EXPERIMENT II	61
METHOD.....	62
Subjects.....	62
Apparatus and Stimuli.....	63
Procedure.....	63
Design.....	65
RESULTS	65
DISCUSSION	67
GENERAL DISCUSSION	70
REFERENCES	75
Appendix A, Median Correct Reaction Times, Error Rates and Block Differences for the First 120 Subjects for Experiment I	79
Appendix B, Median Correct Reaction Times, Error Rates and Block Differences for the Seven Subjects Replacing Outliers for Experiment I	85
Appendix C, Pilot Description and Results	86
Appendix D, Summary of the Overall Analysis of Variance of Mean Median Correct reaction Times and Error Rates for Experiment I	88
Appendix E, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for .3 Degree Target/Flanker Separation for Experiment I	89
Appendix F, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for .6 Degree Target/Flanker Separation for Experiment I	90
Appendix G, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 1 Degree Target/Flanker Separation for Experiment I	91
Appendix H, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 3 Degrees Target/Flanker Separation for Experiment I....	92
Appendix I, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 5 Degrees Target/Flanker Separation for Experiment I....	93

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

**The Effect of Unattended Digits upon Identification of an
Attended Letter: The Influence of Letter-Digit Separation and
Physical Similarity**

**Gregory L. Craig
Carleton University**

**Thesis submitted in partial fulfilment of the degree of
Master of Arts in Psychology**

January 1992

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-75918-5

Canada

The undersigned hereby recommend to the Faculty of
Graduate Studies and Research acceptance of the thesis
submitted by
Gregory L. Craig
in partial fulfilment of the requirements for
the degree of
Master of Arts

....

Chairman, Department of Psychology

....

Thesis Supervisor

Carleton University

January 1992

task demands or cues that were presented in one or both messages. The messages requested that subjects answer questions about a picture of five simple figures (eg., hearts, circles, squares, or arrows) which were numbered. For example, the subject might be asked by one of two different voices (identifying themselves as Turret or G.D.O.) if there was a circle in position one. Subjects were presented with visual cues either before or after both messages were heard indicating which voice to answer. Attention was measured by the number of errors that the subject made in responding. The results showed that fewer errors were made when subjects knew in advance which voice to answer (Broadbent, 1952a). Broadbent proposed that when a message could be selected via a pre-cue, the semantic information from the unattended stimulus could be ignored and therefore did not get "confused" with the stimulus to be attended. He argued that when no cue for selection was provided, the listeners could not fully process all of the stimuli directed at them. Broadbent reasoned that if all information was identified, then subjects should have had no difficulty in responding to a question regardless of when (ie., pre vs post cue) they were told which voice to respond to. This indicated that the amount of information that could be identified at a given time was limited (Broadbent, 1958).

In another experiment (Broadbent, 1952b), one group of subjects heard the same voice to represent both Turret and

ACKNOWLEDGEMENTS

Sincere thanks to my advisor, Lise Paquet, for all of her help and guidance. I would also like to thank the members of my examining committee: Dr. Hoffman, Dr. Herdman, Dr. Stellmach and Dr. Mercier. Finally, I would like to thank my friends and colleagues for their support and input in writing this thesis.

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
INTRODUCTION	2
Early Selection	3
Filter Theory.....	3
Filter-Attenuation Theory.....	9
Evidence for Early Selection from Visual Processing tasks.....	12
Late Selection.....	22
Evidence for Late Selection from Auditory Processing Tasks.....	23
Evidence for Late Selection from Visual Processing Tasks.....	27
Semantic Processing of the Unattended Stimuli: Assessment from an Early Selection Account.....	34
Semantic Processing of the "Unattended" and "Unprimed" Stimuli: A Re-examination.....	37
The Influence of Unattended Digits upon Target Letters: Problematic Observations.....	41
EXPERIMENT I	46
METHOD.....	47
Subjects.....	47
Apparatus and Stimuli.....	47
Procedure.....	48
Design.....	49
RESULTS	49
Overall Description.....	50
Individual Target/Planker Separations.....	52
Comparisons Across Separations.....	55
DISCUSSION	57

EXPERIMENT II	61
METHOD.....	62
Subjects.....	62
Apparatus and Stimuli.....	63
Procedure.....	63
Design.....	65
RESULTS	65
DISCUSSION	67
GENERAL DISCUSSION	70
REFERENCES	75
Appendix A, Median Correct Reaction Times, Error Rates and Block Differences for the First 120 Subjects for Experiment I	79
Appendix B, Median Correct Reaction Times, Error Rates and Block Differences for the Seven Subjects Replacing Outliers for Experiment I	85
Appendix C, Pilot Description and Results	86
Appendix D, Summary of the Overall Analysis of Variance of Mean Median Correct reaction Times and Error Rates for Experiment I	88
Appendix E, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for .3 Degree Target/Flanker Separation for Experiment I	89
Appendix F, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for .6 Degree Target/Flanker Separation for Experiment I	90
Appendix G, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 1 Degree Target/Flanker Separation for Experiment I	91
Appendix H, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 3 Degrees Target/Flanker Separation for Experiment I....	92
Appendix I, Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for 5 Degrees Target/Flanker Separation for Experiment I....	93

Appendix J, Comparison of Separations of One Degree or Less to Separations Greater than One Degree for Experiment I	94
Appendix K, Subjects' Median Correct Reaction Times and Error Rates [Outliers denoted by (*)] for Experiment II	95
Appendix L, Summary of the Overall Analysis of Variance of Mean Median Correct reaction Times and Error Rates for Experiment II	97

LIST OF TABLES

Table 1	Mean Median Correct Reaction Times and Percent Error Rates for Each Target/Flanker Separation (.3, .6, 1, 3, and 5 degrees), Correlation Block (high or low) and Flanker Validity (valid or invalid) in Experiment I	51
Table 2	Mean Median Correct Reaction Times and Percent Error Rates for Each Correlation Block (high or low) and Flanker Validity (valid or invalid) in Experiment I	66

LIST OF FIGURES

Figure 1	Flanker Validity Effect for the High Correlation (.92) Block, for each Target/ Flanker Separation for Experiment I	56
Figure 2	Letter and Digit Stimuli used in Experiment II: Reduced Physical Differences Between Categories	64

INTRODUCTION

Focusing attention on a stimulus is one of the stages involved in processing information from the environment. For example, when watching a movie, people tend to focus on the "foreground" information such as the characters, their dialogue or their actions. Very seldom does one pay attention to what is happening or what is located in the "background" of the movie. Yet without a background for the action to be set in, most movies would seem strange. Thus, even when attention is fully captivated by one aspect of the movie, some information seems to be derived from the surrounding features which enhance the movie. One important question is to determine the nature of the information that is extracted from unattended locations.

Recently, there has been a heated debate in cognitive psychology concerning the processing of unattended stimuli. A predominant concern among researchers is whether selection of attended stimuli occurs before or after all the stimuli included in a visual scene have been identified (Yantis & Johnston, 1990). On one hand, those who advocate late selection assert that all stimuli need to be semantically processed for selection to occur (Deutsch & Deutsch, 1963). On the other hand, early selection proponents argue that selection occurs before stimulus identification is completed and therefore that only selected or attended stimuli are fully

identified (Broadbent, 1982; Kahneman & Treisman, 1984). To date, it has been difficult to find a conclusive answer to this problem as both viewpoints have accumulated experimental support for their claim. This empirical evidence is reviewed in the next section of this thesis.

Early Selection

Early selection theory states that only attended stimuli are processed semantically (Broadbent, 1958; Cherry, 1953; Treisman, 1960). This implies that the semantic content of a stimulus (i.e., its identity) can only be determined when attention is focused on that stimulus. If only attended stimuli are processed semantically then the basis for selecting which stimulus will receive attention cannot be the semantic content of the information. If selection of stimuli to be attended is not based on the semantic content of the stimulus, what is the basis for selection? Broadbent (1957, 1958) states that selection of a stimulus is based on its physical characteristics. It follows from this statement that unattended stimuli would only be processed in terms of their physical characteristics. To understand the basis for Broadbent's claim it is necessary to review the studies that lead to the formulation of his well-known filter theory.

Filter Theory

Broadbent (1952a, 1952b) instructed subjects to listen to two different messages that were presented simultaneously to both ears. The subjects were to identify and respond to some

task demands or cues that were presented in one or both messages. The messages requested that subjects answer questions about a picture of five simple figures (eg., hearts, circles, squares, or arrows) which were numbered. For example, the subject might be asked by one of two different voices (identifying themselves as Turret or G.D.O.) if there was a circle in position one. Subjects were presented with visual cues either before or after both messages were heard indicating which voice to answer. Attention was measured by the number of errors that the subject made in responding. The results showed that fewer errors were made when subjects knew in advance which voice to answer (Broadbent, 1952a). Broadbent proposed that when a message could be selected via a pre-cue, the semantic information from the unattended stimulus could be ignored and therefore did not get "confused" with the stimulus to be attended. He argued that when no cue for selection was provided, the listeners could not fully process all of the stimuli directed at them. Broadbent reasoned that if all information was identified, then subjects should have had no difficulty in responding to a question regardless of when (ie., pre vs post cue) they were told which voice to respond to. This indicated that the amount of information that could be identified at a given time was limited (Broadbent, 1958).

In another experiment (Broadbent, 1952b), one group of subjects heard the same voice to represent both Turret and

G.D.O., while for another group different voices were used. Subjects were told at the beginning of the experiment which voice they should be attending (Turret or G.D.O.). The same versus different voice manipulation was carried out to determine if voice characteristics could serve as the basis for selection. It was found that subjects made more errors in answering the questions when the two voices were the same than when Turret and G.D.O. were represented by different voices. Broadbent concluded that voice characteristics could be used as an effective cue to selectively attend to one of two messages presented simultaneously.

Broadbent (1954) also examined the possible effects of spatial location of the incoming stimuli. Messages were again presented simultaneously (cf. Broadbent, 1952a) and Turret and G.D.O. were represented by two different voices. In this study, one message was sent to one loud-speaker and the other message was sent to a second loud-speaker. In one condition both speakers were placed in front of the subject (minimal spatial location difference). In the second condition one speaker was placed in front of the subject and the second speaker was placed 90° to the side (large spatial location difference). Broadbent found that subjects made more errors in responding to questions when there was minimal spatial separation of the incoming messages than when the spatial location of the messages was separated by 90°. Broadbent concluded that spatial separation was also an effective cue

for selective attention.

A series of experiments by Cherry (1953) confirmed Broadbent's conclusion. Two messages were simultaneously presented to different locations, the different locations being the right and left ears. The listener was asked to repeat out loud the message to one ear while ignoring the message in the other ear, a process called shadowing (Treisman, 1960). No errors were made in repeating the attended message. However, the listener could recall nothing about the content of the unattended message (Cherry, 1953). The spatial location of the incoming message was again found to be an effective characteristic in selecting which message to attend. To determine what kinds of information might be processed from the unattended ear, the content of information in the unattended ear was manipulated (Cherry, 1953). In one study, the message in the unattended ear changed from being read in English to being read in German. Cherry found that when subjects were asked about the content or characteristics of the unattended message they were not able to identify the language of the message. In another study, the voice presenting the message was either changed from male to female, was presented as a tone, or reversed speech. In this study some subjects noticed that the reversed speech seemed "queer" (Cherry, 1953, p.978). Thus, while the semantic content of the unattended message did not seem to be processed, every subject identified the tone and almost all subjects identified

the change from male to female voices in the unattended message. Thus, the unattended stimuli seemed only to be processed in terms of physical attributes such as voice characteristics or spatial location (Broadbent, 1952b; Cherry 1953).

Based on these examples and numerous other studies (cf. Broadbent, 1958), Broadbent proposed a filter theory of attention consisting of three major principles (Broadbent, 1957). The first is that processing of information is limited. For example, Broadbent (1952a) showed that efficient responding to one of two simultaneous questions required pre-direction of attention to one of the questions. When attention was directed after the questions were heard, more errors were made in answering. The second major principle of filter theory is that selection of information is based on a common physical feature in the sensory inputs. Broadbent stated that intensity, pitch and spatial location of sounds were some identified physical characteristics that could serve as the basis for selection (cf. Broadbent, 1952b). Finally, according to the third principle, the semantic content of unattended stimuli is not processed and the only information from an unattended stimulus that is available are the physical characteristics of that stimulus. For example, when shadowing one message, subjects in Cherry's (1953) study had no idea as to the content of the unattended message.

The unavailability of semantic information from

unattended messages was examined by Moray (1959). A list of seven words were read repeatedly 35 times (unattended message) while the listener shadowed a prose passage (attended message). After the listening task, subjects were given a recognition test and only 1.9 out of 7 words from the unattended message were recognized. Moray concluded that repetition alone was not enough to incur semantic processing of the unattended message. In a second study Moray presented two messages, one to be shadowed (attended) and to be ignored (unattended). Instructions were presented in both the attended and unattended messages. For example, subjects might be told at the beginning of the attended message to shadow the message received in a particular ear. Instructions within the unattended message might tell subjects to stop shadowing the message or to change from the message they were shadowing to the message presented to the other ear. Some messages were prefixed by the subject's name, for example, "John Smith, change to your other ear" (Moray, 1959, p. 57). When instructions were presented in the unattended message, without addressing the subject by name, subjects did not respond to the instructions. However, when the subject's name preceded the instructions, subjects obeyed instructions presented in the unattended message (Moray, 1959).

Moray's results suggest that while the unattended message was being ignored, subjects were nonetheless able to recognize their names in the unattended message. This indicated that

some semantic information from the unattended message could be available. Further evidence of semantic processing of some words in unattended messages was provided by Treisman (1960). She found that subjects repeated some words from an unattended message if the words were appropriate to the message that they were shadowing. Given this new evidence that unattended information broke through the filter, Treisman proposed modifications to the filter theory.

