterior letters creates a smaller exterior-letter advantage in the forced choice task than in the bar-probe task (cf., Experiment 9). If the confusability of choice letters with nontarget letters is not sufficiently small, it may be that any effects of lateral interference are obscured by confusions between choice letters and nontarget letters, because extra opportunities for confusabilities between nontarget letters and choice letters may be created when different letters are used. An example of high confusability stimuli and low confusability stimuli is presented in Figure 6.3.

**Figure 6.3.** An example of target and mask display in the high confusability and low confusability condition of Experiment 10.

# EXPERIMENT 10




HIGH CONFUSABILITY




LOW CONFUSABILITY

**Method**

*Subjects*. 16 subjects from the same population as previous experiment participated in one 1-hr session in Experiments 10.

*Stimuli*. The stimuli used in Experiment 10 were the same as in Experiment 9, except that the blank spaces between letters left and right of the fixation point were replaced by three x's (see Figure 6.3). The confusability measures obtained for target letters with the letter *x* are listed in Table A3.2. The average confusability for high confusability members with the letter x was 3.2, while the average confusability for low confusability members with the letter x was 2.18. Thus, the confusability with the letter *x* is equally low for high confusability members and low confusability members of letter-pairs.

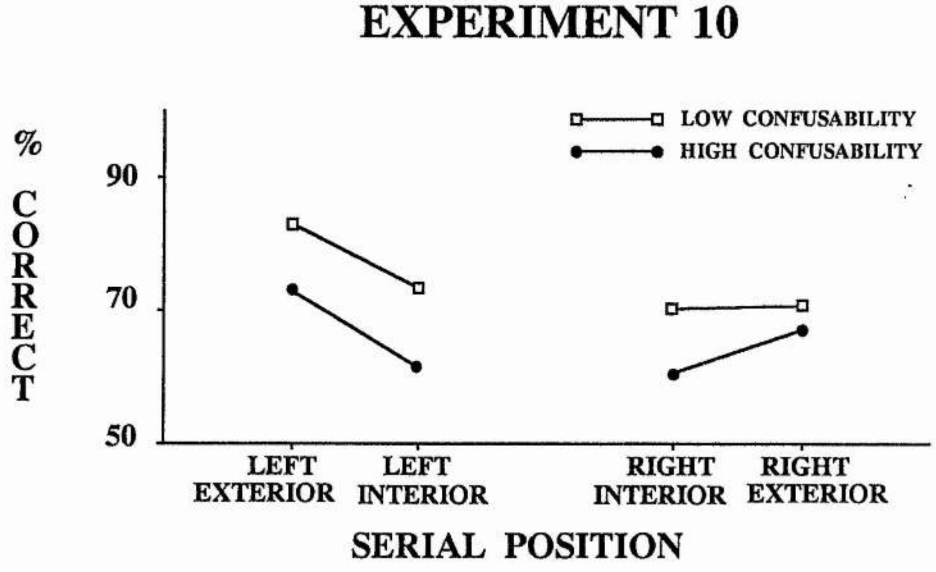
As in Experiment 9, the pattern masks following each of the target stimuli overlay only the positions of the target letters; the positions of the x's were not masked. Average exposure duration for high confusability stimuli and low confusability stimuli in Experiment 10 was 56.6 msec. All remaining aspects of Experiment 9 were identical to those of Experiment 9.

**Results and Discussion**

The results of Experiment 10 are shown in Figure 6.4. Overall percentage correct reports in Experiment 10 was 70.0%. The data were converted to proportions correct, and submitted to an analysis of variance for factorial design, with two within-subjects variables (confusability and target position).

As in Experiment 9, the effect of confusability was highly significant [$F(1,15)=12.06$, $p=.0034$]. The percentage correct reports was 65.6% in the high confusability condition and 74.4% in the low confusability condition. The effect of target position also reached significance, however [$F(3,45)=3.11$, $p=.036$]. Again, there was no evidence of an interaction between confusability and target position [$F(3,45)=1.06$, $p=.374$].

**Figure 6.4.** Mean percentage of critical-letters correctly reported in the low confusability condition and high confusability condition in Experiment 10.



Newman-Keuls tests for pairwise comparisons examined the effect of target position further, and revealed that exterior letters at the left of the fixation point were reported slightly more accurately than letters in any of the other positions (*p*s $< .05$). Thus, the serial position curve showed a slight left side exterior-letter advantage, but no significant exterior-letter advantage was observed for letters on the right side of the fixation point.

The exterior-letter advantage for letters presented on the left of the fixation point indicates that it is possible to obtain an exterior-letter advantage in a two-alternative forced-choice task. Furthermore, in line with the arguments presented previously concerning the role of lateral interference in the exterior-letter advantage, the exterior-letter advantage observed in the present experiment suggests that interior letters on the left of the fixation point suffered more lateral interference than exterior letters on the left of the fixation point. However, in spite of an apparent difference in the amount of lateral interference suffered by interior letters and exterior letters, no evidence for an interaction between confusability and target position was apparent. Indeed, the exterior-letter advantage, for letters on the left of the fixation point, was 11.5% in the low confusability condition and 9.6% in the high confusability condition.

The absence of an interaction between confusability and target position fails to provide evidence suggesting that decisions between choice letters were based on incomplete information more often when interior letters were tested than when exterior letters were tested. Indeed, according to the rational behind the two alternative forced-choice task used in these experiments, if responses were based on incomplete feature information for target letters more often when the target letter was presented in interior positions than when targets were presented in exterior positions, a larger difference in accuracy of report between the high confusability and low confusability conditions would have been expected for interior positions than for exterior positions, because more genuine confusions should be made for interior targets. Thus, the absence of an interaction between confusability and target position indicates that the difference in accuracy of report between interior letters and exterior letters reflects a difference in the number of times responses were based on guessing between the choice letters.

## Experiment 11

The results of Experiment 10 suggest that interior letters suffered more lateral interference than exterior letters (at least on the left of the fixation point), which was not matched by a difference in the effect of confusability for exterior and interior positions. Thus, the results of Experiment 10 provided no evidence to suggest that a choice between the target letter and the alternative response letter was based on partial information more often when target letters were presented in interior position than when target letters were presented in exterior positions. Although at the moment, it may not be clear exactly why the exterior-letter advantage on the left of the fixation point in Experiment 10 was not matched by a differential effect of confusability for interior and exterior positions, the effect of lateral interference was investigated further in Experiment 11.

In particular, the x's presented in the middle positions of every target stimulus in Experiment 10 might not have provided the amount of lateral interference which would be provided by a changing selection of different letters. Indeed, in Experiment 2, in which a large difference in the size of the exterior-letter advantage was observed for gapped arrays and complete arrays, middle letters were selected from a set of six letters which never occurred in any of the other positions in the arrays. The important difference with the complete arrays used in Experiment 10 may have been that a different sequence of three letters was presented in the middle positions on each trial in the complete array condition of Experiment 2.

Therefore, in Experiment 11, six letters were selected to serve as non-target letters used to fill the three positions between the target letters left and right of the fixation point. Each of the non-target letters was selected to be highly distinctive from any of the target letters. For every stimulus, three non-target letters were selected to fill the three positions between the target letters left and right of the fixation point. An example of high confusability stimuli and an example of low confusability stimuli are presented in Figure 6.5.

**Method**

*Subjects*. 16 subjects from the same population as previous experiments participated in one 1-hr session in Experiments 11.

*Stimuli*. The stimuli used in Experiment 11 were the same as in Experiment 9 except that the blank spaces between the letters left and right of the fixation point were replaced by three nontarget letters, randomly selected from a set of six non-target letters (see Figure 6.5). The non-target letters were selected to be as little confusable with the target letters as possible. The confusability measures for each target letter-pair and the non-target letters are shown in Table A3.2. The average confusability for high confusability members with all nontarget letters was 3.78, while the average confusability for low confusability members with all nontarget letters was 3.03. Thus, the confusability with nontarget letters occupying middle positions is equally low for high confusability members and low confusability members of letter-pairs.

As in Experiment 9 the pattern masks following each of the target stimuli overlaid only the positions of the target letters; the positions of the three nontarget letters in the middle of each stimulus were not masked.

Average exposure duration for high confusability and low confusability stimuli in Experiment 11 was 82.8 msec. All remaining aspects of Experiment 11 were identical to those of Experiment 9.

