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The Effect of Selection Factors on the "Attentional Blink"

by

Monty Jesse Martin

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effect of Selection Factors on the 'Attentional Blink'" submitted by Monty Jesse Martin in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

Previous work has shown that there is a visual processing deficit observed for up to 500 ms following the detection of a visual target in a stream of rapidly presented items. This deficit has been called the "attentional blink" (Raymond, Shapiro & Arnell, 1992). The five experiments presented here examine two of the selection factors used to detect objects. They are the temporal predictability of the critical items (targets) in the stream, and the effect of practice or repeated sessions. Both of these selection factors are shown to attenuate (reduce) the effects of the attentional blink.

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A number of people have assisted in the final version of this thesis, and I would like to thank a few of them here. First, I would like to express heartfelt gratitude to my supervisor, Dr. Kim Shapiro, for his kindness and patience in dealing with me as his student over the course of the past two years. I would also like to thank Dr. Jane Raymond for always being supportive and for being available as a sounding board for my ideas (regardless of how good or bad they might be). I would like to recognize the time and effort put in by my other committee members (Jos Eggermont and Joan Vickers), and thank them for their many useful comments and suggestions.

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Without the help and support from those listed above, this thesis would never have been possible. Thank you all.

Dedication

This thesis is dedicated to my wife,

Michelle.

Thank you for making this real.

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Introduction

The human information processing system is a limited capacity processing system, reducing information at each successive step in the process to accommodate its limitations. To exemplify these reductions, in the visual system, the retina is sensitive to only a small portion of the entire electro-magnetic spectrum, and is restricted to approximately 180° of visual angle. Foveal magnification adds a further reduction by enhancing the salience of visual information only in the fovea. Of the small amount of information that falls on the fovea, less is actually processed and even a smaller amount is responded to and remembered (Keele & Neill, 1978). The latter part of this reductionist system, the part responsible for dealing with information selection, response output, and eventually memory is the attentional system.

When attention is unable to completely regulate the flow of information, the result is interference. We know from both subjective experience and empirical observation that interference does occur (Keele & Neill, 1978). When a person attempts to simultaneously process multiple stimuli, or perform multiple tasks, the result is interference. Interference may be defined as two or more tasks being performed at less than optimal performance levels when compared to the same tasks being performed separately.

Interference is not the inevitable result of processing more than one item or task. It is the result of capacity limitations. If the processing demands are less than the total processing capacity, then no interference will be observed (e.g., Shiffrin & Gardner, 1972; Keele & Neill, 1978). If on the other hand, the demands exceed the total available capacity, then interference is observed as the information to be processed competes for the available capacity.

The interference that occurs when processing capacity is overloaded can result from two sources. The first of these sources is time. When individual items are presented at a high rate, interference is observed (too many items too fast). The second source of interference is spatial. When too many individual items are presented simultaneously, and with too little time for full processing, interference can be observed as well (too many items within a spatial region). To understand temporal interference, we must realize that neural processing takes time. Because of this, items (or tasks) that are presented in close temporal proximity may interfere with each other. If the processing of the first item is incomplete before the second item is presented, the processing of the second item must either be delayed until the processing of the first item is finished or it will directly interfere with the processing of the first item. In either case, the processing of the second item will be less efficient than if the item were to be processed alone.

Spatially, there is also a limitation on the number of simultaneous items (or tasks) that can be processed. Each item (or task) will require a portion of the total available capacity. Many tasks that we perform require all of our attention for them to be successfully carried out. Very early in the study of attention, this observation led to the idea that there was a single, limited capacity channel which lead to the processing centres as presented in Broadbent's (1958) filter theory or Welford's (1960) single channel theory. Any information that is not selected very early for further processing does not gain entry into this channel and is eliminated from the information processing system. Modifications to these early theories were required as evidence was presented that unattended information is processed. An example is the cocktail party phenomenon (Moray, 1959). A person at a crowded party filters out all of the distracting noise so that they can attend to a particular conversation. If their name is spoken and they can hear it, it will be processed, even though they may have been originally filtering out that conversation. The early single channel theories were expanded to allow for further processing of unattended stimuli, but with reduced signal strength (Allport, 1989).