Filter-Attenuation theory

Treisman (1960) noted that the relationship between words in a sentence was an important factor in the correct shadowing of these words. When there is a strong relationship between words, the probability of making the transition from one word to the next is high, that is a high transitional probability exists between the words. Treisman dichotically presented passages of high (attended) and low (unattended) transitional probability. However, during the course of the experiment the messages were switched so that the message that had been shadowed became the unattended message. For example,

Left ear: ...she would come and go with rapid glances at us
Right ear: ...boyhood friend from fish and screamed loudly

leaving on her passage an impression of grace and / is idiotic
singing men and then it was jumping in the tree / charm and

almost there is cabbage a horse which was...
a distinct suggestion of watchfulness.

(Treisman, 1960, p. 243). (/ - indicates message switch)

In this example, the message in the left ear is being shadowed

but at some point during the shadowing task the messages would switch ears. After the switch, the message that was being shadowed (high transitional probability) was sent to the unattended ear and the previously unattended message (low transitional probability) was sent to the attended ear to be shadowed. Treisman found that one or two words from the unattended, high transitional probability message were repeated after the attended message was switched to the unattended ear. In terms of the example above, the subject might have said "charm and" rather than "is idiotic". The repeating of words from the unattended ear was more likely if the message in the attended ear had a high transitional probability. Treisman observed that the only unattended words that intruded were those that had a high probability of being the next word in the attended message.

Treisman (1960) proposed that in order for a stimulus to be identified it had to activate some representation in a system which she called a "dictionary". Moreover, the amount of processing performed on a stimulus had to exceed a threshold level in order to activate its representation in the dictionary. For some words, the threshold for activation is always low and those words always have a high probability of being identified (e.g. a person's name). In other instances, the threshold can be temporarily lowered by context (eg. transitional probabilities). An example would be hearing the words "I walked my" (context), which would lower the

threshold for the word "dog" but not for the word "chair". According to Treisman, when a stimulus is attended, it receives full perceptual analysis which is sufficient to activate its representation in the dictionary. On the other hand, unattended stimuli would be attenuated and would receive only a partial perceptual analysis. In most cases, this reduced perceptual analysis would be below the activation threshold and unattended stimuli would remain unidentified. However, in some cases unattended stimuli might be identified because they correspond to stimuli that have a low threshold to begin with, or to stimuli that have temporarily low thresholds due to context (Treisman, 1960). For example, if an attended message was "I walked my" and the words chair and dog were unattended, the reduced perceptual analysis of the word dog might be enough for its semantic activation, because of a temporary lowering of the threshold due to context. However, the threshold for activation of the word chair in the dictionary would remain high and the reduced processing it receives would be insufficient to exceed the threshold for semantic activation.

A key idea of Treisman's model is that attended and unattended stimuli receive different amounts of perceptual analysis. Evidence in favour of this assumption was provided by Treisman and Geffen (1967). Subjects' task was to shadow one of two messages while simultaneously indicating with a key tap when certain target words were heard in either of the two

messages. The same words were used as targets in each message. For example, if the word "nose" was used as a target in the shadowed message it would also be a target word in the unattended message. Since the subjects' task was to identify the same word in both messages any difference in performance between messages would be seen as differences between processing occurring with and without attention. Since the information in the attended (shadowed) message is not attenuated, then targets in the shadowed message would have more cues (physical and semantic) for identification than targets in the unattended message which are attenuated. Treisman's attenuation theory would predict that more tapping responses would be made to attended target words than unattended target words. The results of Treisman and Geffen (1967) were consistent with this prediction and it was concluded that attended messages received more perceptual processing than did unattended messages.

Both filter theory and filter-attenuation theory arose from experiments using auditory tasks. However, support for these early selection models has also been provided by several recent studies which employed visual processing tasks.

Evidence for Early Selection from Visual Processing Tasks

One of the earliest studies of selective attention using visual stimuli was done by Neisser and Becklen (1975). In this study subjects were presented with two videotapes, one showing a hand slapping game and the other showing a ball

throwing game. In the hand slapping game two pairs of hands were seen, one pair of hands resting (palms down) on the other pair of hands (palms up). The palms down player tries to slap the hands of the palms up player and the palms up player tries to avoid being slapped. The subjects task was to press a response button each time a player slapped the other player's hands (target event). In the ball throwing game the subject saw three males throwing a basketball back and forth to each other at random. The subject pressed a response button each time the ball was thrown (target event). Four "odd" episodes were also videotaped. These included the two hand-slap players shaking hands, or throwing a small ball back and forth. In the ball game, the ball was thrown out temporarily but the players continued playing with an imaginary ball, or the male players were replaced by female players. These odd episodes were included to determine whether unusual events in the unattended game would be noticed. In the first trial, subjects viewed only one of the two games and, in the second trial, subjects viewed the opposite game. In the third trial, subjects saw the superimposed images of the two games, but were only required to respond to events in one game (eg., the hand slapping game). In the fourth trial, the subjects again saw both games but responded to events in the opposite game (eg., ball game). In the fifth and sixth trials, subjects saw the superimposed images of the two games again but were asked to respond to events occurring in both games. In the trials

in which the games were superimposed (3-6) the "odd" events were included in the unattended game. In the first four conditions, where subjects were required to attend to one game, less than four percent of the target events were missed. No differences were found in the number of misses when the games were viewed separately (trials 1-2) as compared to when the two game images were superimposed (trials 3-4) and subjects were asked to attend to only one game. However, when subjects were required to respond to both of the games at once, 20-40% of the target events were missed. These results indicated that it was more difficult for subjects to divide attention between both games than to attend to a single game. When asked about the odd events, at most, only 3 out of 24 subjects identified any specific odd event occurring in the unattended game (Neisser & Becklen, 1975). Therefore, although most subjects were aware that the unattended film was present, they were not aware of the nature of events in the unattended game, indicating that the film received physical processing but not full semantic processing. Subjects could only respond to the content of the attended film. This finding supports the filter theory principle that only attended stimuli are semantically processed.

A similar paradigm was used by Rock and Gutman (1981) who presented two overlapping shapes. The purpose of the study was to examine the effects of attention on memory for unknown/novel line-drawn shapes. Two unfamiliar shapes were

placed, one on top of the other on a card, one shape was drawn in red, the other in green. Subjects were asked to rate the attractiveness of either the red or the green shapes at the beginning of the experiment. The shape that was not rated (unattended shape) was to be ignored. After completion of the rating task, subjects were given a recognition test which involved circling any shape that had been seen during the rating task. Attended and unattended shapes as well as shapes that had not been viewed were presented in the test. The attended shapes were recognized more often than the unattended shapes. The unattended shapes were circled as rarely as the shapes that had not been seen before. In the second experiment, the same procedure was used except that two familiar figures, a house and a tree, were presented. The familiar figures were included to see if the poor recognition of unattended unfamiliar shapes was due to difficulties in remembering unfamiliar shapes. It was hypothesized that the familiar shapes would be easier to remember than unfamiliar shapes. When the familiar shapes were attended they were recognized by 85% of the subjects, but only 10% of the subjects remembered the familiar shape when it was not attended. Thus even familiar shapes were not remembered when they were not attended. These results add further support for the early selection principle that only attended stimuli are identified.

Additional evidence of the lack of semantic processing of

unattended stimuli came from Francolini and Egeth (1981) who used colour as a physical cue for selection. Red target digits were presented between black digits in a circular array. The task consisted of reporting how many red items were present in the display. In some trials, the semantic content of the digits presented in red was incompatible with the number of red items in the array. For example, if all of the red digits were the number "3" and there were two red items, the semantic content of the red items (3) and the verbal response ("two") were incompatible. In other trials, the semantic content (identity) of the red items was compatible with the verbal response. In some trials, the semantic content of the digits presented in black was incompatible with the verbal response. For example, if all the black items were the number "4" and there were two red items, the semantic content of the black items (4) and the verbal response ("two") would be incompatible. Finally, in other trials, the digits printed in black were compatible with the response. The results showed that longer response times were found when the semantic content of the attended red items was incompatible with the response (number of red items) than when the semantic content of red items was consistent with the response. Therefore, it was concluded that the content of attended items was semantically processed. However, the results showed no increase in the reaction time with regard to the compatibility or incompatibility of the semantic content

of black digits (unattended) with the response. Therefore, Francolini and Egeth concluded that the identification of an item was restricted to attended stimuli.

One instance where the semantic content of an unattended stimulus seems to be processed is in the Stroop task. When colour names are incompatible with the actual ink colour in which they are printed, response time to name the ink colour is longer than when the colour name is printed in a compatible ink colour (Stroop, 1935). Since the task is to attend to the colour alone, the interference created by the identity of the unattended colour name (word) is inconsistent with early selection models. However, Kahneman and Henik (1981) noted that in the Stroop task, the ink colour and the colour name are both integral aspects of the same stimulus. They reasoned that, since the entire stimulus should be attended in order to process its colour, then it is not surprising that all aspects of this attended stimulus are semantically processed and that an irrelevant aspect of this attended stimulus interferes with performance (Kahneman & Henik, 1981). According to their logic, if incompatible ink colour and colour name are competing because they are integral parts of an attended stimulus, then Stroop interference should not occur if these aspects are spatially separated and belong to different stimulus objects. Therefore, Kahneman and Henik (1981) separated the colour of the ink from the colour name to determine if this spatial separation would reduce the

interference from the identity of the colour name. Two categories of words were presented, neutral and colour words. The neutral words used were: most, cute, shoe, and long. The four colour words used were the names of the four colours of ink that the words were printed in: red, green, yellow, and blue. The words were presented in a circle or a square, and half of the subjects were told to attend to the circle, the other half attended to the square. The subjects' task was to name the ink colour presented in the attended square or circle. On half of the trials the ink colour of a neutral word was attended. In the unattended location, a colour name was presented that was either compatible or incompatible with the attended ink colour. For example, in the incompatible condition the subject might see the word shoe printed in green ink and in the unattended location the word red might be shown. In the compatible condition the word green would appear in the unattended location. In the remaining half of the trials, the ink colour of a colour name was attended. Here, both the colour name and the ink colour would be in the attended location. The subject might see the word red printed in red ink (compatible condition) in the attended location or see the word red printed in green ink (incompatible condition). A neutral word was presented in the unattended location.

When the irrelevant colour names were presented in an unattended location, there was only a 12 millisecond (ms)

difference in reaction times between the compatible and incompatible conditions. However, when irrelevant colour names were presented within the attended object, the difference in reaction time between compatible and incompatible conditions was 250 ms. Since the Stroop effect was unreliable when colour words were in an unattended location, Kahneman and Henik concluded that the semantic processing of unattended colour words was minimal. The semantic processing of colour words that interferes with naming ink colours seems to occur only when the colour words appear in an attended location (Kahneman & Henik, 1981). These results conform to the early selection model of attention.

The difference between the type of processing performed on attended and unattended stimuli was also examined by Johnston and Dark (1985) by using physical and semantic priming. Semantic priming refers to the fact that responding to a word such as "doctor" is facilitated by first presenting the word "nurse". Physical priming refers to the facilitation the response to the word "doctor" by prior presentation of the same word (ie., doctor). Words were presented one at a time in one of four squares. Two squares were placed side by side and the remaining squares were placed above and below the first two squares. Half of the subjects attended the side-by-side squares and the remaining subjects attended the squares on the top and bottom. In one condition, a semantic prime was

presented either in one of the attended squares, or in one of the unattended squares. In another condition, a physical prime was placed in an attended or an unattended square. A row of nine X's (mask) was presented 67, 200, or 500 ms following the prime. Following presentation of the mask, the four square display was replaced by a random patterns of 300 dots placed over a test word. Dots were removed at the rate of one every 20 ms. The task was to identify the test word before all of the dots were removed. Priming of the test word would be indicated by its faster identification, when it had been physically or semantically primed as compared to words which were unprimed (control). The results showed that no semantic priming was apparent for unattended words. However, physical priming for unattended words did occur. On the other hand, for attended words, both semantic and physical priming was observed. Johnston and Dark (1985, 1986) concluded that only physical information is processed from unattended stimuli. In agreement with early selection models, semantic priming, which requires semantic processing, only occurred when a stimulus was attended. Thus the results of this study support the early selection view that attended and unattended stimuli receive different kinds of processing.

Additional evidence that unattended stimuli remain unidentified was provided by Yantis and Johnston (1990). The purpose of their experiment was to determine if attention could be focused narrowly enough to prevent interference from

unattended stimuli. Subjects were asked to determine whether or not a target letter was present in a circular display of eight letters. The target location was indicated prior to display presentation by one of two cues. The first cue was an arrow displayed beside the location where the target would appear (peripheral cue). The second cue was an arrow in the centre of the circle pointing like a clock hand to the location of the target (central cue). In some of the trials, a letter identical to the target was presented in an uncued location (redundant target). According to early selection, if attention was focused only on the cued target location, then the unattended redundant target should not interfere with response time. In contrast, if unattended stimuli are semantically processed, then the semantic content of an unattended redundant stimulus would interfere with responses to the target. As predicted by early selection theory, results indicated that there was no difference between trials where a redundant target was present and trials where there was no redundant target. This indicated that when attention could be reliably pre-cued, irrelevant stimuli did not affect responses to a target. Yantis and Johnston (1990) concluded that subjects could effectively attend to a particular stimulus while excluding irrelevant stimuli from semantic analysis.