**Figure 6.5.** An example of target and mask display in the high confusability and low confusability condition of Experiment 11

## EXPERIMENT 11


**HIGH CONFUSABILITY** **LOW CONFUSABILITY**

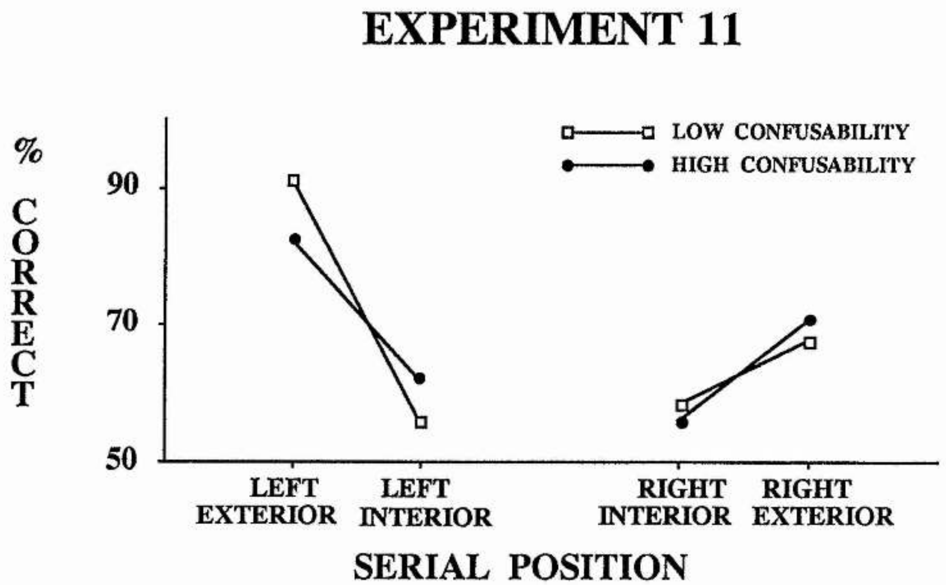
**Results and Discussion**

The results of Experiment 11 are presented in Figure 6.6. Overall percentage correct reports in Experiment 11 was 67.9%. The data were converted into proportions correct and analysed as in Experiment 9. Contrary to the previous two experiments, the effect of confusability was not significant in the present experiment ($F < 1$). However, the effect of target position was highly significant [$F(3,45) = 33.53$, $p < .001$], and the interaction between confusability and target position also reached significance [$F(3,45) = 3.26$, $p = .030$].

Newman-Keuls tests showed that accuracy of report was higher for targets in exterior positions than for targets in interior letters, regardless of confusability ($ps < .05$). Furthermore, targets in the left exterior position were reported more accurately than targets in the right exterior position ($ps < .05$), and consequently there was a larger exterior-letter advantage on the left of the fixation point than on the right; the differences between interior and exterior letters were 27.9% and 14.2% left and right of the fixation point respectively. Finally, there was no significant difference between high confusability and low confusability targets in any of the target positions ($ps > .05$), but the left exterior-letter advantage was somewhat larger in the low confusability condition than in the high confusability condition ($p < .05$).

In contrast to the previous two experiments, a substantial exterior-letter advantage was found in this experiment, which confirms that an exterior-letter advantage is not a feature restricted to the bar-probe task. Furthermore, in line with the arguments presented previously concerning the role of lateral interference in the exterior-letter advantage, the exterior-letter advantage observed in the present experiment suggests that when middle positions were occupied by a variable sequence of three different letters, interior letters suffered substantially more lateral interference than exterior letters. Indeed, interior letters may even have suffered more lateral interference than when middle positions were occupied with three x's. Nevertheless, as in Experiment 10, the exterior-letter advantage was not matched by a differential effect

**Figure 6.6.** Mean percentage of critical-letters correctly reported in the low confusability condition and high confusability condition in Experiment 11.



of confusability on accuracy for target letters in interior or exterior positions. Thus, it appears that the difference in accuracy of report between interior letters and exterior letters was not caused by a difference in the number of genuine confusions. If that had been the case, more of these confusions should have occurred in the high confusability condition than in the low confusability condition. Moreover, since there was no difference in accuracy of report for interior letters and exterior letters between confusability conditions, it may be assumed that incorrect reports were predominantly the result of guesses between choice letters. If that is the case, the exterior-letter advantage suggests that subjects had to guess between choice letters more often if the target letter was presented in interior positions than when the target letter was presented in exterior positions.

**Conclusions**

The first indication to emerge from the results of Experiments 9-11 is that the exterior-letter advantage in the two alternative forced-choice task may not reflect a difference in the number of genuine confusions for interior letters and exterior letters. More specifically, even when accuracy of report was higher for exterior letters than for interior letters, there was no evidence to suggest that incorrect reports reflected more genuine confusions when interior positions were tested than when exterior-letter positions were tested. Indeed, if that had been the case more of these confusions should have occurred in the high confusability condition than in the low confusability condition. However, that is not what was found. Indeed, in Experiment 11, in which the exterior-letter advantage was most pronounced, accuracy of report for left interior letters may have been slightly higher in the high confusability condition than in the low confusability condition.

The suggestion that the exterior-letter advantage was inspired by a difference in the frequency of guessing between interior positions and exterior positions, may indicate that the difference in the amount of lateral interference suffered by interior letters and exterior letters was not caused by feature interactions. However, before any conclusions about the role of feature interactions in the exterior-letter advantage can be drawn, it needs to be established that it is unlikely that feature interactions could have produced the pattern of result observed in Experiments 9-11. Conceivably, there are two situations in which a loss of feature information for interior letters may not necessarily have led to a difference in the frequency of genuine confusions between the high confusability condition and the low confusability condition.

First, a loss of feature information would not cause more genuine confusions in the high confusability condition than in the low confusability condition if the loss of feature information is so severe that most responses result from guessing between the choice letters. That is, it may be that the loss of feature information has such a detrimental effect on the amount of feature information available for making a decision that responses necessarily have to be based on guessing between choice letters. In that case, performance would be expected to be at chance level. However, although accuracy of report for interior letters in the low confusability condition in Experiment 11 is not far above chance level, accuracy of report for interior letters in both confusability conditions of Experiment 10 was clearly above chance level. Therefore, if feature interactions caused such a loss of feature information that most responses had to be based on guessing in Experiment 11, this could not have been the case in Experiment 10. Yet there was no indication to suggest that the exterior-letter advantage in Experiment 10 reflects a difference in the frequency of genuine confusions for interior letters and exterior letters. Thus, the absence of an interaction between confusability and target position in Experiments 10 and 11 was probably not caused by scaling effects.

Second, a decrease in the quality of feature information would not necessarily have caused an increase in genuine confusions if information about the identity of letters was poor to start with. In this situation, any decrease in the quality of information would have led primarily to an increase in guessing between choice letters.

Indeed, this may have been the case in Experiments 9 and 10. In both experiments, there was an appreciable difference in performance between the high confusability condition and the low confusability condition, even for exterior letters. Although comparing the effects of confusability between target positions may be the only legitimate way of examining the processes underlying performance in the forced-choice task, the rational behind this experiment, developed in the introduction, posits that a difference in accuracy of report between the high confusability condition and the low confusability condition may indicate that on a proportion of the trials decisions are based on incomplete information about the features of the target letter, which would lead to more genuine confusions in the high confusability condition than in the low confusability condition. Thus, an explanation for the difference in accuracy of report between the high confusability condition and the low confusability condition observed in both interior and exterior positions in Experiments 9 and 10 is easily provided. In particular, in these experiments, target displays were presented briefly (42 and 56.6 msec) followed immediately by pattern masks, to ensure that performance was in the midrange of the performance scale. Although the precise effects of backward pattern masking are as yet unclear (see Breitmeyer, 1984), considering that the masks used in the present experiment were able to render stimuli undetectable at sufficiently brief exposure durations, it seems likely that masks affected the ability to extract feature information from the target displays. Therefore, if the difference in accuracy of report between the high confusability condition and the low confusability condition reflects the effect of brief exposure durations and backward pattern masks, it may be that, the amount of feature information was already limited to such an extent that a further loss of feature information only led to more guessing between choice letters. If that is the case, no difference in the number of genuine confusions would have been expected to arise from a further loss of feature information caused by lateral interference.

However, the suggestion that no evidence for feature interactions was found because feature information was already degraded to a level such that a further loss of feature information would only lead to an increase of guessing may not be a likely one, for the following reasons. First, performance in the experiments reported in this chapter was maintained approximately at the midrange of the performance scale, ensuring that on the majority of trials sufficient information was available to accurately identify the target letter. Second, no difference in performance between the high confusability condition and the low confusability condition was observed in Experiment 11. This may be explained if it is considered that the average exposure duration in Experiment 11 was considerable longer (82 msec) than the average exposure duration in Experiments 9 and 10. This difference in average exposure duration may have allowed almost prefect acquisition of feature information in Experiment 11 and performance may have been limited by other factors. If that is the case, a further loss of feature information caused by lateral interference should have resulted in a difference in accuracy of report between the high confusability condition and the low confusability condition in Experiment 11.