In summary, studies from both visual and auditory attention provide converging evidence in favour of the three

main principles of early selection stated by Broadbent (1957). First they demonstrate that the perceptual system is limited in its capacity to perform semantic processing. Second, they show that only attended stimuli receive semantic processing, while unattended stimuli are only processed on a physical level. Finally, they establish that physical characteristics of stimuli can serve as effective cues for attentional selection. However, as the evidence for early selection accumulated, an impressive number of studies were being produced which were consistent with the rival view that stimulus identification is an automatic process, not requiring attention.

Late Selection

Late selection theorists proposed that all stimuli are first identified before they are selected for further processing. Since all stimuli are identified, an unattended stimulus could have an influence on the ongoing processing of an attended stimulus (Miller, 1987).

Deutsch and Deutsch (1963) were the first researchers to propose a late selection theory of attention, to try to explain how stimuli from an unattended message could influence processing of an attended message. Ironically, their starting point was the same experimental result which had prompted the development of filter-attenuation theory. Deutsch and Deutsch (1963) cited the results of Moray (1959; see section on early selection) as evidence for their theory of attention. Since

Moray's subjects could respond to hearing their names in an unattended message, Deutsch and Deutsch argued that semantic information must have been fully processed from the unattended message. Deutsch and Deutsch proposed that selection occurred based on the importance of the stimulus. A stimulus that was very important, a person's name for example, would gain access to awareness. However, a less important stimulus, presented at the same time would not gain access to awareness. A "discriminatory mechanism" (Deutsch & Deutsch, 1963, p. 83) would weigh the importance of each stimulus and the most important stimulus would be selected to receive further processing. A key difference between Deutsch and Deutsch's theory and filter attenuation theory (Treisman, 1960) is that the former claims that "all sensory messages which impinge upon the organism are perceptually analyzed at the highest level" (p. 85). This belief is not shared by the filter-attenuation model which postulates that attended stimuli receive a more complete perceptual analysis than unattended stimuli.

Evidence for Late Selection from Auditory Processing Tasks

One of the earliest supporters of the Deutsch and Deutsch (1963) late selection theory was Norman (1968). Norman used a dichotic listening task in which subjects in the experimental condition shadowed a list of words presented to one ear while six two-digit numbers were presented simultaneously to the unattended ear. A tone was presented in

the unattended ear which indicated to the subject to stop shadowing. Immediately or following a 20 s delay subjects were presented with a number and asked to say whether it had been previously presented in the unattended ear. In a control condition, subjects were only presented the with list of numbers and were asked to shadow it. A tone was presented either immediately after presentation of the list or with a 20 s delay and subjects were given the same recognition task as in the experimental condition.

The results showed no difference between the number of digits correctly recognized in the experimental condition when the recognition test was given immediately after shadowing (68%) and the control condition (70% immediate test, 67% delayed test). For both groups, subjects incorrectly identified new numbers as being part of the previously presented list on only 35% of the trials. In the experimental condition where the number recognition test was delayed, 69 percent of the numbers were recognized correctly but 62 percent of the new numbers were falsely recognized. Therefore, Norman concluded that the unattended numbers had been semantically processed. Furthermore, he stated that, since the numbers were only correctly recalled immediately after they had been presented to the unattended ear, the unattended numbers must quickly decay from a short-term memory store.

Norman (1968) proposed that all stimuli are initially

processed physically and are stored in short-term store where they contact their semantic representations. Based on incoming stimuli, the semantic information available and expectation of future inputs, a level of stimulus pertinence is established. Norman proposed that the strength of pertinence and of sensory input would determine which stimuli were selected for further processing. Therefore, in accordance with Deutsch and Deutsch's model, the selection of a stimulus to be attended only occurred after the semantic processing of all stimuli is completed.

Mackay (1973) also found that semantic processing of unattended words occurs. His subjects shadowed ambiguous sentences. For example, the subject might shadow the sentence "They threw stones toward the bank yesterday" (Mackay, 1973, p. 27). In this sentence, the word "bank" could be interpreted as being either a building or a river. In the unattended message, words were presented that would bias the subject to one of the two possible interpretations. For example, the word "river" was presented to half of the subjects and the word "money" was presented to the remaining subjects. Subjects were given a test after they had shadowed all of the messages, which consisted of presenting the two alternative sentence meanings for each of the sentences that had been shadowed. Subjects were asked to pick the sentence that was the closest in meaning to the shadowed sentence. Mackay found that subjects picked the alternative that

corresponded to the word presented in the unattended message. For example, if the unattended word was "river" the subject was more likely to pick the sentence, "They threw stones toward the side of the river yesterday" than, "They threw stones toward the savings and loan association yesterday" (Mackay, 1973, p. 26). Since subjects picked the meaning related to the word that they had been exposed to in the unattended ear more often than chance would predict, Mackay concluded that the unattended words were semantically processed.

Underwood (1977) used a dichotic listening paradigm to seek further evidence for semantic processing of unattended messages. In his experiment, subjects shadowed sentences or lists of words and the latency for stating the final word was measured. In the experimental condition, when a sentence was being shadowed, the unattended message was a string of words, and when a string of words was shadowed, the unattended message was a sentence. The final word in the word list was sometimes appropriate to the context of the sentence. In the control condition, subjects were presented with two lists of unrelated words one of which they were required to shadow. Underwood hypothesized that when context information was provided, subjects would name the final word faster than when no context information was supplied. The results showed that latencies for stating the final word of the sentence were shortest when subjects had been presented with a related word

in the unattended list. Similarly, when the context sentence was unattended, latencies for naming the last word in the word list were shorter than the latencies for the control condition. Thus, the semantic information from the unattended message did have a facilitating influence on the naming of attended words. Therefore, Underwood concluded that semantic information from the unattended stimuli was being processed.

The results of the auditory studies reviewed above, support the notion that semantic processing of unattended information takes place. This conclusion has also been confirmed by several experiments using visual stimuli.

Evidence for Late Selection from Visual Processing Tasks

As previously mentioned, one of the most common paradigms used for selective attention studies is the Stroop task. The Stroop task involves naming the colour of ink that colour words are printed in (e.g., the word BLUE is printed in yellow ink; the correct response is yellow), while ignoring the colour word. When the colour word and ink colour are incompatible, naming the ink colour requires more time than when the colour word and ink colour are compatible.

Keele (1972) used the Stroop task to determine if Stroop interference was due to ink colours and colour names gaining access to memory at the same time. If the two incompatible colours (the colour word and the ink colour) activate memory at the same time, additional time would be required to choose which of the two colour responses should control subject's

behaviour. If the effect is due to the activation of two colours, then presentation of a noncolour word should not interfere with naming the ink colour for that word. Keele presented colour words (red, green, yellow and blue), noncolour words (rat, glass, yankee and bird) and a control condition (letter-like symbols matched in number to the number of letters in the colour words). Subjects saw a word and were asked to press the colour coded button that corresponded with the ink colour of the word. The results showed that only reaction times for colour words were significantly slower than the control condition. Thus, the noncolour words did not cause interference. Keele noted however, that for colour words to cause interference and noncolour words not to interfere, discrimination of word meaning was necessary. Discrimination of word meanings would occur at the memory retrieval stage. Thus, the results of Keele (1972) indicate that both the attended and unattended aspects of the words are processed at the memory retrieval stage. Furthermore, evidence from Posner's lab (Posner and Boies, 1971) indicate that selection might not occur until the response selection stage.

Posner and Boies (1971) used two tasks, a primary and a secondary task, to assess the capacity to make more than one response at a time. The primary task involved viewing the presentation of one letter followed by the presentation of a second letter. The subjects were required to decide if the

letters were the same or different. The secondary task simply involved responding to an auditory stimulus (probe) that was presented at variable times during the presentation of the primary task.

Posner and Boies found that probe reaction time was faster when the probe was presented during the display of the first letter in the primary task. The primary task at this point would have involved the first letter contacting its internal representation in memory (Posner & Boies, 1971). When the probe was presented after the onset of the second letter, reaction time to the probe was slowed. In this portion of the primary task, the subject would be preparing to execute a same/different response. Therefore Posner and Boies concluded that letter recognition was automatic and that interference only occurred when subjects must respond to two events. Therefore, it seems that all stimuli (attended and unattended) could be fully processed (identified) before selection for the purpose of executing a response would occur.

Van Der Heijden, Hagenaar, and Bloem (1984) provide further evidence that unattended words are identified. Van Der Heijden et al. (1984) focused subjects' attention on a neutral word (e.g., late, early, and small), and required them to name the ink colour of the word. These target words, printed in red or blue ink were presented above or below a fixation point. A colour name (the word RED or BLUE) was presented opposite to the position of the target word. Black

bars flanking the coloured word indicated where attention was to be directed. In a control condition, a neutral word (small) was presented opposite the coloured word. Subjects were asked to name the ink colour of the coloured word as quickly as possible. Van Der Heijden et al. found that when the colour of the attended word (red) was compatible with the unattended colour name (RED), colour naming was facilitated. When the attended ink colour and the unattended colour name were incompatible, colour naming was inhibited. Van Der Heijden et al. (1984) proposed that attended and unattended stimuli are both identified.

Underwood (1976) provided converging evidence of semantic processing of unattended stimuli. In his study, pictures were presented on the left side of a screen and words appeared on the right side of the screen. The words were either semantically related or unrelated to the picture. For example, the word "table" would be presented next to a picture of a chair (related) or the word "sail" would be presented beside the picture of a lemon (unrelated). In the control conditions, non-words or no words were presented. The subjects were informed that the picture that they were to name would always be presented on the left side of the screen. Reaction times for naming pictures when unrelated words, non-words or no words were presented were not significantly different. However, there was a significant picture naming delay when an unattended semantically-related word was

presented with the picture to be named. This indicated that semantic information from the unattended word could interfere with responses to a semantically-related, attended stimulus. Underwood concluded that semantic information from attended and unattended stimuli was being processed before selection of the picture occurred.

One source of evidence frequently cited in support of late selection theories has been a study conducted by Eriksen and Eriksen (1974). They used two sets of letter targets, one set being "H" and "K", the other being "S" and "C". Subjects responded by pressing one button if the target was an "H" or a "K" and by pressing a different button if the target was an "S" or a "C". Three letters (the flankers) were presented on both sides of the target. The flanker letters could be the same as the target (hhhHhhh), from the same response set as the target (kkkHkkk), or from the other response set (sssHsss). Thus, the flankers were from a response set that was compatible or incompatible with the target letter. The target letter was presented alone in the control condition. The spacing of the letters was varied. Letters were separated by .06, .50 or 1.00 degree of visual angle. Subjects were told to respond to the target letters and to ignore the flanker letters.

Eriksen and Eriksen found that targets were identified faster when the flanker was from a compatible response set. Responses were slower when flankers were from an incompatible

response set. These effects were noted at the .06, .50 and 1° letter separation conditions, with the .06° producing the greatest difference in reaction times. Eriksen and Eriksen noted that responses to the target were facilitated not only when the target and flankers were physically identical but that response facilitation was also apparent when the flankers and target were from the same response set. This indicated that the flankers had been processed on more than just a physical basis. The semantic relationship between the flanker identity and the target must also have been processed for the flankers to have a facilitory or inhibitory effect on target identification.

One question that remains unanswered from the previous studies is to determine what are the mechanisms by which selection of an attended stimulus occurs. Tipper and Driver (1983) proposed that selection of a relevant item was the result of an active inhibition of the internal representations of unattended stimuli. They reasoned that if inhibition of an unattended stimulus occurs during the selection process, then the subsequent processing of the same or similar stimuli should be delayed. This delay in processing was termed "negative priming". In order to validate this inhibition concept, four stimuli were presented on each trial. In the first presentation, a priming display consisting of either two overlapping pictures or two overlapping words was presented. The picture or word to be attended was drawn in red; the

unattended picture or word was drawn in green. For example, a picture of a dog drawn in red (attended) would be presented, overlapping the picture of a wrench drawn in green (unattended). Subjects were told to determine what category the attended stimulus belonged to, but not to make an overt response. In the above example, the category name for dog would be animal. In the second display, a probe display consisting of a second pair of overlapping pictures/words was presented. For this display, subjects named the category of the picture/word drawn in red. For half of the subjects, the prime display consisted of pictures followed by a probe display of words (or word primes followed by picture probes). The remaining subjects received picture primes followed by picture probes or word primes followed by word probes. The prime was related to the probe in one of five ways: 1) the attended stimulus in the prime display could be attended again in the probe display (e.g., dog-dog), 2) the attended prime could be semantically related to the attended probe (e.g., cat-dog), 3) the unattended prime could be the attended stimulus in the probe display, 4) the unattended prime could be semantically related to the attended probe, and finally 5) neither of the prime stimuli were related to either of the probe stimuli (control condition).

Tipper and Driver (1988) found that when prime words or pictures were attended, responses to the same probe or a semantically related probe were faster than for the control

condition. However, when the prime words/pictures were unattended, responses to the same picture/word or semantically related pictures/words were slower than for an unrelated probe. This result is consistent with the notion that inhibition of the unattended stimulus would delay responses to the same stimulus when that stimulus is subsequently attended. Furthermore, this negative priming also occurred when the unattended stimulus was only semantically related to the attended probe. Tipper and Driver concluded that unattended stimuli are processed for meaning but that their internal representation is inhibited during the course of attentional selection.

In sum, the auditory and visual processing experiments reviewed above all show that information from unattended stimuli can be semantically processed in conjunction with information from the attended stimulus. In addition, late selection theories generally propose that selection of a stimulus for further processing or selecting a stimulus to respond to requires that the stimulus first be semantically processed.

Semantic Processing of the Unattended Stimuli: Assessment from an Early Selection Account

As discussed in the previous section, experiments supporting late selection theories of attention have found that the semantic information available from unattended stimuli can influence responses to an attended stimulus.