Finally, even though lateral interference has been extensively studied, considerable disagreement still exists concerning the processes underlying this phenomenon. Theories have been proposed describing interference between letters in terms of interactions on a feature extraction level of processing (Bjork, & Murray, 1977; Estes, 1972; Krumhansl, 1977; Wolford, 1975), but also in terms of attentional processes (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979; Kahneman, & Henik, 1977, 1981; Kahneman & Treisman, 1984; Styles & Allport, 1986; Treisman, & Schmidt, 1982). Accounts falling into the first category have in common that the interference occurs at a level of processing such that stimulus input from a nontarget letter reduces the likelihood that feature information from a target letter is accurately extracted. Accounts that can be classified as attentional interference, however, have in common that the amount of interference is related to the tendency of nontarget letters to prevent attention to be directed exclusively towards the target. As I have argued previously, if it is assumed that the exterior-letter advantage reflects a difference in the amount of lateral interference suffered by interior letters and exterior letters, the results of the experiments reported in this chapter suggest that this lateral interference does not involve feature interactions. That is, the results of the experiments suggest that the exterior-letter advantage does not reflect a difference in the number of genuine confusions between these positions, as would have been expected if lateral interference caused a loss of feature information for interior letters relative to exterior letters. If the exterior-letter advantage does not reflect a loss of feature information caused by lateral interference, the type of processes reflected in the exterior-letter advantage remains to be determined.

# General discussion

Before discussing the main findings of this thesis, a note of caution for the interpretation of some of the findings is warranted. Some conclusions are based on comparisons between conditions in a single experiment, while others are based on comparisons between the findings of different experiments. Conclusions based on comparisons between experimental conditions within a single experiment may be limited by the fact that the relationship between the underlying psychological property, which is subject of investigation, and the dependent variable (accuracy of report) is unknown (see Loftus, 1978). Conclusions based on comparisons between experiments may be limited by the fact that experimental conditions are not necessarily the same between experiments. That is, although overall levels of performance were equated between experiments, exposure durations of the target stimulus may have varied, which may indicate that different processes function as the bottle-neck determining accuracy of report. Thus, even the presence of an exterior-letter advantage in one experiment and the absence of an exterior-letter advantage in another may not be unambiguously attributed to a manipulation of stimulus and mask characteristics between experiments. In these situations comparisons between and within experiments may at best provide strong indications for the importance of stimulus and mask characteristics, while only additional experimentation could resolve this ambiguity in the interpretation of the results.

The experiments reported in this thesis investigated the role of lateral interference and mask configuration in the exterior-letter advantage in linear multi-letter arrays. Recall that, among others, Estes (1978) suggested that the exterior-letters advantage reflects an imbalance in the number of immediately flanking letters for interior letters and exterior letters and that Mewhort and Campbell (1978) suggested that the exterior-letter advantage reflects spatial anchors for exterior letters provided for the exterior boundaries of linear arrays. Although both accounts may be appropriate in some respects, the findings of this thesis suggest that considerably more is involved. Indeed, the findings of this thesis indicate that several factors contribute to the exterior-letter advantage, which may interact in ways which are, as yet, not clearly understood. Nevertheless, although the findings of this thesis may not allow a detailed account of the processes underlying the exterior-letter advantage, they do have implications for further investigations into the mechanisms underlying the exterior-letter advantage. Before the implications the findings may have for theories and studies of the role of lateral interference and backward pattern masking in the exterior-letter advantage in linear multi-letter arrays are discussed, the main findings can be summarized as follows:

1. An exterior-letter advantage was found even when interior letters and exterior letters of centrally fixated linear arrays were both immediately flanked by blank spaces on one side. The exterior-letter advantage was larger, however, when interior letters had immediately flanking letter on both sides.

2. An exterior-letter advantage was found even when masks extended beyond the horizontal boundaries of centrally fixated linear arrays. The exterior-letter advantage was larger, however, when mask boundaries matched the horizontal boundaries of target arrays.

3. An exterior-letter advantage was found for single letter-pairs presented at an eccentricity of more than $1^{o}$ of visual angle from the fixation point but not for single letter-pairs presented at eccentricities of less than $1^{o}$ of visual angle from the fixation point.

4. When interior and exterior letters of linear arrays were both flanked by blank spaces on one side, the exterior-letter advantage depended critically on the presence of letters

or digits presented on the opposite side of blank spaces flanking interior letters but not on the presence of ampersands presented in those positions.

5. When interior letters and exterior letters of centrally fixated linear letter-arrays were both flanked immediately by blank spaces on one side, the effects of mask contours flanking interior letters on the foveal side depended critically on the presence of letters on the opposite side of blank spaces flanking interior letters.

6. The magnitude of the exterior-letter advantage in linear letter-arrays without middle letters depended critically on the size of the space between interior letters.

The first indication to emerge from these findings is that Estes' (1978) account of the exterior-letter advantage may not be inadequate in every respect, althou it may not be able to explain the exterior-letter advantage entirely. More specifically, even though an imbalance in the number of *immediately* flanking letters for interior letters and exterior letters is not crucial for the exterior-letter advantage to be obtained, the findings of this thesis present several indications to suggest that interior letters of linear arrays may suffer more lateral interference than exterior letters. In particular, the finding that the exterior-letter advantage in complete 7-letter arrays was almost halved when middle letters were replaced with blank spaces (such that the remaining interior letters and exterior letters were flanked by blank spaces on one side only), indicates that interior letters suffered less lateral interference when flanked by blank spaces on one side compared to interior letters flanked by letters on both sides. Furthermore, lateral interference between letters of centrally fixated linear letter-arrays may be restricted to immediately adjacent letters, as the effect of replacing letters at and adjacent to the fixation point with blank spaces was restricted to performance for the remaining interior letters but not for the remaining exterior letters. Thus, Estes' (1978) arguments for the importance of an imbalance in the number of immediately flanking letters for interior letters and exterior letters may, therefore, actually account for most of the difference in the amount of lateral interference suffered by interior and exterior letters. However, since removing middle letters from complete 7-letter arrays did not remove the exterior-letter advantage entirely, the fact that interior letters of complete linear arrays are immediately flanked by letters on both sides while exterior letters are immediately flanked by letters on one side only may be a much smaller component of the exterior letter advantage in complete arrays than previously thought.

However, if part of the exterior-letter advantage in centrally fixated linear letter-arrays reflects a difference in the amount of lateral interference suffered by interior letters and exterior letters, the nature of that lateral interference is not clear. In particular, the findings of Experiment 11 suggest that the exterior-letter advantage in complete 7-letter arrays does not reflect a difference in the amount of feature information available for interior and exterior letters, effectively excluding a feature interaction explanation for the role of lateral interference in the exterior-letter advantage. Furthermore, the role of lateral interference in the exterior-letter advantage appears to be specific for linear arrays of letters and digits, as lateral interference does not have the same effect for linear arrays of nonsense ("letter like") characters (e.g., Hammond & Green, 1980; Mason & Katz, 1976). The absence of an exterior-letter advantage in linear arrays of nonsense characters substantiates the suggestion that lateral interference as suggested by the feature interaction account plays no role in the exterior-letter advantage. That is to say, according to the feature interaction account of lateral interference the perceptibility of interior characters of linear arrays of nonsense characters should be affected by feature interactions to the same extent as interior letters of linear letter-arrays. Furthermore, an exterior-character advantage would also be expected for linear arrays of nonsense characters if feature interactions accounted for the exterior-letter advantage. Therefore, if an imbalance in the amount of lateral interference suffered by interior and exterior letters plays a role in the exterior-letter advantage, the nature of this lateral interference must be such that it would be able to accommodate the absence of an exterior-letter advantage in linear arrays of nonsense characters. The feature interaction account of lateral interference would be able to accommodate this requirement only if it is assumed that feature interactions are specific for features of letters and digits, or if feature interactions for nonsense characters would have a different effect on performance. However, this possibility seems unlikely.

An alternative account for the role of lateral interference in the exterior-letter advantage suggested by Hagenzieker et al. (1990) may be able to accommodate the findings described above. Hagenzieker et al. (1990) argued that lateral interference is caused by inhibitory interactions between "recognition units", a concept introduced by Kahneman (1973) to denote hypothetical entities that represent identity information. According to Hagenzieker et al., each letter in a linear letter-array activates its corresponding recognition unit signalling the presence of that letter in the array. Two factors determine the strength of activation in a recognition unit: the visual acuity gradient and inhibitory interactions between immediately adjacent letters. Because interior letters have immediately flanking letters on both sides while exterior letters have immediately flanking letters on one side only, recognition units for exterior letters suffer less inhibition than recognition units for interior letters, which may offset the initial advantage of more favourable positions in the visual field for interior letters compared to exterior letters (see Hagenzieker et al., 1990, for more details). According to Hagenzieker et al.'s (1990) account of lateral interference, if it is assumed that recognition units more or less correspond with stored representations of familiar objects (in this case letters), the perception of letters may suffer lateral interference without affecting the amount of feature information available for these letters. Furthermore, according to this account of lateral interference, lateral interference may affect performance for letters and digits but not for nonsense characters (letter-like characters made up of letter features or Greek characters).[1] Thus, Hagenzieker et al.'s

[1] Although Greek characters may be familiar to a certain extent, to English readers they may be assumed to be much less familiar than letters of the English alphabet or digits.