However, early selection theorists have put forth two alternative explanations for the results of those experiments. The first early selection account is that there are limitations on how selective processing can be (Paquet & Lortie, 1990; Yantis & Johnston, 1990). Specifically, subjects may not be able to restrict their attention to the target alone, and because of a spreading of attention over neighbouring regions, information from the "unattended" stimuli could be semantically processed. Put simply, the irrelevant information might have been attended and therefore it is not surprising that it was identified. For example, with regards to the Eriksen and Eriksen (1974) study, early selection supporters have argued that subjects cannot selectively attend to one of two (or more) stimuli presented within 1° of visual angle (Yantis & Johnston, 1990). Therefore, even the maximum separation of the flankers and the target used in Eriksen and Eriksen (1974) may not have been sufficient to prevent attention from spreading to the flankers. Hence, in those conditions selective attention was sub-optimal.

The second, related, argument is that the unattended stimuli that are presented are often one of the other responses alternatives, that is, they belong to the same response set as the attended stimuli. The presentation of one member of a response set as relevant material may serve to prime responses to other members from the same set (Kahneman

& Treisman, 1984; Miller, 1987). If we assume that unattended information receives partial perceptual analysis (i.e., filter/attenuation theory), then it is possible that response priming would allow this partial processing to lead to response activation of the unattended information. For example, in the Eriksen and Eriksen (1974) study, the letter flankers were also used as targets. The thresholds for identification of the flankers may have been lowered because the flankers were potential targets.

One clear prediction from this early selection account is that if flanker priming is eliminated, then the unattended flankers should not influence responses to the target. This prediction was tested by Miller (1987) who removed flanker priming by presenting flankers that were never used as targets. Using a variation of the Eriksen and Eriksen (1974) paradigm, Miller presented non-target flankers to determine if semantic processing of nonattended flankers would occur in the absence of priming. Three letters were displayed and subjects were required to identify the middle letter (target) while ignoring the letters on each side (flankers). To see if the flankers were semantically processed, Miller correlated certain flankers with certain responses. For example, an H target (requiring a left-handed response) would be presented more often, that is, 92% (high correlation) or 58% (low correlation) of presentations, with Q's for flankers (valid flankers- QHQ). An S target (right-handed response) would be

presented less often, that is, 8% (high correlation) or 42% (low correlation) of presentations, with Q's for flankers (invalid flankers- QSQ). In contrast, a K flanker was presented more often with the S target (valid flankers- KSK) than with the H target (invalid flankers-KHK). Miller (1987) found that valid flankers, when highly correlated (92%) with a target, facilitated responses to that target by as much as 60 ms (p. 421). When valid flankers were only moderately correlated (58%) with a target, responses to the target were facilitated by only 4 ms. In subsequent experiments, the amount of facilitation noted in the first experiment varied from 20 to 36 ms, but the response facilitation due to the unprimed flankers remained present. Thus Miller concluded that semantic processing of the unattended flankers occurred in the absence of response priming.

Semantic Processing of "Unattended" and "Unprimed" Stimuli: A Re-examination

Miller's study seemed to provide strong evidence of semantic processing of the unattended flankers. However, the amount of influence that the flankers had on responses varied greatly. For example, in his Experiment 1, the flanker effect for valid trials was 60 ms, but in his Experiment 4, the flanker effect was reduced to 20 ms; a difference of 40 ms between experiments. One methodological difference between those experiments that could account for this variation was the use of a fixation point in Experiment 4 to pre-cue the

target location. With a cue specifying the target location, attention could have been pre-directed to the target, facilitating the selection of the target and exclusion of the flankers (Johnston & Dark, 1986; Paquet & Lortie, 1990; Yantis & Johnston, 1990). This early selection argument was advanced by Paquet and Lortie (1990) who argued that the flanker effect might be the result of attention being inadvertently directed at the flankers.

A second problem raised by Paquet and Lortie was that the flankers and targets were from the same semantic category. The main difficulty associated with the exclusive use of letters as targets and flankers is that items from the same small semantic category may be so strongly related that the presentation of one item might prime other members of the same category (Johnston & Dark, 1986; Kahneman & Treisman, 1984). Although Miller did eliminate response set priming, his experiments did not take into account the possible effect of semantic category priming.

In order to test the validity of their claim, Paquet and Lortie (1990) investigated how the magnitude of the flanker-validity effect was affected by 1) whether or not subjects' attention was directed to the precise target location in advance, and 2) whether or not the target and flankers belonged to the same semantic category. Four between subjects conditions were used. The first condition was a replication of Miller's first study. In this condition, attention was not

pre-directed to the target location by a pre-cue and targets and flankers were from the same semantic category (letters). In the second condition, a fixation point was used to pre-cue the target location and letter flankers were used. It was reasoned that when a pre-cue specified the precise target location, attention could be pre-directed to the target more efficiently, facilitating the selection of the target while reducing the likelihood of paying attention to the flankers. For the third condition flankers from a different semantic category (digit) than the target (letter) were used and attention was not pre-directed to the target location. The purpose was to show that the flanker effect, found by Miller, could be reduced by the use of different-category flankers and targets. In the final condition, attention was pre-directed to the target location and the target and flankers were from different semantic categories. This condition investigated whether the influence of flanker category could be seen when early selection of the target on the basis of spatial location was possible.

Paquet and Lortie (1990) replicated the substantial flanker effect found by Miller (1987) when attention was not pre-directed to the target location and when targets and flankers were from the same semantic category. They found a 50 ms reduction in reaction time for valid letter flankers (as compared to invalid flankers) in the 92% (high correlation) block. Only a 2 ms difference was found between valid and

invalid flankers in the 58% (low correlation) block. However, in Condition 2 where attention was pre-directed to the target location, there was only a 25 ms flanker-validity effect in the high correlation block. Moreover, the letter flanker effect was significantly smaller (50 vs 25 ms) when subjects knew the precise location of the target. This indicated that when subjects were uncertain of target location (no pre-cue), it may have been more difficult to restrict attention to the target. This result also suggests that reduced semantic processing of distractors occurs when subjects can pre-direct attention to the target location. The results also showed that, under positional uncertainty (no pre-cue), the flanker validity effect was also reduced (from 50 to 23 ms) when the flankers were digits. This category effect indicated that, when the target location was uncertain, flankers from a semantically different category (from the target) were easier to ignore than flankers from the same semantic category as the target. Finally, the results showed that when subjects' attention was pre-directed to the target (pre-cue), there was no difference in the magnitude of letter flankers (23 ms) and digit flankers (23 ms) validity effect. This finding confirmed the suggestion that semantic processing of the flankers is reduced when prior selection of the target location is possible. Since in Miller's experiment target location was not pre-cued, his claim that flankers were unattended is questionable. In addition, since his targets

and flankers were from the same semantic category, the argument that target responses were un-primed by flankers is doubtful. In sum, the results reported by Paquet and Lortie (1990) are consistent with early selection accounts of selective attention. Specifically, when stimuli can be differentiated early in terms of physical characteristics (e.g., spatial location) or when the likelihood of category and response priming is reduced then the influence of unattended distractors is curtailed (Broadbent, 1982; Johnston & Dark, 1986; Paquet & Lortie, 1990; Yantis & Johnston, 1990).

The Influence of Unattended Digits upon Target Letters:

Problematic Observations

Although Paquet and Lortie (1990) interpreted their results as evidence of early selection, two issues arise from their findings that are puzzling; 1) why was the flanker-validity effect only reduced and not eliminated and, 2) what source of information underlie the category effect (letter vs digit) observed under the no pre-cue condition?. In regard to the first issue, late selection theory would argue that the flanker effect cannot be eliminated because attended and nonattended stimuli are always identified (Deutsch & Deutsch, 1963). This would account for the finding of a residual 23 ms flanker validity effect when attention was pre-directed to the precise target location and the flankers were digits. This can be taken as evidence that, even with pre-knowledge of target location and the absence of flanker category and

response priming, effective early selection is not possible. Alternatively, these results can be accounted for by the failure of selection argument presented earlier. Specifically, it can be argued that subjects cannot selectively attend to one of two (or more) stimuli located within 1° of visual angle (Yantis & Johnston, 1990). Since both Miller (1987) and Paquet and Lortie used a $.3^\circ$ spatial separation between the targets and flankers, it may have been impossible for subjects to totally exclude the distractors from attentional processing. In fact Paquet and Lortie (1990) proposed that if the separation of target and flankers was increased beyond 1° , then selective processing of the target should improve and flanker-validity effect should be eliminated. On the other hand, late selection theory would predict that increasing the spatial separation of targets and flankers will not have a large effect on the flanker-validity effect since attended and unattended stimuli are always identified (Eriksen & Webb, 1989). This question will be examined in the first experiment reported in the present thesis.

The second issue concerns the basis for the category effect. Specifically, one could ask whether physical versus semantic differences underlie the category effect (Cardosi, 1986; Dixon & Shedden, 1987; Duncan, 1983). For example, Cardosi (1986), Dixon and Shedden, (1987), Duncan (1983) and Krueger (1984) have found that it takes longer to find a

letter (digit) when placed in a group of letters (digits) (within-category search) than to find a digit (letter) placed in a group of letters (digits) (between-category search). Two accounts have been put forward regarding the basis of this category effect.

The first account is that the advantage of the between category search is based on the detection of differences in physical features between letters and digits. This account relies on the fact that letters typically look like other letters more than they look like digits. Thus, it would take longer to find a stimulus in a group of physically-similar stimuli (within-category search), than to find a stimulus in a group of physically dissimilar stimuli (between-category search) (Cardosi, 1986). Cardosi (1986) reported data in favour of this account. In her first experiment, half of the subjects had to search for letters among letter distractors (within-category) in the first or second block of trials. In the other block of trials, subjects searched for letters among digit distractors (between-category). The remaining subjects searched for digits among letter (between-category) or digit (within-category) distractors. The letters and numbers used were not physically similar. Cardosi found category effects in that it took longer to find a target among same-category distractors than to find a target among different-category distractors. In a second experiment, the same procedure was used but the letter and number stimuli were highly similar in

appearance. Overall the between-category search was not faster than the within-category search for physically similar letters and numbers. This suggests that the between-category advantage was produced by a physical rather than a categorical difference between digits and letters.

However, there is also evidence supporting a second account of the category effect stipulating that it results from the detection of a categorical distinction between letters and digits. Therefore it would take longer to find a target from a group of stimuli from the same semantic category than to find a stimulus from a different semantic category. Dixon and Shedden (1987) also reduced the physical differences between digit and letter stimuli and found a substantial category effect. They presented the target digit (3), followed by either an array of nine digits (523976129) or an array of eight letters and one digit (PGT3ISZTG). One of the digits presented was either the target digit or a distractor, similar in appearance to the target digit (528976129, same category; PGT8ISZTG, between category). Subjects were asked to determine the target's presence or absence in the array. Their results showed that subjects could determine the presence or absence of digits faster among letter distractors than among digit distractors, indicating a category effect. Since physical differences were reduced and the category effect was still present, then these authors argued that it is likely that semantic differences between letters and digits

produced the category effect.

In light of these results, it is appropriate to ask whether the category effect (i.e., reduction in the flanker-validity when the flankers are digits) reported by Paquet and Lortie (1990) was the result of improved selection based on the early selection of a physical distinction between the letters and digits, or was it based on a later detection of a categorical distinction between the letter target and digit flankers which would help exclude the flankers from full semantic analysis leading to identification. An early selection account of the category effect would state that the category effect resulted from improved target selection based on obvious physical differences between letters and digits (Cardosi, 1986). That is, the reduction in the magnitude of the flanker effect found when digit flankers were used, may have resulted from using the physical differences between the digit flankers and the letter target to locate the target and exclude the flankers. In the second experiment reported in the present thesis, an attempt to settle this issue will be made by reducing the physical similarity between the target letters and the digit flankers. Early selection accounts would predict that reducing these physical differences should decrease the efficiency with which subjects can locate the target, and consequently an increase in the digit flanker-validity effect might be found. However, if a categorical distinction is responsible for the effect, then no difference

in the magnitude of the digit flanker-validity effect should be found whether physically similar or physically dissimilar digit flankers are used. In other words, improved target selection should continue to occur based on the late detection of a categorical distinction between target and flankers.

EXPERIMENT I

As two conflicting theoretical implications can be drawn from Paquet and Lortie (1990)'s report of residual flanker-validity effects, a systematic manipulation of the target/flanker separation ($.3^\circ$, $.6^\circ$, 1° , 3° , and 5°) was undertaken in Experiment I. If subjects cannot selectively attend to a target within 1° ($.3^\circ$, $.6^\circ$ and 1°) of visual angle then Paquet and Lortie's results should be replicated when distractors are within 1° of visual angle from the target. Increasing the separation of the targets and flankers beyond 1° (3° and 5°) should facilitate target selection. Therefore, at the largest separations (beyond 1°), the flanker effect should be eliminated. This result would be consistent with an early selection view of attention. In contrast, the observation of residual flanker-validity effects, at the largest separations (3° and 5°), would be consistent with late selection accounts of selective attention.

Method

Subjects

Subjects were 120 students from Carleton University ranging in age from 18-45 years who participated for course

credit in a single session lasting 45 minutes. Seven subjects (See Appendix A) were excluded from further analysis because in comparison with Lortie (1989) and Paquet and Lortie (1990), their absolute median reaction time was unusually long (more than 2.5 standard deviations from the mean, or greater than 968 ms) or because they exhibited an atypical reaction time difference between the two blocks of trials (more than 2.5 standard deviations from the mean block difference, or a block difference of more than 379 ms). Data for the seven subjects were replaced with those collected from seven additional subjects (See Appendix b).

Apparatus and Stimuli

Each stimulus display consisted of a letter target with a digit appearing on both sides of the target. The stimuli were white, presented on a black background. All characters subtended 2.29° of visual angle vertically and 1.1° horizontally. The characters were separated by $.3^\circ$, $.6^\circ$, 1° , 3° or 5° of visual angle (edge to edge). A pilot test (See Appendix C for a description of procedures and data analysis) was conducted to determine if flanker stimuli could be identified when they appeared 5° in the periphery. The pilot test indicated that characters could be accurately identified ($\chi^2(4) = 6257.75$, $p < .01$). Stimuli were presented on a Zenith ZCM-1490 14" monitor and subjects were positioned 60 cm away from the monitor. Responses were made by pressing one of two buttons ("1" and "0") at the top of the keyboard. Subjects

initiated each trial by pressing the spacebar at the bottom of the keyboard. The subjects used the index fingers of each hand to press the response buttons.

Procedure

Subjects were asked to serve in two blocks of 192 trials. For each subject in each block of trials a set of four letter targets was chosen at random from the set A-W and two digits were randomly selected from 1-9 to serve as flankers.

A digit flanker in the high-correlation block (.92) was presented 88 times (valid flanker) with the two targets requiring a right response (44 trials per target). The same digit flanker was presented with targets requiring a left hand response eight times (invalid flankers; 4 trials per target). A different digit flanker was presented 88 times with the set of targets requiring a left hand response and eight times with targets requiring a right hand response. In the low-correlation block (.58) there were 56 trials where targets were presented with valid flankers and 40 trials where targets were presented with invalid flankers. Half of the subjects received the low- correlation block first and the other half received the high-correlation block first.

The four target letters were presented on-screen at the beginning of each block of trials. The target letters were printed on tags, taped above the corresponding response key. Subjects were informed that they were going to see a fixation point at the beginning of each trial. The fixation point (+)

appeared in the same spatial location as the target. When they pressed the start button, the fixation point was replaced by a row of three characters. Subjects were told that targets only appeared in the middle position and to ignore the other characters. The stimulus display remained on-screen until the subject responded or until 10 seconds have elapsed. Accuracy information was presented for one second at the end of each trial. Subjects were told to try to make all responses quickly and accurately.

Design

A 5 X 2 X 2 mixed Analysis of Variance was used. Target/flanker separation (.3°, .6°, 1°, 3° or 5°) was a between-subjects factor; response correlation strength (.92 or .58) and flanker validity (valid or invalid) were within-subjects factors. Subjects were randomly assigned to each level of the between subjects factor. The dependent variable was mean median reaction time for target identification and mean number of errors in target identification.

Results

The results section is composed of three parts. The first part presents the results of the overall analysis. The second part presents the results for each level of target/flanker separation (between-subjects variable). The third section compares the magnitude of the flanker-validity effect for the high correlation block across target-flanker separations.

Overall Description

Median correct reaction times (RT) for each flanker validity level in each correlation block were calculated for each subject under each level of target/flanker separation. The mean median RTs and the error rate (%) for each testing condition are presented in Table 1. A mixed design analysis of variance (ANOVA) was conducted on the reaction time and error data (outliers excluded) to examine the effects of target/flanker separation, correlation block, and flanker validity (See Appendix D).

The ANOVA of the median correct reaction times revealed a main effect of flanker validity, $F(1,115) = 8.90$, $MS_e = 630.23$, $p < .005$. Target identification was faster when targets were presented with valid flankers (571 ms) than when presented with invalid flankers (578 ms). No other main effects were significant. There was also a significant interaction of correlation block and flanker validity, $F(1,115) = 7.09$, $MS_e = 420.73$, $p < .01$. There was a reliable difference between reaction times for invalid (581 ms) and valid (570 ms) flankers in the high correlation block [$F(1,119) = 10.61$, $MS_e = 790.62$, $p < .005$] but not in the low correlation block where valid (573 ms) and invalid (575 ms) flankers difference was not significant [$F(1,119) = .736$, $MS_e = 278.55$, $p > .05$]. No other interaction was significant.

The error rate was low (3 %) across all testing sessions. The main effect of separation was significant, $F(4,115) = 3.33$,

Table 1

Mean Median Correct Reaction Times and Percent Error Rates for
Each Separation (.3°, .6°, 1°, 3°, or 5°) X Correlation Block
(High or Low) and Flanker Validity (Valid or
Invalid) in Experiment 1

		<u>Flankers</u>				
		<u>Valid</u>		<u>Invalid</u>		
		RT	%	RT	%	Validity
<u>Separation</u>	<u>Correlation (in ms)</u>	<u>Error (in ms)</u>	<u>Error</u>	<u>Error</u>	<u>Error</u>	<u>Effect</u>
.3°	High	559	3.1	583	6.2	24
	Low	574	3.4	576	3.4	2
.6°	High	579	2.5	599	2.5	20
	Low	573	2.5	577	3.1	4
1°	High	538	3.0	548	6.4	10
	Low	555	3.5	553	4.1	-2
3°	High	566	2.5	562	3.0	-4
	Low	574	2.2	573	1.9	-1
5°	High	607	1.8	614	1.7	7
	Low	590	1.6	597	2.0	7

$MS_e = .0033$, $p < .01$. Post-hoc analysis (Tukey's HSD) indicated that subjects were less accurate (95.8 %) at the 1° target/flanker separation than at the 5° separation (98.2 %), $p < .05$. The main effect of flanker validity was significant [$F(1,115) = 7.73$, $MS_e = .0011$, $p < .01$] and target identification was more accurate when targets were presented with valid flankers (97.4 %) than with invalid flankers (96.6 %). No other main effects were significant. The correlation X validity interaction was significant, $F(1,115) = 4.06$, $MS_e = .0001$, $p < .05$. Subjects responded more accurately to targets presented with valid flankers (97.4 %) than invalid flankers (96.0 %) in the high correlation block [$F(1,119) = 7.33$, $MS_e = .0016$, $p < .01$] while in the low correlation block, error rates for targets with valid (97.4 %) or invalid (97.1) flankers were approximately equal [$F(1,119) = .896$, $MS_e = .0005$, $p > .05$]. No other interactions were significant.

Individual Target/Flanker Separations

In accordance with Paquet and Lortie (1990), analysis of reaction times and error rates were conducted to determine the effect of correlation block and validity at each level of target/flanker separation.

.3 Degrees. The RT ANOVA (See Appendix E) showed a significant effect of validity, $F(1,23) = 7.68$, $MS_e = 528.40$, $p < .01$. The main effect was due to faster responses (566.5 ms) to targets with valid flankers than to targets with invalid flankers (579.5 ms). The correlation X validity interaction

[$F(1,23) = 6.75$, $MS_e = 430.36$, $p < .02$] was also significant. As can be seen in Table 1, a significant flanker effect (24 ms) was evident in the high correlation block [$F(1,23) = 11.01$, $MS_e = 627.59$, $p < .005$], but not in the low correlation block (2 ms) [$F(1,23) = .14$, $MS_e = 331.17$, $p > .1$]. No other effects were significant.

Analysis of the error rates indicated that the main effect of validity was marginally significant [$F(1,23) = 3.44$, $MS_e = .0016$, $p = .07$] due to subject responses being more accurate when valid flankers (96.8 %) were presented than when invalid flankers were presented (93.2 %). The correlation X validity interaction also approached significance, $F(1,23) = 3.63$, $MS_e = .0015$, $p = .07$. Analysis of the high correlation block established that subjects responded less accurately when invalid flankers (93.8 %) were presented than when valid flankers (96.9 %) were presented [$F(1,23) = 6.51$, $MS_e = .00492$, $p < .05$]. In the low correlation block there was no difference in subjects' response accuracy between valid (96.58 %) and invalid (96.58 %) flanker presentations.

.6 Degrees. The RT analysis (See Appendix F) showed a significant effect of validity, $F(1,23) = 6.40$, $MS_e = 548.73$, $p < .02$. As with the .3° separation, subjects responded faster when valid flankers (576 ms) were presented than when invalid flankers were presented (588 ms). The correlation X validity interaction was significant, $F(1,23) = 5.38$, $MS_e = 298.01$, $p < .05$. In agreement with the pattern of results for the .3°

separation, the 20 ms validity effect in the high correlation block was significant [$F(1,23) = 8.34$, $MS_e = 591.47$, $p < .01$] but the 4 ms validity effect in the low correlation block was not [$F(1,23) = .72$, $MS_e = 255.27$, $p > .1$]. No other effects were significant. Analysis of the error rates did not reveal any significant effects.

1 Degree. Analysis of median correct reaction times at this level of target/flanker separation revealed that only the correlation X validity interaction was reliable, $F(1,23) = 4.70$, $MS_e = 224.90$, $p < .05$. No other effects were significant (See Appendix G). However, the 10 ms validity effect in the high correlation block was not significant [$F(1,23) = 2.71$, $MS_e = 525.53$, $p = .11$], nor was the -2 ms effect in the low correlation block [$F(1,23) = .21$, $MS_e = 323.01$, $p > 1$].

Analysis of the error rates revealed a marginal main effect of validity, [$F(1,23) = 3.98$, $MS_e = .0025$, $p = .06$]. Similarly, the correlation X validity interaction only approached significance [$F(1,23) = 2.91$, $MS_e = .0016$, $p = .1$]. Analysis of the high correlation block indicated a significant effect of validity [$F(1,23) = 4.18$, $MS_e = .0034$, $p < .05$] where target identification was more accurate for valid (97 %) than for invalid flankers, whereas analysis of the low correlation block did not expose a significant validity effect ($F < 1$) indicating approximately equal accuracy for valid (96.5 %) and invalid (95.9 %) flankers.

3 Degrees The RT and error data both failed to show

significant effects for correlation, validity, or for the correlation X validity interaction ($F < 1$ for all effects; See Appendix H).

5 Degrees As with the previous ANOVAs, no significant effects of correlation, ($F < 1$), validity [$F(1,23) = 1.29$, $MS_e = 957.17$, $p > .1$] or the correlation X validity interaction ($F < 1$) (See Appendix I).

Comparisons Across Separations

Consistent with Paquet and Lortie (1990), planned comparisons were conducted to determine if target/flanker separation had an effect on the magnitude of the flanker validity effect in the high correlation block. A flanker validity score was found by subtracting valid trials' median latency from invalid trials' median latency for each subject at each of the five levels of target/flanker separation. The results are presented in Figure 1. As can be seen in Figure 1, the magnitude of the flanker-validity effect tends to decrease around 1° target/flanker separation and was eliminated at 3° and 5° separations.

In order to verify the prediction that distractors presented more than 1° away from the target would not affect target responses as much as those presented within 1°

separation, the average flanker-validity effect for separations of $.3^\circ$, $.6^\circ$, and 1° was compared with that for 3° and 5° separations. Flanker-validity effects for each subject in the $.3^\circ$, $.6^\circ$ and 1° groups were collapsed and compared to

Figure 1

Flanker Validity Effect for the High Correlation (.92) Block, for each Target/Flanker Separation for Experiment I

the flanker-validity effects for each subject, collapsed across the 3° and 5° groups. A summary of this analysis is presented in Appendix J. The difference in magnitudes of the flanker-validity effect between separations of 1° or less and separations greater than 1° was significant, $F(1,46) = 4.05$, $MS_e = 799.55$, $p < .05$. Thus, highly correlated flankers presented more than one degree from the target had no effect on target responses (1.97 ms flanker validity effect). However, at separations of one degree or less, flankers had a reliable effect on responses to targets (18.39 ms).

Discussion

The results of the present experiment are in general agreement with those reported by Paquet and Lortie (1990). In particular, the magnitude of the flanker-validity effect in the high correlation block at the .3° target/ flanker separation (24 ms) is approximately equal to the 23 ms effect found by Paquet and Lortie. Effects of such magnitude are observed when, as in the present study, a fixation point is used to pre-direct attention to the target location and when the target letter is surrounded by digit flankers. On the other hand, the results from the low correlation block in the present study were somewhat different, in that no reliable effect (2 ms) was found, while a small but reliable effect was found by Paquet and Lortie. The reason for this discrepancy is unclear. However, despite this difference, the two studies show the same pattern of results. That is, larger validity

effects are observed in the high correlation block than in the low correlation block.

At the $.6^\circ$ and 1° target/flanker separations, the same pattern of results was evident. That is, the effect of flanker-validity in the high correlation block was larger than the effect of validity in the low correlation block. This pattern suggests that it was difficult to exclude or filter out distractors completely when they were presented 1° from the target (Yantis & Johnston, 1990).

Beyond 1° of target/flanker separation, a very different pattern of results emerged. At 3° and 5° separations, there were no reliable validity effects in the high or the low correlation blocks. Thus, effective exclusion or filtering of the distractors (ie., flankers) is possible when the distractors are presented 3° or 5° away from the target.

The results of Experiment 1 are more consistent with early selection theories of attention. First, the results confirm the idea that Miller's (1987) original flanker-validity effect might have been the outcome of a selective attention failure due to target position uncertainty (ie., no fixation) and to the use of letters as flankers. Specifically, the results for the $.3^\circ$ target/ flanker separation clearly show that when subjects are informed in advance of the target (letter) location and when digits are used as flankers, only modest flanker-validity effects are observed.