(1990) account of lateral interference may explain that an apparent difference in the amount of lateral interference suffered by interior and exterior letters was not matched by a difference in the amount of feature information for interior and exterior letters. Furthermore, this account of lateral interference may also explain the absence of an exterior-character advantage in linear arrays of nonsense characters. Therefore, at first sight, it appears that Hagenzieker et al.'s (1990) account of lateral interference may provide a powerful explanation for the role of lateral interference in the exterior-letter advantage in linear letter-arrays.

However, it seems unlikely that an imbalance in the amount of lateral interference suffered by interior letters and exterior letters can explain the exterior-letter advantage in centrally fixated linear letter-arrays entirely. Indeed, the finding that an exterior-letter advantage was observed for arrays without middle letters in the bar-probe task while this exterior-letter advantage was absent in the forced choice task indicates that a difference in spatial uncertainty for interior and exterior letters contributed to the exterior-letter advantage. In Chapter Six, it was argued that the effect of spatial uncertainty for letters on performance in the forced choice task should be minimal while performance in the bar-probe task may be very sensitive to spatial uncertainty for letters in the array. That is to say, when on each trial the choice of response is restricted to the target letter and a letter not presented in the array, knowing the position of the target letter should not increase the chance of a correct response if the identity of the target is also known. However, in the bar-probe task knowing the position of the target letter is crucial, as the target letter is indicated through its position. Therefore, a difference in spatial uncertainty for interior and exterior letters may not affect performance in the forced choice task when it does have an effect in the bar-probe task. Other differences in the procedure of the forced choice task and the bar-probe task may have imposed different processing requirements in these two tasks. For example, presentation of the target letter in the response display in the forced choice task, may have helped to retrieve the identity of target letters whereas in the bar-probe task this information would be lost. Indeed, an investigation into task specific processes, comparing performance in the bar-probe task and performance in the forced choice task using linear arrays of unrelated letters may be warranted.

However, another finding suggesting that the exterior-letter advantage in arrays without middle letters may reflect a difference in spatial uncertainty for interior and exterior letters was discussed in Chapter Four. That is, when interior letters and exterior letters were both flanked by blank spaces on one side, letters presented on the opposite side of the blank space flanking interior letters on the foveal side may have obscured the interior boundary created by the blank space flanking interior letters. If exterior boundaries functioned as spatial anchors for exterior letters, the lack of spatial anchors for interior letters may have created a difference in spatial uncertainty for interior and exterior letters. This difference in spatial uncertainty for interior and exterior letters may have produced an exterior-letter advantage in arrays without middle letters.

An alternative account for the absence of spatial anchors at interior boundaries may be provided if it is assumed that spatial anchors for interior boundaries are not developed through everyday reading experience. If this is the case, some support for this suggestion can be obtained from Pollatsek and Rayner's (1982) finding that, in textual reading, the first inter-word space to the right of fixation is not used to locate the beginning of the first word in the reading order. Thus, when two letter arrays are presented close to the point of fixation, the interior boundaries of arrays appear to be ignored. However, the effects on spatial uncertainty of mask contours flanking interior letters on the foveal side observed in Experiment 4 indicate that interior boundaries can function as spatial anchors. More specifically, when single letter-pairs were presented to the right of the fixation point, positional uncertainty for interior letters was higher when interior letters were flanked on the foveal side by mask contours than when interior letters were not flanked by mask contours. Thus, flanking mask contours may have disrupted spatial anchors provided by interior boundaries of single letter-pairs presented on the right of the fixation point. Therefore, the most likely explanation for the absence of spatial anchors at interior boundaries, when two letter-pairs were presented simultaneously on either side of a gap centred across the fixation point, is that letters across the gap disrupted spatial anchors at the interior boundaries. Furthermore, if this is the case, the lack of spatial anchors would have affected not only interior letters in arrays without middle letters but also interior letters in complete 7-letter arrays. Thus, a difference in spatial uncertainty for interior and exterior letters may have contributed to the exterior letter advantage in complete 7-letter arrays.

The possibility that spatial anchors are available for exterior letters but not for interior letters corresponds to Mewhort and Campbell's (1978) account of the exterior-letter advantage discussed previously. Mewhort and Campbell (1978) further argued that when the horizontal boundaries of backward masks extended beyond the exterior boundaries of linear letter-arrays, the disruption of spatial anchors for exterior letters should remove the exterior-letter advantage. However, the findings presented in Chapters Three and Four clearly show that this is not the case, as a sizeable exterior-letter advantage was obtained when mask width exceeded the width of target arrays by a substantial amount. Nevertheless, accuracy of report for exterior letters was reduced when mask boundaries extended beyond the boundaries of target arrays compared to when mask boundaries matched the boundaries of target arrays. In part, this effect of mask configuration on the exterior-letter advantage could be attributed to lateral interference provided by flanking mask contours. That is, when wide masks were used, exterior letters may have suffered lateral interference from peripherally flanking mask contours, possibly decreasing the difference in the amount of lateral interference suffered by interior letters and exterior letters in arrays followed by appropriate masks. However, an additional reduction in the exterior-letter advantage when mask boundaries extended beyond array boundaries may have been by a disruption of spatial anchors normally provided by exterior boundaries of linear arrays when mask boundaries match the boundaries of target arrays. Indeed, the analyses of the effects of mask configuration on the position of location error responses in Experiments 2 and 3 suggest that mask contours peripherally flanking exterior letters increased spatial uncertainty for exterior letters when masks extended beyond the horizontal boundaries of target arrays compared to mask matching the boundaries of target arrays. Thus, the effects on performance for exterior letters of mask contours peripherally flanking exterior letters appear to be twofold: on the one hand, the perceptibility of exterior letters may be reduced by lateral interference from peripherally flanking mask contours, while on the other hand, positional uncertainty for exterior letters may be increased.

Although these qualitatively different effects of flanking mask contours on performance do not necessarily have a common cause, it may be that there is some sort of relationship between lateral interference and spatial uncertainty. Furthermore, this relationship between lateral interference and spatial uncertainty may not be restricted to the effects of mask configuration on performance. Indeed, lateral interference and the availability of spatial anchors appear to be closely linked in yet another way. Recall that mask contours flanking interior letters of arrays without middle letters on the foveal side had no effect on performance for either interior letters or exterior letters. That is, there was no difference in performance for interior letters in arrays without middle letters followed by connected masks compared to gapped masks (Experiment 3). The finding that mask contours overlaying the gap in the middle of gapped arrays have no effect on performance for interior letters could be explained by the effect of letters across the gap disrupting spatial anchors at interior boundaries. In addition, however, the effects on performance for interior letters of varying the size of the gap between letter pairs on either side of the fixation point in arrays without middle letters suggests that interior letters also suffered lateral interference from letters across the gap. Thus, letters pairs presented on the opposite side of the gap in arrays without middle letters relative to target letters may have caused lateral interference while simultaneously disrupting spatial anchors.

An account of the effects of mask configuration on performance observed in the experiments reported in this thesis may be provided by the *integration-discrimination hypothesis* of the role of mask configuration proposed by Jordan and colleagues (Jordan & Bevan, 1994a, 1994b; Jordan & de Bruijn, 1993). According to the integration-discrimination hypothesis, target and mask fields can become integrated to form a composite percept incorporating aspects of both stimulus fields. When masks are composed of features similar to those in the letters used in the target display, the integration of mask and target into a composite percept makes it difficult to discriminate between target and mask. Thus, when features of the mask occupy locations adjacent to target letter positions (flanking mask contours), the precise location and spatial extent of each target stimulus may be particularly difficult to determine. The integration/discrimination account of pattern masking may account for the effects of mask configuration observed in the present study. That is, when mask boundaries extended beyond the boundaries of target arrays, information about the horizontal boundaries of arrays may have been lost, because the integration of the mask with the target array may have obscured the precise location and spatial extent of the target array. This may have particularly disastrous effects for spatial anchors at the exterior of linear letter arrays.

It must be noted that the mechanisms underlying the exterior-letter advantage may not be the same for complete 7-letter linear arrays presented unilateral to the fixation point as for complete 7-letter linear arrays presented centred across the fixation point. In particular, when the eccentricity of exterior letters and immediately flanking interior letters on the peripheral end of unilaterally presented complete 7-letter arrays exceeds approximately $1^{\circ}$ of visual angle, an exterior-letter advantage may be produced on that end of the array by an asymmetry in lateral interference between exterior letters and immediately flanking interior letters.[2] Unilaterally presented linear letters arrays have been used to study the exterior-letter advantage with extended exposure durations (Butler & Currie, 1986; Estes, Allmeyer & Reder, 1976; Taylor & Brown, 1972; Townsend, Taylor & Brown, 1971). These studies have used extended exposure durations in order to study the exterior-letter advantage while circumventing contributions of processing order and short-term memory. In these studies, linear arrays were presented generally for as long as it took subjects to report all the letters in the array or for sufficiently long to allow complete read out during stimulus presentation. However, in order to control the level of performance in these studies, arrays were presented unilateral to the fixation point, extending not less than approximately $3.5^{o}$ degrees of visual angle into the periphery. Therefore, although the serial position curve obtained with long exposures of unilaterally presented linear arrays generally shows a sizeable exterior-letter advantage for letters at the peripheral end of the arrays (accuracy for letters close to the fixation point on the foveal side was perfect), it may be that this exterior-letter advantage reflects a particularly large contribution of an asymmetry in lateral interference between exterior letters and immediately flanking interior letters, because of the extreme eccentricity of these letters. Indeed, the contribution to the exterior-letter advantage of an asymmetry in lateral interference may be larger for arrays presented unilateral to the fixation point than for centrally fixated arrays. Thus, the significance of studying the exterior-letter advantage using extended exposure durations of unilaterally presented linear letter-arrays for the study of the exterior-letter advantage in tachistoscopically presented

[2] The visual angle at which an asymmetry of lateral interference between interior-letters and exterior letters of single letter-pairs appeared to produce an exterior-letter advantage was approximately $1^{o}$ for the stimulus material used in the present study. However, the minimum visual angle at which an asymmetry in lateral interference between interior and exterior letters produces an exterior letter advantage may vary according to, for example, the size of the letters used or the interletter spacing.

centrally fixated linear letter-arrays may be limited.