Furthermore, the present results shed some light

concerning the presence of this modest but reliable digit flanker-validity effect. One explanation as to why the flanker-validity effect remained when exclusion of the flankers from processing was facilitated by pre-directing attention to the target location and by using targets and flankers from different categories is that residual flanker-validity effects were the result of incomplete focusing of attention (Paquet & Lortie, 1990). Specifically, residual flanker effects may have been due to the small ($.3^\circ$) separation of the target from the flankers. Early selection theories state that subjects may have been incapable of filtering out the distractors from the targets when targets and distractors were separated by 1° or less (Johnston & Dark, 1986; Paquet & Lortie, 1990). The results of the present study support this view in that modest but reliable flanker-validity effects (18 ms) were observed when flankers were presented within 1° from the target. In addition, the magnitude of this residual effect is very similar to that found by Paquet and Lortie. In comparison, no validity effects (2 ms) were observed for flankers presented more than 1° from the target. Therefore, selection of the target and exclusion of the flankers from semantic processing leading to identification (ie., elimination of flanker-validity effects) was possible when the spatial separation of the targets and flankers exceeded 1° , but not when flankers were presented within 1° from the targets. In early selection terms, at

separations of 1° or more no validity effects were observed because the flankers were not attended to and therefore were not identified.

The results of Experiment 1 are problematic for late selection theories of attention. Late selection theories state that unattended stimuli are always semantically processed or identified (Deutsch & Deutsch, 1964). In late selection terms, the relationship between the target identity and the flanker identity is always processed and therefore reliable flanker-validity effects should always be found. In other words, it should not matter what the semantic category of the flanker was, if the target location was pre-cued or not, or how far away from the target the flanker is presented (Eriksen & Webb, 1989). These assumptions lead to the following predictions. First, when the target/flanker separation is $.3^\circ$, a large flanker-validity effect should be observed, similar in magnitude to the effect found by Miller (1987). This was not the case in the present experiment. Secondly, residual flanker-validity effects should have been apparent, even at the largest (5°) target/flanker separation. However, no flanker-validity effects were found at the 3° or the 5° target/flanker separations. While late selection theories could account for a reduction in the magnitude of the flanker-validity effect, elimination of the effect is very difficult to reconcile with the in late selection approach.

Late selection theorists might account for the

elimination of the flanker-validity effect at 3° and 5° separations by claiming that subjects could not see the flankers. If the flankers could not be seen, due to reduced acuity associated with increased flanker eccentricities, the flankers would not be identified. In the present study, a pilot test indicated that subjects were able to identify flankers at the maximum target/flanker separation (5°). Therefore, the elimination of the flanker-validity effect at 3° and 5° separations reflected improved exclusion of flanker identities rather than an inability to see and identify the flankers.

In summary, significant effects of flanker validity were found at target/flanker separations of one degree or less but not at separations of more than one degree. These results concur with early selection theories, which state that efficient target selection occurs when distractors are presented more than one degree away from the target.

EXPERIMENT II

The primary purpose of this experiment was to determine which selection mechanism is responsible for the reduction in the flanker-validity effect which occurs with digit flankers when attention is not directed in advance to the target location (Paquet & Lortie, 1990). As noted earlier, this reduction could be accounted for in two different ways. The first attributes the reduction to the outcome of an early selection mechanism which signals the presence of a basic

featural difference between the target and the flankers. On the other hand, the second explanation invokes the action of a later selection mechanism which signals the presence of a basic categorical difference between the targets and flankers. In Experiment II, physical differences between the targets (letter) and flankers (digits) were reduced by using stimuli very similar to those employed by Dixon and Shedden (1987). If the reduction in the digit-flanker effect found in Paquet and Lortie (1990) was due to physical differences between letters and digits, then reducing these differences should increase the digit-flanker effect. In contrast, if the category effect resulted from categorical processing of the flankers, then simply changing the physical shape of the digit-flankers should have no effect on the magnitude of the flanker effect.

Method

Subjects

Twenty-four students ranging in age from 18-45 from Carleton University participated in a single session lasting 45 minutes for course credits. Data for one subject (See Appendix K) was excluded from further analysis because in comparison with Lortie (1989) and Paquet and Lortie (1990), this subject's absolute median reaction time was unusually long (more than 2.5 standard deviations from the mean, or greater than 1490 ms). Data from this subject was replaced by data collected from an additional subject (See Appendix K).

Apparatus and Stimuli.

Each stimulus display consisted of a letter target with a digit flanker appearing on both sides of the target. Similar to the stimuli used in Paquet and Lortie (1990), all characters will subtend 1.1° of visual angle vertically and 1.52° horizontally. Targets and flankers were separated by $.3^\circ$ of visual angle. Letter and digit stimuli were designed so as to minimize physical differences between letters and digits (See Figure 2). The shapes of the letters were altered so as to further minimize letter/digit physical differences. The apparatus to be used in this study was the same as those used in Experiment I.

Procedure

Subjects were asked to serve in two blocks of 192 trials. Two sets of four letter targets were chosen from the following set of letters: A, B, C, E, F, G, H, P, and S or from target sets D, O, Q, U or I, J, L, and T. Two digits were selected from the set 2, 3, 4, 5, 6, 8, and 9 to serve as flankers for target letters selected from the first set of letters. The digits 0, 8 and 1, 7 were used as flankers for the last two sets of target letters. Digit flankers were assigned to target sets based on visual inspection of the physical similarity of targets and flankers.

The procedure of this experiment was the same as was used for Experiment 1, with one exception. No fixation point was presented at the beginning of each trial to pre-cue the target

Figure 2

Letter and Digit Stimuli used in Experiment II: Reduced Physical Differences Between Categories

SET 1

Letters

A B C E F G H P S

Digits

2 3 4 5 6 8 9

SET 2

Letters

O O U Q I J L T

Dig ts

0 8 1 7

location. Subjects instead saw a blank screen for 1.5 sec before the stimulus was presented. The instructions stressed both speed and accuracy of responses.

Design

A 2 X 2 factorial design was used. Response correlation strength (.92 or .58) and flanker validity (valid or invalid) were the within-subjects factors. The dependent variables were mean median reaction time for target identification and mean number of errors in target identification.

Results

Median correct reaction times (RT) for each flanker-validity level in each correlation block were calculated for each subject. The mean median RTs and the error rate (%) for each testing condition are presented in Table 2. Within subjects ANOVAs were conducted on the reaction time and error data (outliers excluded) to examine the effects correlation block and flanker validity (See Appendix L).

The ANOVA of the median correct reaction times revealed a main effect of validity that approached significance, $F(1,23) = 3.02$, $MS_e = 923.44$, $p = .09$ (see Appendix L). Target identification was faster when targets were presented with valid flankers (680 ms) than when presented with invalid flankers (590 ms). There was also a significant interaction of correlation block and flanker validity, $F(1,23) = 12.63$, $MS_e = 654.89$, $p < .005$. As can be seen in Table 2, there was a larger difference between reaction times for invalid (688

Table 2

Mean Median Reaction Times and Percent Error Rates for Digit
Flankers at Each Level of Correlation Block (High or
Low) and Flanker Validity (Valid or
Invalid) in Experiment 2

	<u>Flankers</u>				Validity
	<u>Valid</u>		<u>Invalid</u>		
	RT	%	RT	%	
<u>Correlation</u>	<u>(in ms)</u>	<u>Error</u>	<u>(in ms)</u>	<u>Error</u>	<u>Effect</u>
High	659	2.2	688	2.3	29
Low	700	3.8	692	2.2	-8

ms) and valid flankers (659 ms) in the high correlation block than in the low correlation block (700 ms, valid; 692 ms, invalid). Planned comparisons revealed that the flanker-validity effect in the high correlation block was significant [$F(1,23) = 10.64$, $MS_e = 970.39$, $p < .005$], whereas no reliable effect was found in the low correlation block [$F(1,23) = 0.14$, $MS_e = 329.35$, $p > .1$].

As in Experiment I, the error rate was very low, 2.6%. The main effect of validity approached significance [$F(1,23) = 3.95$, $MS_e = .0003$, $p = .056$] as did the correlation X validity interaction [$F(1,23) = 3.62$, $MS_e = .0005$, $p = .066$] (See Appendix L). Analysis of the high correlation block did not show a significant effect of validity ($F < 1$). However, analysis of the low correlation block did show a significant effect of validity [$F(1,23) = 5.57$, $MS_e = .0006$, $p < .05$]. Subjects were more accurate when invalid flankers were presented (97.8 %) than when valid flankers were presented (96.2 %), in the low correlation block. All other effects were not significant.

Discussion

The results of the second experiment replicate those found in Experiment 1 when the target/flanker separation was .3° and they also reproduce the no fixation, digit flanker condition of Paquet and Lortie (1990). In the present study, where subjects' attention was not pre-directed to the target location, and where digit flankers were used, a modest (29 ms) flanker-validity effect was found for physically similar digit

flankers and letter targets. If the reduction in the digit-flanker effect found by Paquet and Lortie had been due to presence of obvious physical differences between letters and digits (e.g., Cardosi, 1986), then removing these differences should have lead to an increase in the digit-flanker effect. Specifically, the digit-flanker effect should have increased to a level of approximately 60 ms, similar to the effects found for letter flankers which do not contain obvious physical features distinguishing them from the target (e.g., Miller, 1987). This increase would have occurred if the presence of obvious physical differences between letter targets and digit flankers helped subjects select the target early in the Paquet and Lortie study. If these obvious differences are reduced, then the target should not be selected early and more processing of the flankers should occur. This would lead to an increased influence of the flankers of similar magnitude to the validity effect found for letter flankers (approximately 60 ms). However, the modest flanker-validity effect found in the second experiment do not support this prediction and suggest that the reduced digit flanker-validity effect reported by Paquet and Lortie (1990) was not the outcome of an early selection mechanism sensitive to basic featural differences. Instead, the results of the present study suggests the involvement of a somewhat later selection mechanism which contributes to improved selection of the target by preventing full identification of the flankers.

This is consistent with the notion (Broadbent, 1982; Paquet & Lortie, 1990; Yantis & Johnston, 1990) that early selection of the target is impaired, efficient target selection might still occur at a later stage, if discrimination based on broad semantic differences (categorical differences) is possible.

As noted in the introduction, Dixon and Shedden (1987) have found that letter/digit categorization is the result of conceptual rather than physical differences. Based on their study, it can be argued that the presence of physical differences is not necessary for a category discriminations to occur in the flanker task. Consequently, discrimination of targets (letters) and flankers (digits) based on their alphanumeric category may well have been responsible for the reduced magnitude of the flanker-validity effect found in the second experiment. Since attention was not pre-directed to the target location and obvious physical differences between the target letters and digit flankers were reduced, early selection cues were not available. However, subjects may have been able to use category information to select the target and reduce the effects of the flankers' identity.

In summary, the second experiment revealed a modest flanker validity effect for physically similar letter targets and digit flankers when the target location was not pre-cued. This finding suggests that when obvious physical cues (early selection) are not available, efficient selection may still occur based on categorical differences (late selection cues)

between the target and the flankers.

General Discussion

The results of Experiment I were consistent two prediction derived from with early selection theories (eg., Treisman, 1960). First, the presence of an early selection cue should reduce distractor interference. In particular, the presence of a fixation point to pre-direct attention to the target location should limit the impact of the distractors. However, modest but reliable effects of distractors have been reported in experiments that used a target location pre-cue (e.g., Experiment 1; LaBerge, Brown, Carter, Bash & Hartley, 1991; Paquet & Lortie, 1990). For example, LaBerge et al. (1991) found reduced distractor interference when subjects' attention was narrowly focused on the target location. This narrowing of attention was achieved by having subjects identify a digit that appeared in the target location before they identified the target letter. However, when the separation of the targets and flankers was increased from $.14^{\circ}$ to $.32^{\circ}$ the distractor effect was completely eliminated.

The LaBerge et al. (1991) study raises the possibility that the flanker-validity effects found in Experiment I might be eliminated even with target/flanker separations of less than 1° . Larger reductions in semantic processing of flankers might be possible using the Laberge et al. procedure of attention narrowing than by using a fixation point, which subjects are not required to process. Such a finding would

have important methodological implications for studies of selective attention. In particular, it would suggest that pre-directing attention to a specific location is not so efficient as to prevent attention from spreading to irrelevant locations.

Secondly, the elimination of the flanker-validity effect (Experiment I) at target/flanker separations greater than one degree is also consistent with early selection theories. The disappearance of the flanker-validity effect at 5° is inconsistent with recent findings reported by Miller (1991). Miller found flanker congruency effects for letter flankers positioned 4.6° from the target letter using the Eriksen and Eriksen (1974) paradigm. Miller concluded that response relevant flankers could affect target identification latencies at large target/flanker separations when flankers were "large enough" to be identified (p. 32). However, there are two possible arguments against accepting this conclusion. The first involves the possibility of response set priming. To reiterate, the presentation of one member of a response set as relevant material may serve to prime responses to other members from the same set (Kahneman & Treisman, 1984; Miller, 1987). Targets may well have a low threshold for identification, low enough so that minimal amounts of processing resulting from attenuation of the flanker is nonetheless enough to cause identification of the target letters when they appear in the unattended flanker positions.

The second problem is the use of flankers and targets from the same category (Paquet & Lortie, 1990). Items from the same small semantic category may be so strongly related that the presentation of one item might prime other members of the same category (Johnston & Dark, 1986; Kahneman & Treisman, 1984). Therefore, although Miller found evidence of flanker effects at large separations, such effects may result from response set and/or category priming. The present demonstration that the digit flanker-validity effect can be eliminated lends support for this interpretation.

In Experiment II, modest flanker-validity effects were found for digit flankers when physical differences between the letter targets and digit flankers were reduced. This finding leads to the conclusion that the modest flanker-validity effect could be explained as the result of efficient target selection based on a late detection of a categorical difference between the targets and flankers. However, an alternative explanation is that the degree of similarity between the letters and digits in Experiment II was insufficient to prevent the action of an early selection mechanism. Dixon and Shedden (1987) conducted a study using a same/different paradigm to measure confusability within and between categories of letters and digits. This paradigm could easily be used to determine if the letters and digits used in Experiment II could be considered physically similar (highly confusable). Another possibility would involve a signal

detection task in which subjects would be instructed to respond to visual displays of a letter or a digit. Results of such studies would allow one to decide more precisely than by visual inspection alone, whether the character set used in Experiment II effectively reduced the physical differences between the letters and digits. However, since the present character set was based on that of Dixon and Shedden, and since they established that digits and letters in that set were highly similar, it is suspected that Experiment II achieved its purpose and effectively reduced feature similarity between the target and the digits.

One important implication of Experiment II is that attentional selection of a stimulus seems to occur at various stages of processing. This suggestion is compatible with several theories of attention (Broadbent, 1982; Paquet & Lortie, 1990; Yantis & Johnston, 1990) which support the notion that stimuli that are not early selected on the basis of physical properties (e.g., featural differences) can be later selected on the basis of semantic distinction such as the category to which it belongs. However, as Paquet and Lortie (1990) noted, category information did produce further reductions in the flanker-validity effect when an early selection cue (fixation) was available. This suggests that the late selection mechanisms may only act as a "back-up" system in case of failure of an early selection mechanism. As noted by Broadbent (1958), physical cues may well be the most

efficient information on which to base target selection, but when they fail selection can also occur based on other kinds of information, such as broad semantic information.

References

- Broadbent, D.E. (1952a). Failures of attention in selective listening. Journal of Experimental Psychology, 44, 428-433.
- Broadbent, D.E. (1952b). Listening to one of two synchronous messages. Journal of Experimental Psychology, 44, 51-55.
- Broadbent, D.E. (1954). The role of auditory localization in attention and memory span. Journal of Experimental Psychology, 47, 191-196.
- Broadbent, D.E. (1957). A mechanical model for human attention and immediate memory. Psychological Review, 64, 205-215.
- Broadbent, D.E. (1958). Perception and communication. London: Pergamon.
- Broadbent, D.E. (1982). Task combination and selective intake of information. Acta Psychologica, 50, 253-290.
- Cardosi, K.M. (1986). Some determining factors of the alphanumeric category effect. Perception and Psychophysics, 40, 317-330.
- Cherry, E.C. (1953). Some experiments on the recognition of speech, with one and two ears. Journal of the Acoustic Society of America, 25, 975-979.
- Deutsch, J.A., & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 87, 272-300.
- Dixon, P., & Shedden, J.M. (1987). Conceptual and physical differences in the category effect. Perception and Psychophysics, 42, 457-464.
- Duncan, J. (1983). Category effects in visual search: A failure to replicate the "oh-zero" phenomenon. Perception and Psychophysics, 34, 221-232.
- Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a noisearch task. Perception and Psychophysics, 16, 143-149.
- Eriksen, C.W., & Webb, J. (1989). Shifting of attentional focus within and about a visual display. Perception and Psychophysics, 45, 175-183.

- Francolini, C.M., & Egeth, H.E. (1980). On the nonautomaticity of "automatic" activation: Evidence of selective seeing. Perception and Psychophysics, 27, 331-342.
- Johnston, W.A., & Dark, V.J. (1985). Dissociable domains of selective processing. In M.I. Posner & O.S.M. Marin (Eds.), Mechanisms of attention: Attention and performance (pp. 567-583). Hillsdale, N.J.: Erlbaum.
- Johnston, W.A., & Dark, V.J. (1986). Selective attention. Annual Review of Psychology, 37, 43-75.
- Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J.R. Pomerantz (Eds.), Perceptual organization (pp. 181-211). Hillsdale, N.J.: Erlbaum.
- Kahneman, D., & Treisman, A. (1984). Changing views of attention. In R. Parasuraman, R. Davies, & J. Beatty (Eds.), Varieties of attention (pp. 29-61). New York: Academic Press.
- Keele, S.W. (1972). Attention demands of memory retrieval. Journal of Experimental Psychology, 93, 245-248.
- Krueger, L.E. (1984). The category effect in visual search depends on physical rather than conceptual differences. Perception and Psychophysics, 35, 558-564.
- LaBerge, D., Brown, V., Carter, M., Bash, D., & Hartley, A. (1991). Reducing the effects of adjacent distractors by narrowing attention. Journal of Experimental Psychology: Human Perception and Performance, 17, 65-76.
- Lambert, A. (1985). Selectivity and stages of processing- An enduring controversy in attentional theory: A review. Current Psychological Research and Reviews, 4, 239-256.
- Lortie, C. (1989). The role of category priming in the processing of non-attended stimuli. Unpublished honours thesis, Carleton University, Ottawa, Canada.
- Mackay, D. (1973). Aspects of the theory of comprehension, memory, and attention. Quarterly Journal of Experimental Psychology, 25, 22-40.
- Miller, J. (1987). Priming is not necessary for selective-attention failures: Semantic effects of unattended, unprimed letters. Perception and Psychophysics, 41, 419-434.

- Miller, J. (1991). The flanker compatibility effect as a function of visual angle, attentional focus, visual transients and perceptual load. Perception and Psychophysics, 49, 270-288.
- Moray, N.P. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. Quarterly Journal of Experimental Psychology, 11, 56-60.
- Neisser, U. & Becklen, R. (1975). Selective looking: Attending to visually specified events. Cognitive Psychology, 7, 480-494.
- Norman, D.A. (1968). Toward a theory of memory and attention. Psychological Review, 75, 522-536.
- Paquet, L., & Lortie, C. (1990). Evidence for early selection: Precuing target location reduces interference from same-category distractors. Perception and Psychophysics, 48, 382-388.
- Posner, M.I. & Boies, S.W. (1971). Components of attention. Psychological Review, 78, 391-408.
- Rock, I. & Gutman, D. (1981). The effect of inattention on form perception. Journal of Experimental Psychology: Human Perception and Performance, 7, 275-285.
- Stroop, J.R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-662.
- Tipper, S.P. & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. Memory and Cognition, 16, 64-70.
- Treisman, A.M. (1960). Contextual cues in selective listening. Quarterly Journal of Experimental Psychology, 12, 242-248.
- Treisman, A.M. & Geffen, G. (1967). Selective attention: Perception or response? Quarterly Journal of Experimental Psychology, 19, 1-17.
- Underwood, G. (1976). Semantic interference from unattended printed words. British Journal of Psychology, 67, 327-338.

- Underwood, G. (1977). Contextual facilitation from attended and unattended messages. Journal of Verbal Learning and Verbal Behaviour, 16, 99-106.
- van der Heijden, A.H.C., Hagedaars, R., & Bloem, W. (1984). Two stages in postcategorical filtering and selection. Memory and Cognition, 12, 458-469.
- Yantis, S., & Johnston, J.C. (1990). On the locus of visual selection: Evidence from focused attention tasks. Journal of Experimental Psychology: Human Perception and Performance, 16, 135-149.

Appendix A

Median Correct Reaction Times, Error Rates and Block Differences for the First 120 Subjects [Outliers denoted by (*)] in Experiment I

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
1*	3°	High	540	4	541	6	921.0
		Low	1531.5	31	1392.5	42	
2*	.6°	High	1013.5	0	1306	0	477.3
		Low	688	0	677	0	
3	.3°	High	556	3	599	12	76.5
		Low	511	1	491	1	
4	.3°	High	617.5	5	713	0	53.8
		Low	699	1	739	6	
5	3°	High	464	0	474	6	11.8
		Low	461.5	0	453	0	
6	.6°	High	497.5	1	530.5	0	16.3
		Low	532.5	0	528	1	
7	.6°	High	823.5	3	756	0	225.8
		Low	538	1	530	0	
8	.6°	High	718	5	786	0	10.0
		Low	763	4	761	5	
9	1°	High	443.5	2	407	6	44.0
		Low	475.5	7	463	1	
10	.3°	High	526.5	9	497.5	12	90.0
		Low	413	14	431	11	
11	1°	High	505	7	520	25	9.5
		Low	516	11	490	19	
12	.3°	High	419	6	430	0	52.0
		Low	484	4	470	9	
13	1°	High	631	1	603	6	127.3
		Low	489.5	2	490	2	
14	5°	High	654	2	629	6	91.5
		Low	552	1	548	0	
15	5°	High	494	2	504.5	0	5.8
		Low	517	1	493	4	
16	.6°	High	482	1	513.5	0	30.8
		Low	513	0	544	1	
17	.6°	High	661	1	646	6	61.8
		Low	602.5	0	581	1	
18	.3°	High	499	1	513	0	81.5
		Low	584	1	591	1	
19	3°	High	692	0	709	0	103.3
		Low	607	1	587.5	0	

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
20	5°	High	488.5	3	482.5	0	51.0
		Low	542	4	531	6	
21	.6°	High	571	4	600	0	28.0
		Low	605	4	622	9	
22	1°	High	601	1	630.5	0	19.8
		Low	602.5	1	590	1	
23	.6°	High	586.5	2	637	12	37.0
		Low	585.5	0	564	1	
24	.3°	High	555	0	601	0	26.5
		Low	555	3	548	0	
25	.3°	High	568	0	569	0	38.3
		Low	530	0	530.5	0	
26	1°	High	519	1	516	0	86.0
		Low	598	3	609	4	
27	1°	High	511	2	511.5	12	37.8
		Low	570	2	528	0	
28	1°	High	661	0	685	0	242.5
		Low	936	1	895	0	
29	1°	High	696	6	659.5	0	190.0
		Low	890.5	11	845	21	
30*	1°	High	1046	1	1114.5	1	109.5
		Low	982	0	959	1	
31	1°	High	698	1	685	0	34.5
		Low	655	0	659.5	0	
32	5°	High	528.5	3	551	6	22.3
		Low	552	3	572	9	
33	3°	High	461	2	439	0	56.3
		Low	500	8	512.5	2	
34	1°	High	425	9	468	6	12.8
		Low	442	9	476.5	15	
35	3°	High	514.5	0	537.5	0	39.3
		Low	548.5	0	582	1	
36	3°	High	813	2	727	0	142.0
		Low	628	0	628	1	
37	3°	High	525	11	514	19	85.8
		Low	602	1	608.5	2	
38	.6°	High	452.5	3	484	6	38.3
		Low	502	3	511	16	
39	3°	High	532	2	630.5	0	28.3
		Low	595	1	624	4	

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
40*	5°	High	770.5	1	1165.5	12	387.8
		Low	569	1	591.5	0	
41	3°	High	550	1	548.5	0	76.8
		Low	637	4	615	5	
42	5°	High	489	1	504	0	40.8
		Low	521	3	553.5	0	
43	5°	High	495	2	510	1	181.0
		Low	647	4	720	7	
44	3°	High	596	1	581	0	42.5
		Low	542	1	550	1	
45	.3°	High	714	1	733	0	127.3
		Low	611.5	2	581	2	
46	.3°	High	373	6	370.5	0	10.3
		Low	383.5	12	380.5	5	
47	3°	High	393	6	416	6	184.0
		Low	489	11	481.5	10	
48	5°	High	461	3	521	12	58.3
		Low	441.5	2	424	3	
49	.6°	High	472	1	498.5	0	15.8
		Low	514	2	488	2	
50	5°	High	558	1	536.5	0	65.8
		Low	602	3	624	2	
51	.3°	High	460	0	485	0	37.3
		Low	507.5	0	512	4	
52	.3°	High	706	6	670	12	15.0
		Low	655	7	691	4	
53*	.6°	High	1151	6	1272	0	157.5
		Low	1046	2	1062	1	
54	1°	High	531	0	574.5	0	103.8
		Low	648	0	665	0	
55	3°	High	473	1	465.5	0	141.0
		Low	617.5	3	603	1	
56	3°	High	844.5	0	847	0	169.8
		Low	674	0	678	0	
57	.6°	High	472	0	505	0	1.3
		Low	483	4	496.5	5	
58	5°	High	872.5	1	975	0	135.8
		Low	844	0	849.5	0	
59*	.3°	High	762	0	671	0	425.0
		Low	1167.5	2	1116	0	

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
60	5°	High	455	4	446.5	0	11.0
		Low	445.5	0	434	4	
61	.3°	High	500.5	0	612.5	0	20.0
		Low	530.5	0	542.5	2	
62	.6°	High	574	4	522.5	0	98.5
		Low	656	4	637.5	2	
63	1°	High	505.5	1	486	0	5.5
		Low	502.5	2	500	1	
64	.3°	High	470	3	512	19	14.5
		Low	498	4	513	4	
65	.3°	High	548.5	9	571	6	80.5
		Low	484	6	474.5	0	
66	.6°	High	572.5	1	601	12	53.5
		Low	633.5	9	647	4	
67	3°	High	407.5	3	380	0	56.8
		Low	438	3	463	1	
68	3°	High	472.5	5	419	6	34.8
		Low	480	5	481	9	
69	3°	High	784	1	733	0	87.3
		Low	687.5	0	655	0	
70	.6°	High	540	2	511.5	0	85.8
		Low	631	4	592	5	
71	3°	High	531	3	560	6	70.3
		Low	458.5	0	492	0	
72	3°	High	466	12	467	6	6.3
		Low	486	1	459.5	5	
73	5°	High	486	5	488	6	14.8
		Low	466.5	2	478	6	
74	5°	High	614	2	621.5	0	47.3
		Low	582	1	559	2	
75	.3°	High	420.5	3	423	12	38.0
		Low	463	6	456.5	5	
76	.6°	High	484	1	516.5	0	37.0
		Low	548.5	2	526	4	
77	5°	High	562	1	553.5	0	134.5
		Low	576.5	0	708	1	
78	5°	High	506.5	0	536	6	65.8
		Low	589	1	585	0	
79	5°	High	644.5	1	563	6	11.0
		Low	589.5	4	596	0	