The purpose of this study was to investigate the mechanisms underlying the exterior-letter advantage. Although these mechanisms are probably not specific to word recognition, as the influence of word recognition processes was limited by using arrays of unrelated letters, it seems reasonable to assume that the same mechanisms are involved in the processing of words. Thus, unravelling the mechanisms underlying the processing of arrays of unrelated letters will provide powerful indications towards how words are initially encoded in the visual system. In turn, knowing about how words are initially encoded may impose constraints on theories of word recognition, as it would restrict the nature of the information available to word recognition processes.

In particular, the findings presented in this thesis may have implications for computational models of word recognition (e.g., McClelland & Rumelhart, 1981; McClelland, 1986; Mozer, 1987). For example, the currently most influential computational theory of word recognition is outlined in the *Interactive Activation Model* (IAM) of McClelland and Rumelhart (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). The IAM has three levels of representation: one for letter features (see Chapter Two), one for letters, and one for words. Each level contains a series of nodes: Each word node represents a particular word, each letter node represents a particular letter in a particular position within a word, and a letter-fragment node represents a particular letter fragment in a particular letter position within a word. When a word is presented, letter fragments in each of the letter positions are analysed first and in parallel, and this information feeds forward into the letter level and activates the appropriate letter node for each of the positions in the word. Information about letters in the word then feeds forward to the word level, where a word node is activated which corresponds to the activated letter nodes. When an array of unrelated letters is presented, similar processes occur at the feature and letter levels of processing.

However, although information from the letter level will feed forward into the word level, no word node will be activated, as none of the words corresponds with the combination of all letters. An important aspect of the IAM is that processing in the feature and letter levels is independent across letter positions. That is, nodes in the feature and letter levels are specific for one particular letter position. Thus, the IAM does not accommodate interactions between nodes representing letters in different positions, nor does the IAM allow for supra-letter features like, for example, word boundaries, to play any role in word recognition. In order to account for serial position effects Rumelhart and McClelland (1982, p.76) suggested that information about letters in different positions may become available at different times after target presentation, because processing of input information occurs at different rates for letters in different positions. In particular, Rumelhart and McClelland suggest that input information may become available for exterior letters before interior letters because of lateral interference or attention. When different input processing rates for different letter positions were implemented in the model, a series of simulations produced serial position curves for letters in word recognition very similar to those observed using human subjects. Nonetheless, although lateral interference and attentional processes may cause the exterior-letter advantage, these mechanisms are not explicitly dealt with in the model, as they were implemented only implicitly by arbitrarily setting input processing parameters for each of the letter positions.

However, the findings presented in this thesis suggest that information about array boundaries may also play an important role in the exterior-letter advantage, as they may function as spatial anchors for the location of exterior letters. Furthermore, the importance of information about word boundaries in the word recognition process was highlighted by Jordan (1990, 1994). Jordan argued that the IAM, as presented by McClelland and Rumelhart (1981), is unable to account for the pair-letter effect (see Chapter One). According to Jordan (1990), the feature level would also need to accommodate information about supra-letter features like word boundaries, in addition to information about letter features. Thus, by revealing some of the properties of the exterior-letter advantage, the present thesis may suggest how the IAM may be extended to include more realistic input representations, which could enable this model to account more successfully for human performance.

For example, one way in which words and arrays of unrelated letters may initially be processed is suggested by Watt and Morgan's (1985; see also Watt, 1988) MIRAGE model. At the first stage of MIRAGE the visual image is processed through a wide range of spatial frequency channels. The initial product is a grouping of the large scale structures in the image, and the detection (without localisation) of the finer textual structures. To measure the location of each of the texture elements the contribution of the coarser channels must be progressively switched out. Progressing from the coarsest to finest level of localisation will take time. Thus, initially, only very global information is available in the system, but as processing continues more details about the image become available (Watt, 1988). In such a system, information about array boundaries could become available at relatively early stages of processing, and exterior letters may, therefore, be localised before interior letters. Such a system may explain the important role of array boundary information in the exterior-letter advantage. Furthermore, the IAM with a system such as MIRAGE at its input side may similarly explain how exterior letters of words in combination with word boundary information may play a particularly important role in word recognition.

Finally, another important feature of the IAM is that the activation of letter nodes for each of the letter positions in a word is equally important for activating word nodes at the word level. However, as discussed in the introduction to this thesis, recent research has suggested a special role for exterior letters in the word recognition process (e.g., Bouma, 1973; Forster & Gartlan, 1975; Humphreys, Evett & Quinlan, 1990; Jordan, 1990, 1994; McCusker, Gough & Bias, 1981). As a consequence of the important role of exterior letters in the word recognition process, the IAM needs to attach more importance to the activation of word nodes by activated nodes for exterior letters than to activated nodes for interior letters. Indeed, if information about exterior letters becomes available before information about interior letters, possibly because of reduced lateral interference for exterior-letters, then these letters are particularly suited to both initiate and guide the word recognition process. For example, Forster (1976) proposed that exterior letters are used as an access code to partially activate a subset of word entries and that full lexical access occurs only when sufficient information from the remainder of the word has been extracted to specify one member of this subset.

In conclusion, in these last few pages I have argued that models of word recognition have to deal with the finding that information about exterior letters is processed more effectively than information about interior letters. The findings of this thesis specifically suggest, however, that there is not a single mechanism underlying this exterior-letter advantage. In the IAM this would mean that implementation of lateral interference alone would not be sufficient to capture all of the mechanisms which may be underlying the special role of exterior letters in the word recognition process. At least, a provision would have to be made for the spatial anchoring function of array boundaries as observed in the present study. Furthermore, this thesis shows that the precise mechanisms of lateral interference are not as clear cut as previously assumed. However, before a real appreciation of the effects of lateral interference and the role of spatial anchors can be developed, future research would have to investigate these factors further.

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**Appendix 1:** Target arrays used in stimulus groups 1 and 2 in Experiment 2.

### Stimulus Group 1

Letters in target positions: b,d,g,p,q,t,x,z.
Letters in non-target positions: f,h,n,v.

| *gapped arrays* | | | | *complete arrays* | |
|---|---|---|---|---|---|
| tb | pq | zt | xd | tbvfnpq | ztnvhxd |
| bt | qp | tz | dx | btfvnqp | tzhnvdx |
| pq | tb | xd | zt | pqnfvtb | xdvhnzt |
| qp | bt | dx | tz | qpvnfbt | dxhvntz |
| zb | dp | dq | gt | zbvhfdp | dqnfhgt |
| bz | pd | qd | tg | bzhfvpd | qdfhntg |
| dp | zb | gt | dq | dphfnzb | gthnfdq |
| pd | bz | tg | qd | pdfnhbz | tgnhfqd |
| bg | xq | gz | xp | bgfhvxq | gznhvxp |
| gb | qx | zg | px | gbhvfqx | zgvnhpx |
| xq | bg | xp | gz | xqvfhbg | xpnvfgz |
| qx | gb | px | zg | qxvfhgb | pxfnvzg |

### Stimulus Group 2

Letters in target positions: b,f,h,n,q,v,x,z.
Letters in non-target positions: d,g,p,t.

| *gapped arrays* | | | | *complete arrays* | |
|---|---|---|---|---|---|
| xv | zf | zn | hx | xvpdtzf | znptdhx |
| vx | fz | nz | xh | vxdptfz | nztdpxh |
| zf | xv | hx | zn | zftpdxv | hxgtpzn |
| fz | vx | xh | nz | fzdtpvx | xhtpgnz |
| vh | zq | vb | nf | vhgdpzq | vbdgpnf |
| hv | qz | bv | fn | hvdpgqz | bvpdgfn |
| zq | vh | nf | vb | zqdtgvh | nfpgdvb |
| qz | hv | fn | bv | qztgdhv | fngpdbv |
| bx | nq | qf | bh | bxdgtnq | qfgptbh |
| xb | qn | fq | hb | xbgdtqn | fqpgthb |
| nq | bx | bh | qf | nqtdgbx | bhptgqf |
| qn | xb | hb | fq | qngtdxb | hbtgpfq |

**Appendix 2:** The set of all characters used in the experiments reported in the thesis.

**Appendix 3:** An empirical inter-letter confusion matrix

In the experiments reported in Chapter Six, letters were selected on the basis of their confusability with other letters in the alphabet. However, before that could be done, a measure of the confusability between letters had to be obtained. Therefore, in a separate experiment, the confusability between letters was established.

Over the past one hundred years or so, investigators have established the confusability between letters of various fonts, under various experimental circumstances, and for various reasons (e.g., Bouma, 1971; Gilmore, Hersch, Caramazza & Griffin, 1979; Geyer & De Wald, 1973; Geyer & Gupta, 1981; Sanford, 1888; Townsend, 1971a, 1971b; Van der Heijden, Malhas & Van den Roovaart, 1984). However, most studies were restricted to establishing the confusability among upper-case letters (Geyer & De Wald, 1973; Townsend, 1971; Van der Heijden et al., 1984), while in the present study target arrays consisted of lower-case letters. Only one study, by Bouma (1971), provides a full set of confusability scores for the entire lower-case alphabet. However, for the present study, even the confusability measures reported by Bouma (1971) may be of limited value. Even in Bouma's study confusability was measured for letters of a different typeface than the letters used in the present study. The confusability between letters may be different for different fonts.[1] The most important reason for not using the confusability values provided Bouma (1971), however, is that Experiments 9-11 used briefly presented backward pattern masked displays. The masks consisted of pseudo-random arrangements of letter features. These letter features, overlaying (and flanking) briefly presented letters may affect the

[1] Bouma (1971) obtained confusability measures for letters of the typeface "Courier 10", which has pronounced serifs, while the font used in the present study has no serifs at all (see Appendix 2).

appearance of previously presented letters and, therefore, the confusability with other letters in an unpredictable way. Indeed, Bouma (1971) found pronounced differences between the pattern of confusabilities under different experimental conditions. This indicates that confusability scores needed to be obtained under conditions which resembled the conditions of Experiments 9-11 as closely as possible.

Therefore, Experiment 12 measured the confusability between letters of the font used throughout the experiments reported in this thesis were obtained, using briefly presented display of backward pattern masked single letters.

**Method**

*Subjects.* 21 subjects from the same population as the experiments reported in the body of this thesis participated in two 1-hr sessions in Experiment 12.

*Stimuli.* Target displays consisted of single lower-case letters of the same font as used in the previous experiments, presented at the fixation point.[2] All 26 letters of the alphabet were used.

*Visual Conditions.* The width of letters varied between approximately $0.03^{o}$ of visual angle for the narrowest letters (i.e., 'i' and 'l') and approximately $0.30^{o}$ of visual angle for the widest letters (i.e., 'm' and 'w').

For each trial, a pattern mask was constructed similar to those used in Experiments 9-11. The horizontal visual angle of pattern masks was approximately $0.60^{o}$, and the vertical visual angle was approximately $0.50^{o}$.

*Design.* Each session was divided into two sections (practice and test), with no obvious transition from one section to the next. In the test sections each letter was shown 8 times during 208 trials. Practice sections consisted of 78 trials in which each letter was shown 3 times.

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[2] Although targets in Experiments 9-11 were not presented at the fixation point, even the most eccentric letters were separated from the fixation point by less than a degree of visual angle. It is assumed that within this small area around the fixation point, no serious deviations in the pattern of confusabilities would occur.

*Procedure*. During the practice and test sections for each subject the order in which the letters were shown was re-randomized in both sessions, the only constraint being that in the practice section every letter was shown once in every cycle of 26 trials, and during the test section twice in every cycle of 52 trials.[3]

Stimuli remained on the screen for a predetermined time, after which they were replaced immediately by pattern masks. Masks remained on the screen for 65 msec. After mask offset the screen remained blank until subjects responded by pressing one of the keys on the keyboard corresponding with the letter they thought was presented in the display. The response-letter appeared on the screen approximately $1.0^{o}$ of visual angle below the position in which the test-letter had been presented. The response-letter remained on the screen until subjects pressed a second key to enter their response and move on to the next trial. Before entering a response, subjects were allowed to change their response as often as they liked.

Throughout the practice section exposure durations were re-assessed after each cycle of 26 trials, and throughout the test section after each cycle of 52 trials, and were adjusted if accuracy differed substantially from 50% correct to ensure that performance was in the midrange of the performance scale. The average exposure duration was 33.4 msec.

**Results and Discussion**

The overall percentage correct reports was 50.6%. Frequencies of correct reports for each of the letters are presented along the diagonal starting in the top left corner of Table A3.1. The other cells of Table A3.1 represent the frequency with which letters displayed along the columns of Table A3.1 were incorrectly given as a response when letters displayed along the rows were presented.

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[3] The use of larger blocks in the test sections ensured that a greater degree of randomness could be obtained, which prevented subjects keeping track of the letters presented in each block, and thereby being able to predict to some degree the identity of the letter presented on some trials.

The data presented in Table A3.1 may be converted into percentages, which makes the pattern of incorrect reports more comprehensible. Thus, the proportion of trials in which the target was correctly reported are listed along the diagonal starting in the top left corner of Table A3.2. The other cells of Table A3.2 represent the proportion of incorrect responses in which letters displayed along the columns were reported when letters along the rows were presented.

For Experiments 9-11 the proportions of incorrect reports were used rather than the absolute frequencies. It was thought that the proportion of incorrect reports provides a better reflection of the confusability between letters. That is, the proportion of correct reports is different for each letter. Therefore, if a particular letter was reported the same number of times when two different stimulus letters were presented, it is assumed that the incorrectly reported letter is more confusable with the stimulus letter for which the least number of incorrect reports were made.

Another assumption about the confusability between letters that played an important role in the experiments reported in Chapter 6 was that the pattern of confusions between letters is not necessarily symmetric. That is, it may be the case that letter A is often mistaken for letter B, but not the other way around. This would mean that letter B may be reported more often when letter A is presented than letter A when letter B is presented. However, a popular probability model for estimating the confusability between letters, the so-called *Choice Model* (Luce, 1963, in Heiser, 1988; see also Townsend, 1971), assumes a symmetric matrix of confusabilities. The asymmetry often observed in empirical confusion matrices is attributed by the choice model to response bias (the tendency to favour some responses over others). The choice model was applied to the data listed in Table A3.1, and the matrix of estimated confusability and a vector for response bias were obtained. A method for testing for quasi-symmetry provided by Heiser (1988) showed that the model could account for the observed data ($G^2=350.7$, $p>.05$). However, the deviation of quasi-symmetry almost reached the significance threshold. Furthermore, Heiser (1988) used the same test on a confusability matrix provided by Van der Heijden et al. (1984), and found that the value for quasi-symmetry was too high to believe that the model was satisfactory. Although Van der Heijden et al. (1984) reported a confusability matrix for upper-case letters, there is no reason to assume that an asymmetry in confusabilties is restricted to upper-case letters.

**Table A3.1:** Frequencies of correct reports of stimulus letters and of incorrect reports of not presented letters (next page).

**Table A3.2:** Proportion of correctly reported stimulus letters and the proportion of incorrect responses that each letter was reported when a particular stimulus letter was presented.