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
80	.3°	High	622	2	653	6	36.5
		Low	591	1	611	5	
81	1°	High	546	4	584	25	73.5
		Low	494	6	489	7	
82	1°	High	449.5	3	475	31	68.3
		Low	383.5	0	404.5	7	
83	3°	High	468	3	466	6	70.3
		Low	546.5	5	528	1	
84	1°	High	475	3	508	0	24.5
		Low	458	4	476	2	
85	.3°	High	504	1	523.5	0	50.8
		Low	563	4	566	0	
86*	.3°	High	522.5	0	511	0	426.3
		Low	943	1	943	0	
87	.3°	High	517.5	1	593	0	102.8
		Low	446	0	459	0	
88	1°	High	614	0	589.5	0	1.3
		Low	600	2	606	2	
89	3°	High	654	2	678.5	0	131.5
		Low	547.5	2	522	2	
90	5°	High	604.5	1	643.5	0	44.0
		Low	675	3	661	1	
91	.6°	High	511	5	494	6	43.5
		Low	465	3	453	4	
92	.6°	High	546.5	9	556	12	41.3
		Low	565.5	7	619.5	5	
93	3°	High	557	3	579	6	73.8
		Low	498.5	5	490	1	
94	3°	High	532	1	520.5	0	62.3
		Low	577	2	600	0	
95	1°	High	505	3	565.5	0	2.3
		Low	516	4	550	1	
96	1°	High	549	1	535	0	26.5
		Low	515	1	516	0	
97	3°	High	701	0	692.5	0	23.8
		Low	671	1	675	1	
98	5°	High	770.5	1	698.5	0	87.5
		Low	656.5	0	637.5	0	
99	.6°	High	583.5	2	591.5	0	100.8
		Low	472	0	501.5	2	

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
100	.6°	High	539	2	553	0	116.5
		Low	420	0	439	2	
101	.6°	High	884	1	936	0	196.8
		Low	710	3	716.5	2	
102	.3°	High	620.5	0	605.5	0	80.0
		Low	673	0	713	4	
103	1°	High	446	8	478	12	102.8
		Low	580.5	4	549	5	
104	.6°	High	600	1	642.5	0	59.3
		Low	662.5	0	698.5	0	
105	5°	High	729	2	849	0	203.8
		Low	571	1	600	1	
106	5°	High	476	0	483.5	0	22.3
		Low	479	1	525	0	
107	.3°	High	754	4	781	6	92.3
		Low	890	3	829.5	0	
108	.3°	High	628	7	683	19	216.5
		Low	859	7	885	8	
109	.6°	High	565	1	594.5	0	82.8
		Low	486	1	508	1	
110	.3°	High	523	3	520	19	114.8
		Low	664	4	608.5	0	
111	5°	High	662	0	608	0	88.5
		Low	550	0	543	1	
112	3°	High	524	6	534	12	10.8
		Low	513	3	524	4	
113	1°	High	532	5	504	6	82.3
		Low	626	4	574.5	0	
114	1°	High	457	2	478	6	26.0
		Low	485.5	0	501.5	0	
115	5°	High	799	1	922.5	0	297.0
		Low	562	0	565.5	0	
116	5°	High	824	1	762	0	8.8
		Low	775	1	793.5	1	
117	5°	High	743.5	3	849.5	0	40.3
		Low	757	2	755.5	0	
118	1°	High	516	4	497	6	53.0
		Low	449	4	458	4	
119	1°	High	512	6	586	6	112.3
		Low	423	4	450.5	2	
120	.6°	High	688	3	758.5	0	101.5
		Low	817	1	832.5	0	

Appendix B

Median Correct Reaction Times, Error Rates and Block Differences for the Seven Subjects Replacing Outliers in

Sub#	Spacing	Correlation	Valid		Invalid		Block Diff
			Reaction Time	% Error	Reaction Time	% Error	
1	3°	High	516	0	512	0	251.0
		Low	782	0	748	2	
2	.6°	High	465	3	493	0	77.5
		Low	403	4	404	2	
30	1°	High	573.5	1	617	6	125.0
		Low	464	1	476	5	
40	5°	High	949.5	1	899	0	42.8
		Low	970.5	0	963.5	0	
53	.6°	High	602	2	650	6	15.0
		Low	640	4	642	1	
59	.3°	High	611.5	0	629	0	26.8
		Low	584	0	603	1	
86	.3°	High	691.5	1	694	0	92.5
		Low	600	0	600.5	0	

Appendix C
Pilot Test Description and Results

METHOD

Subjects

The subjects were 5 students from Carleton University who volunteered to participate in a single testing session lasting 30 minutes.

Apparatus and Stimuli

Each stimulus display consisted of a fixation cross and a single digit presented 5 degrees to the right or left of fixation. The stimuli presented were to be used in Experiment 1. Thus, stimuli were white, $2.29^\circ \times 1.1^\circ$, and presented on a black background. Stimuli were presented on a Zenith ZCM-1490 14" monitor and subjects were positioned 60 cm away from the screen. Responses were made by pressing one of the digit-keys at the top of the keyboard (1-9) corresponding to the digit presented. Trials were initiated by pressing the spacebar at the bottom of the keyboard.

Procedure

Subjects were asked to serve in two blocks of 90 trials (10 presentation of digits 1-9 per block). The digit was presented for 100 ms to the right or left of fixation. Subjects were asked to fixate on the cross while identifying the digit. Subjects were asked to make responses quickly and accurately.

RESULTS

The error rate for identifying peripherally presented digits was low (1 %). The error rates for subjects 1-5 were 3.3, 0, .6, 1.2 and 0 %, respectively. Subjects accuracy data was analyzed using a Chi-Square. The Chi-Square confirmed that subjects were able to identify the digits presented at 5° at levels significantly higher than chance, $\chi^2(4) = 6257.75$, $p < .01$.

of/de

2

A resolution test chart featuring several groups of horizontal and vertical lines of varying thicknesses. Each group is accompanied by a numerical value indicating the resolution. The values include 1.0, 1.1, 1.25, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.2, 3.6, 4.0, 4.5, and 5.0. The lines become progressively thinner and closer together as the numerical value increases.

PRINTED IN METHYLENE BLUE TESTING SINCE 1974

[illegible]

Appendix D

Summary of the Overall Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for Experiment I

Reaction Time Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Separation	4	36472	115	40461	0.90	0.467
Correlation	1	224	115	8816	0.03	0.848
Validity	1	5609	115	630	8.90	0.004
Sep X Corr	4	4321	115	8816	0.49	0.746
Sep X Val	4	939	115	630	1.49	0.209
Corr X Val	1	2891	115	421	7.09	0.009
Sep X Corr X Val	4	654	115	421	1.55	0.190

Error Rate Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Separation	4	0.01087	115	0.00326	3.33	0.013
Correlation	1	0.00285	115	0.00136	2.10	0.146
Validity	1	0.00843	115	0.00109	7.73	0.006
Sep X Corr	4	0.00105	115	0.00136	0.77	0.547
Sep X Val	4	0.00187	115	0.00109	1.72	0.150
Corr X Val	1	0.00391	115	0.00096	4.07	0.043
Sep X Corr X Val	4	0.00173	115	0.00096	1.79	0.134

Appendix E

Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rate for .3 Degree Target/Flanker Separation for Experiment I

Reaction Time Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	500.00	23	6653.77	0.075	0.777
Validity	1	4056.00	23	528.40	7.676	0.011
Cor X Val	1	2904.00	23	430.35	6.748	0.015

Error Rate Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	.00363	23	.00174	2.082	0.159
Validity	1	.00555	23	.00161	3.439	0.073
Cor X Val	1	.00555	23	.00153	3.635	0.066

Appendix F

Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rate for .6 Degree Target/Flanker Separation for Experiment I

Reaction Time Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	4767.13	23	7979.49	0.597	0.453
Validity	1	3510.25	23	548.73	6.397	0.018
Cor X Val	1	1604.63	23	298.01	5.384	0.028

Error Rate Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	.00030	23	.00077	0.391	0.545
Validity	1	.00023	23	.00062	0.379	0.551
Cor X Val	1	.00018	23	.00078	0.226	0.643

Appendix G

Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rate for 1 Degree Target/Flanker Separation for Experiment I

Reaction Time Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	2779.00	23	8352.40	0.333	0.576
Validity	1	435.50	23	623.64	0.698	0.417
Cor X Val	1	1056.50	23	224.90	4.698	0.039

Error Rate Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	.00184	23	.00236	0.778	0.391
Validity	1	.01000	23	.00252	3.977	0.055
Cor X Val	1	.00454	23	.00156	2.915	0.098

Appendix H

Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rate for 3 Degrees Target/Flanker Separation for Experiment I

Reaction Time Analysis

<u>Effect</u>	<u>df</u> <u>Effect</u>	<u>MS</u> <u>Effect</u>	<u>df</u> <u>Error</u>	<u>MS</u> <u>Error</u>	<u>F</u>	<u>p</u>
Correlation	1	2128.00	23	10616.30	0.200	0.662
Validity	1	130.75	23	493.70	0.265	0.617
Cor X Val	1	28.25	23	317.96	0.089	0.761

Error Rate Analysis

<u>Effect</u>	<u>df</u> <u>Effect</u>	<u>MS</u> <u>Effect</u>	<u>df</u> <u>Error</u>	<u>MS</u> <u>Error</u>	<u>F</u>	<u>p</u>
Correlation	1	.00128	23	.00142	0.900	0.355
Validity	1	.00005	23	.00042	0.118	0.731
Cor X Val	1	.00046	23	.00043	1.076	0.311

Appendix I

Summary of Analysis of Variance of Mean Median Correct Reaction Times and Error Rate for 5 Degrees Target/Flanker Separation for Experiment I

Reaction Time Analysis

<u>Effect</u>	<u>df</u> <u>Effect</u>	<u>MS</u> <u>Effect</u>	<u>df</u> <u>Error</u>	<u>MS</u> <u>Error</u>	<u>F</u>	<u>p</u>
Correlation	1	7332.25	23	10478.50	0.700	0.416
Validity	1	1232.88	23	957.17	1.288	0.267
Cor X Val	1	.75	23	832.86	0.001	0.926

Error Rate Analysis

<u>Effect</u>	<u>df</u> <u>Effect</u>	<u>MS</u> <u>Effect</u>	<u>df</u> <u>Error</u>	<u>MS</u> <u>Error</u>	<u>F</u>	<u>p</u>
Correlation	1	.00000	23	.00049	0.008	0.891
Validity	1	.00007	23	.00028	0.242	0.633
Cor X Val	1	.00010	23	.00052	0.194	0.667

Appendix J**Comparison of Separations of One Degree or Less to Separations
Greater than One Degree for Experiment I**

<u>Effect</u>	<u>df</u> <u>Effect</u>	<u>MS</u> <u>Effect</u>	<u>df</u> <u>Error</u>	<u>MS</u> <u>Error</u>	<u>F</u>	<u>p</u>
Separation	1	3235.45	46	799.55	4.047	0.047

Appendix K

**Subjects' Median Correct Reaction Times And Error Rates
[Outliers denoted by (*)] for Experiment II**

Subject	Correlation	RT	Valid	RT	Invalid
			% Error		% Error
1	High	824	0	960	0
	Low	746	0	807.5	0
2	High	631.5	1	694	5
	Low	600.5	4	577	1
3	High	619	1	632	0
	Low	586	1	583	2
4	High	445	14	436	19
	Low	515	17	500	4
5	High	711	2	708.5	0
	Low	864	5	843.5	2
6	High	598	3	625	6
	Low	549	2	589	4
7	High	483.5	7	493	6
	Low	611.5	12	569	4
8	High	622	2	649	0
	Low	668	7	614	7
9	High	645	4	665	6
	Low	652.5	4	661	5
10	High	529	0	537.5	0
	Low	562	6	588.5	7
11	High	623	1	581	0
	Low	687	1	669	0
12	High	515.5	2	573	6
	Low	628.5	2	632	2
13	High	688	2	665.5	0
	Low	745	1	731	1
14	High	645	1	637	0
	Low	635.5	0	636	0
15	High	861	2	940	6
	Low	1087	3	1060.5	4
16	High	647	3	717	0
	Low	818	0	895	1
17	High	520.5	1	546	0
	Low	527.5	0	506.5	0
18	High	819	0	826	0
	Low	893	0	888	0
19	High	575	0	609	0
	Low	602	1	565.5	0
20*	High	2270	0	2097	0
	Low	1786.5	5	1773.5	0
21	High	683	0	658	0
	Low	922	5	956.5	0

Subject	Correlation	RT	Valid	RT	Invalid
			% Error		% Error
22	High	671.5	1	734	0
	Low	822	1	810	0
23	High	831	1	924.5	0
	Low	718	8	680	4
24	High	944.5	2	945.5	0
	Low	859	2	795	0
Replacement					
20	High	671	1	658	0
	Low	822	2	956.5	1

Appendix L

Summary of the Overall Analysis of Variance of Mean Median Correct Reaction Times and Error Rates for Experiment II

Reaction Time Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	11971.30	23	12538.80	0.955	0.341
Validity	1	2784.25	23	923.44	3.015	0.092
Cor X Val	1	8269.75	23	654.89	12.628	0.002

Error Rate Analysis

Effect	df Effect	MS Effect	df Error	MS Error	F	p
Correlation	1	0.00150	23	0.00081	1.860	0.183
Validity	1	0.00135	23	0.00034	3.952	0.056
Cor X Val	1	0.00184	23	0.00051	3.624	0.066

END

21.1 2.92

FIN