| | | | | | | | | | | | | | *RESPONSE* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o | p | q | r | s | t | u | v | w | x | y | z |
| | a | **64** | 6 | 9 | 77 | 3 | 7 | 24 | 12 | 2 | - | - | 3 | - | 8 | 33 | 20 | 34 | 15 | 2 | 4 | 4 | 1 | - | - | 2 | 6 |
| | b | 6 | **236** | 8 | 31 | 1 | 3 | 2 | 7 | - | - | 2 | - | 1 | 3 | - | 8 | 3 | 6 | 2 | 2 | 2 | 1 | - | 1 | 1 | - |
| | c | 7 | 8 | **138** | 49 | 11 | 12 | 5 | 10 | 2 | 2 | 5 | - | 2 | 5 | 11 | 11 | 6 | 18 | 11 | 9 | 5 | 2 | 1 | 1 | 3 | 2 |
| | d | 7 | 9 | 11 | **250** | 3 | 6 | 3 | 3 | 1 | 2 | 4 | 1 | 1 | 3 | 7 | 10 | 2 | 8 | - | 2 | - | - | - | - | 2 | 1 |
| | e | 3 | 1 | 22 | 9 | **231** | 6 | 4 | 5 | 3 | 1 | 1 | 1 | - | 2 | 3 | 2 | 4 | 8 | 10 | 5 | - | 1 | - | 5 | 2 | 7 |
| | f | 3 | 7 | 9 | 12 | 1 | **206** | 5 | 7 | 2 | 6 | 5 | 5 | 1 | 2 | 4 | 8 | 3 | 32 | 1 | 7 | 3 | 1 | - | - | 3 | 3 |
| | g | 8 | 4 | 4 | 24 | 3 | 11 | **202** | 3 | 2 | 3 | 2 | - | - | 4 | 6 | 8 | 32 | 6 | 7 | 3 | - | - | 1 | 1 | 2 | - |
| | h | - | 9 | 6 | 11 | 1 | 10 | 6 | **225** | - | 5 | 7 | 2 | 3 | 15 | 3 | 4 | 3 | 12 | 2 | 2 | 5 | - | - | - | 2 | 2 |
| | i | 4 | 1 | 10 | 22 | 2 | 38 | 6 | 15 | **36** | 32 | 17 | 41 | 6 | 6 | 1 | 10 | 8 | 36 | 3 | 19 | 1 | 1 | 1 | 5 | 5 | 8 |
| *S* | j | 3 | 6 | 5 | 40 | 1 | 27 | 14 | 12 | 16 | **83** | 10 | 18 | 6 | 7 | 2 | 8 | 7 | 22 | 3 | 14 | 3 | 3 | 3 | 4 | 13 | 6 |
| *T* | k | 5 | 12 | 7 | 26 | 3 | 24 | 2 | 21 | 9 | 11 | **107** | 19 | 2 | 4 | 4 | 9 | 2 | 14 | 6 | 13 | 7 | 5 | 3 | 5 | - | 5 |
| *I* | l | 3 | 8 | 2 | 21 | - | 26 | 5 | 9 | 26 | 32 | 11 | **89** | 8 | 1 | - | 11 | 10 | 34 | 4 | 17 | - | 3 | 1 | - | 7 | 7 |
| *M* | m | 2 | 1 | 1 | 2 | 3 | 1 | - | 6 | - | 1 | 1 | 2 | **262** | 17 | 3 | 3 | 2 | 9 | 1 | 3 | 3 | 1 | 11 | 1 | - | - |
| *U* | n | 2 | 1 | 4 | 13 | 3 | 11 | 2 | 38 | - | 1 | 1 | - | 17 | **172** | 5 | 13 | 2 | 21 | 4 | 6 | 3 | 1 | 5 | 5 | 3 | 2 |
| *L* | o | 4 | 12 | 14 | 26 | 5 | 12 | 7 | 3 | - | 2 | 3 | 1 | 2 | 14 | **169** | 24 | 8 | 13 | 8 | 3 | 2 | - | - | - | - | 3 |
| *U* | p | 1 | 7 | 6 | 20 | 5 | 4 | 3 | 2 | - | - | 1 | - | - | 3 | 4 | **249** | 8 | 7 | 7 | 1 | - | 1 | 1 | - | 1 | 4 |
| *S* | q | 9 | 4 | - | 29 | - | 9 | 4 | 2 | 1 | - | 2 | 2 | 1 | 3 | 1 | 24 | **223** | 6 | 5 | 5 | 3 | - | 1 | - | 1 | - |
| | r | - | 7 | 7 | 22 | 2 | 29 | - | 16 | 3 | 10 | 5 | 7 | 2 | 8 | 5 | 10 | 7 | **163** | 8 | 6 | 2 | 3 | 1 | 4 | 4 | 4 |
| | s | 4 | 1 | 19 | 15 | 11 | 6 | 7 | 3 | - | 3 | 1 | 1 | 2 | 5 | 2 | 11 | 3 | 24 | **197** | 6 | 2 | - | 2 | 4 | 3 | 4 |
| | t | - | 9 | 15 | 11 | 11 | 8 | 2 | 13 | 2 | 3 | 7 | 3 | 3 | 4 | 1 | 4 | 2 | 22 | 5 | **193** | 6 | 1 | 1 | 2 | 2 | 6 |
| | u | 5 | 3 | 7 | 21 | 4 | 13 | 3 | 14 | 6 | 6 | 8 | 5 | 7 | 17 | 7 | 5 | 5 | 14 | 8 | 4 | **130** | 12 | 14 | 2 | 13 | 2 |
| | v | 2 | 5 | 16 | 18 | 4 | 24 | - | 14 | 4 | 8 | 3 | 5 | 3 | 10 | 3 | 8 | 3 | 32 | 2 | 11 | 6 | **118** | 5 | 9 | 15 | 8 |
| | w | 2 | - | 1 | 8 | 2 | 5 | 2 | 4 | - | 2 | 2 | 1 | 38 | 5 | 1 | 1 | 2 | 3 | 2 | 1 | 13 | 6 | **239** | 2 | 2 | 1 |
| | x | 3 | 3 | 21 | 32 | 10 | 21 | 6 | 12 | 12 | 10 | 14 | 4 | 7 | 9 | 3 | 3 | 5 | 41 | 7 | 18 | 5 | 11 | 4 | **50** | 8 | 16 |
| | y | 2 | 2 | 5 | 25 | 4 | 11 | 31 | 9 | 4 | 5 | 12 | 3 | 3 | 10 | 5 | 5 | 13 | 14 | 3 | 6 | 8 | 4 | 2 | 6 | **141** | 3 |
| | z | 1 | 2 | 10 | 9 | 3 | 3 | 2 | 4 | 1 | 1 | 3 | - | 3 | 5 | 2 | 4 | 3 | 18 | 2 | 7 | 3 | 1 | 4 | 6 | 5 | **234** |
| | | **150** | **364** | **357** | **823** | **327** | **533** | **341** | **469** | **132** | **229** | **234** | **213** | **380** | **342** | **285** | **473** | **400** | **598** | **310** | **367** | **216** | **177** | **300** | **113** | **238** | **334** |

| | | | | | | | | | | | | | *RESPONSE* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **a** | **b** | **c** | **d** | **e** | **f** | **g** | **h** | **i** | **j** | **k** | **l** | **m** | **n** | **o** | **p** | **q** | **r** | **s** | **t** | **u** | **v** | **w** | **x** | **y** | **z** |
| | **a** | **19.0** | 2.2 | 3.3 | 28.3 | 1.1 | 2.6 | 8.8 | 4.4 | 0.7 | - | - | 1.1 | - | 2.9 | 12.1 | 7.4 | 12.5 | 5.5 | 0.7 | 1.5 | 1.5 | 0.4 | - | - | 0.7 | 2.2 |
| | **b** | 6.0 | **73.2** | 8.0 | 31.0 | 1.0 | 3.0 | 2.0 | 7.0 | - | - | 2.0 | - | 1.0 | 3.0 | - | 8.0 | 3.0 | 6.0 | 2.0 | 2.0 | 2.0 | 1.0 | - | 1.0 | 1.0 | - |
| | **c** | 3.5 | 4.0 | **41.1** | 24.7 | 5.6 | 6.1 | 2.5 | 5.1 | 1.0 | 1.0 | 2.5 | - | 1.0 | 2.5 | 5.6 | 5.6 | 3.0 | 9.1 | 5.6 | 4.5 | 2.5 | 1.0 | 0.5 | 0.5 | 1.5 | 1.0 |
| | **d** | 8.1 | 10.5 | 12.8 | **74.4** | 3.5 | 7.0 | 3.5 | 3.5 | 1.2 | 2.3 | 4.7 | 1.2 | 1.2 | 3.5 | 8.1 | 11.6 | 2.3 | 9.3 | - | 2.3 | - | - | - | - | 2.3 | 1.2 |
| | **e** | 2.9 | 1.0 | 21.0 | 8.6 | **68.8** | 5.7 | 3.8 | 4.8 | 2.9 | 1.0 | 1.0 | 1.0 | - | 1.9 | 2.9 | 1.9 | 3.8 | 7.6 | 9.5 | 4.8 | - | 1.0 | - | 4.8 | 1.9 | 6.7 |
| | **f** | 2.3 | 5.4 | 6.9 | 9.2 | 0.8 | **61.3** | 3.8 | 5.4 | 1.5 | 4.6 | 3.8 | 3.8 | 0.8 | 1.5 | 3.1 | 6.2 | 2.3 | 24.6 | 0.8 | 5.4 | 2.3 | 0.8 | - | - | 2.3 | 2.3 |
| | **g** | 6.0 | 3.0 | 3.0 | 17.9 | 2.2 | 8.2 | **60.1** | 2.2 | 1.5 | 2.2 | 1.5 | - | - | 3.0 | 4.5 | 6.0 | 23.9 | 4.5 | 5.2 | 2.2 | - | - | 0.7 | 0.7 | 1.5 | - |
| | **h** | - | 8.1 | 5.4 | 9.9 | 0.9 | 9.0 | 5.4 | **67.0** | - | 4.5 | 6.3 | 1.8 | 2.7 | 13.5 | 2.7 | 3.6 | 2.7 | 10.8 | 1.8 | 1.8 | 4.5 | - | - | - | 1.8 | 1.8 |
| | **i** | 1.3 | 0.3 | 3.3 | 7.3 | 0.7 | 12.7 | 2.0 | 5.0 | **10.7** | 10.7 | 5.7 | 13.7 | 2.0 | 2.0 | 0.3 | 3.3 | 2.7 | 12.0 | 1.0 | 6.3 | 0.3 | 0.3 | 0.3 | 1.7 | 1.7 | 2.7 |
| *S* | **j** | 1.2 | 2.4 | 2.0 | 15.8 | 0.4 | 10.7 | 5.5 | 4.7 | 6.3 | **24.7** | 4.0 | 7.1 | 2.4 | 2.8 | 0.8 | 3.2 | 2.8 | 8.7 | 1.2 | 5.5 | 1.2 | 1.2 | 1.2 | 1.6 | 5.1 | 2.4 |
| *T* | **k** | 2.2 | 5.2 | 3.1 | 11.4 | 1.3 | 10.5 | 0.9 | 9.2 | 3.9 | 4.8 | **31.8** | 8.3 | 0.9 | 1.7 | 1.7 | 3.9 | 0.9 | 6.1 | 2.6 | 5.7 | 3.1 | 2.2 | 1.3 | 2.2 | - | 2.2 |
| *I* | **l** | 1.2 | 3.2 | 0.8 | 8.5 | - | 10.5 | 2.0 | 3.6 | 10.5 | 13.0 | 4.5 | **26.5** | 3.2 | 0.4 | - | 4.5 | 4.0 | 13.8 | 1.6 | 6.9 | - | 1.2 | 0.4 | - | 2.8 | 2.8 |
| *M* | **m** | 2.7 | 1.4 | 1.4 | 2.7 | 4.1 | 1.4 | - | 8.1 | - | 1.4 | 1.4 | 2.7 | **78.0** | 23.0 | 4.1 | 4.1 | 2.7 | 12.2 | 1.4 | 4.1 | 4.1 | 1.4 | 14.9 | 1.4 | - | - |
| *U* | **n** | 1.2 | 0.6 | 2.4 | 7.9 | 1.8 | 6.7 | 1.2 | 23.2 | - | 0.6 | 0.6 | - | 10.4 | **51.2** | 3.0 | 7.9 | 1.2 | 12.8 | 2.4 | 3.7 | 1.8 | 0.6 | 3.0 | 3.0 | 1.8 | 1.2 |
| *L* | **o** | 2.4 | 7.2 | 8.4 | 15.6 | 3.0 | 7.2 | 4.2 | 1.8 | - | 1.2 | 1.8 | 0.6 | 1.2 | 8.4 | **50.3** | 14.4 | 4.8 | 7.8 | 4.8 | 1.8 | 1.2 | - | - | - | - | 1.8 |
| *U* | **p** | 1.1 | 14.9 | 6.9 | 23.0 | 5.7 | 4.6 | 3.4 | 2.3 | - | - | 1.1 | - | - | 3.4 | 4.6 | **74.1** | 9.2 | 8.0 | 8.0 | 1.1 | - | 1.1 | 1.1 | - | 1.1 | 4.6 |
| *S* | **q** | 7.8 | 3.5 | - | 25.7 | - | 8.0 | 3.5 | 1.8 | 0.9 | - | 1.8 | 1.8 | 0.9 | 2.7 | 0.9 | 21.2 | **66.4** | 5.3 | 4.4 | 4.4 | 2.7 | - | 0.9 | - | 0.9 | - |
| | **r** | - | 4.0 | 4.0 | 12.7 | 1.2 | 16.8 | - | 9.2 | 1.7 | 5.8 | 2.9 | 4.0 | 1.2 | 4.6 | 2.9 | 5.8 | 4.0 | **48.5** | 4.6 | 3.5 | 1.2 | 1.7 | 0.6 | 2.3 | 2.3 | 2.3 |
| | **s** | 2.9 | 0.7 | 13.7 | 10.8 | 7.9 | 4.3 | 5.0 | 2.2 | - | 2.2 | 0.7 | 0.7 | 1.4 | 3.6 | 1.4 | 7.9 | 2.2 | 17.3 | **58.6** | 4.3 | 1.4 | - | 1.4 | 2.9 | 2.2 | 2.9 |
| | **t** | - | 6.3 | 10.5 | 7.7 | 7.7 | 5.6 | 1.4 | 9.0 | 1.4 | 2.1 | 4.9 | 2.1 | 2.1 | 2.8 | 0.7 | 2.8 | 1.4 | 15.4 | 3.5 | **57.4** | 4.2 | 0.7 | 0.7 | 1.4 | 1.4 | 4.2 |
| | **u** | 2.4 | 1.5 | 3.4 | 13.6 | 1.9 | 6.3 | 1.5 | 6.8 | 2.9 | 2.9 | 3.9 | 2.4 | 3.4 | 8.3 | 3.4 | 2.4 | 2.4 | 6.8 | 3.9 | 1.9 | **38.7** | 5.8 | 6.8 | 1.0 | 6.3 | 1.0 |
| | **v** | 0.9 | 2.3 | 7.3 | 8.3 | 1.8 | 11.0 | - | 6.4 | 1.8 | 3.7 | 1.4 | 2.3 | 1.4 | 4.6 | 1.4 | 3.7 | 1.4 | 14.7 | 0.9 | 5.0 | 2.8 | **35.1** | 2.3 | 4.1 | 6.9 | 3.7 |
| | **w** | 2.1 | - | 1.0 | 8.2 | 2.1 | 5.2 | 2.1 | 4.1 | - | 2.1 | 2.1 | 1.0 | 39.2 | 5.2 | 1.0 | 1.0 | 2.1 | 3.1 | 2.1 | 1.0 | 13.4 | 6.2 | **71.1** | 2.1 | 2.1 | 1.0 |
| | **x** | 1.0 | 1.0 | 7.3 | 11.2 | 3.5 | 7.3 | 2.1 | 4.2 | 4.2 | 3.5 | 4.9 | 1.4 | 2.4 | 3.1 | 1.0 | 1.0 | 1.7 | 14.3 | 24.5 | 6.3 | 1.7 | 3.8 | 1.4 | **14.9** | 2.8 | 5.6 |
| | **y** | 1.0 | 1.0 | 2.6 | 12.8 | 2.1 | 5.6 | 15.9 | 4.6 | 2.1 | 2.6 | 6.2 | 1.5 | 1.5 | 5.1 | 2.6 | 2.6 | 6.7 | 7.2 | 1.5 | 3.1 | 4.1 | 2.1 | 1.0 | 3.1 | **42.0** | 1.5 |
| | **z** | 1.0 | 2.0 | 9.8 | 8.8 | 2.9 | 2.9 | 2.0 | 3.9 | 1.0 | 1.0 | 2.9 | - | 2.9 | 4.9 | 2.0 | 3.9 | 2.9 | 17.6 | 2.0 | 6.9 | 2.9 | 1.0 | 3.9 | 5.9 | 4.9 | **69.6** |

**Appendix 4**: Target arrays used in Experiments 9.

| *Target Pair* | *Target position* 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | emgp cmgp | mepy mcpy | ypem ypcm | pgme pgmc |
| | ewpy cwpy | wegp wcgp | pgew pgcw | ypwe ypwc |
| e/c | egmb cgmb | gebw gcbw | wbeg wbcg | bmge bmgc |
| | eybw cybw | yemb ycmb | bmey bmcy | wbye wbyc |
| | ebyw cbyw | bewg bcwg | gweb gwcb | wybe wybc |
| | epwg cpwg | peyw pcyw | wyep wycp | gwpe gwpc |
| | ymep gmep | mypc mgpc | cpym cpgm | pemy pemg |
| | ywpc gwpc | wyep wgep | peyw pegw | cpwy cpwg |
| y/g | yewp gewp | eypm egpm | mpye mpge | pwey pweg |
| | ycpm gcpm | cywp cgwp | pwyc pwgc | mpcy mpcg |
| | ypem gpem | pymc pgmc | cmyp cmgp | mepy mepg |
| | ybmc gbmc | byem bgem | meyb megb | cmby cmbg |
| | weyb meyb | ywcb ymcb | bcwy bcmy | ebyw ebym |
| | wcbg mcbg | gwbe gmbe | gbwe gbme | byew byem |
| w/m | wgcb mgcb | ewbg embg | egwp egmp | yepw yepm |
| | wbge mbge | pwge pmge | ebwg ebmg | bcgw bcgm |
| | wybe mybe | cwyb cmyb | yewb yemb | gbcw gbcm |
| | wpey mpey | bwey bmey | bywc bymc | egbw egbm |

| | | | | |
|---|---|---|---|---|
| b/p | begm pegm | ybwe ypwe | mgbc mgpc | cymb cymp |
| | bcmy pcmy | cbgm cpgm | gcbm gcpm | ewgb ewgp |
| | bycw pycw | mbcg mpcg | ewby ewpy | gcwb gcwp |
| | bgwe pgwe | gbcw gpcw | ymbe ympe | mgeb mgep |
| | bmyc pmyc | ebmy epmy | wcbg wcpg | ymcb ymcp |
| | bwcg pwcg | wbyc wpyc | cybw cypw | wcyb wcyp |