Attention is used when target selection from among non-targets is necessary. As an example, when picking an apple off a tree, the apple (target) must be selected from among the leaves (distractors or non-targets) for the task to be successfully completed. Interference is minimized when the target contains the most compatible information needed for the task to be completed. In other words, when the target information is dissimilar enough along the selection dimension to be considered by the processing center to be unique, then little, if any processing interference is observed. In the apple example, the colour, shape and size of the apple are different enough from the leaves so that they proffer little interference in the task. However, when the target is similar to the distractors, or the distractors contain information on the to be selected feature domain that is just as compatible as the targets information on that domain, then interference is observed (Allport, 1989; Duncan & Humphreys, 1989). Thus picking an apple off a tree has less interference associated with it than picking a good apple out of a basket of the fruit. This suggests that interference is not only dependent on how much, or how fast information is presented to the processing centres, but also to the relationship of the target to the distractor items along the selection dimension.

The selection of the information that our processing system prioritizes and passes on for further processing must be more complete or more salient than the competing, distractor information. This can be accomplished in two ways: (1) the information to be processed can be enhanced and maintained as much as the available sensory information allows while the distractor information decays, or (2) the competing, distractor information can be actively inhibited. Either one of these processes will increase the salience of the information being processed relative to the non-important distractor information. The use of both mechanisms would provide a more efficient method of selection than either of the two mechanisms alone (Tipper, 1985).

Attention

Attention is a dynamic spatio-temporal mechanistic operation, operating over both time and space. The mechanism of attention has been analogized to a spotlight that can be moved across space from object to object (Posner, Snyder & Davidson, 1980). Attention can be directed at specific objects in real space or it can be directed inward to be focused on mental images or concepts. Most research has focused on the attributes and characteristics of spatial attention which is the control and movement of attention through space.

There appear to be two different control mechanisms for attention, endogenous and exogenous (see for reference Klein, 1993). Endogenous control is an internal, active and subjective control mechanism directed to items or tasks about which a person wants more information. When attention is not under the control of the individual, or is driven by external sources, it is called exogenous control. Exogenous control, by an external source (e.g., a threatening sound) occurs when your attention is drawn to something. For example, if a ball is thrown at a person and they can see it in their visual field, they will have their attention drawn to it in a reflexive manner. Both methods of control are important when considering how information is processed.

Spatial Attention

The paradigm used most often for examining spatial attention is called spatial search. Spatial search usually involves a subject responding to the presence, absence or identity of a target embedded in an array of distractors (i.e. non-targets). The typical spatial search experiment involves displaying an array of stimuli. The subject's task is to search the array for a predefined target to which they respond. Response measures include either target accuracy or reaction time. The manner in which the subject responds, the display parameters and the distractor characteristics are varied and this provides insight into the mechanisms underlying spatial attention.

One of the most influential theories of spatial attention in recent years has been the feature integration theory proposed by Treisman (Treisman & Gelade, 1980; Treisman & Souther, 1985; Treisman & Gormican, 1988; Treisman, 1988). The basic theory is that object features are extracted and encoded automatically in parallel, and then are reassembled, or conjoined to provide an internal representation of the object that has been processed. The latter process requires attention.

Examples of the basic sensory features of objects are color, orientation and size. Each basic feature is coded in a specialized module that processes the information specific to that feature and then a conjoining process is carried out to put the various features back together to form an object. For example, the color module would contain information about colors and would therefore be able to assign a color value (red, blue green, etc.) to the object.

Attention is the mechanism that conjoins the features in the various modules, or the attributes of an object, to build an internal representation. According to Treisman (Treisman & Gelade, 1980; Treisman & Souther, 1985; Treisman & Gormican, 1988; Treisman, 1988), the bonding is done based on the spatial location of the object. Attention focuses on a particular spatial location on a "master map" of locations, and the corresponding modules that are attached to that location allow the features encoded there to be extracted and conjoined to represent an object. Thus, attention is the "glue" that integrates the individually processed features into a single, internally represented object.

Evidence for this theory has been based on experiments in which attention is overloaded. The basic idea is that there is too little attention available for the conjunction process. When the attentional system is overloaded, conjunction errors occur. For example, if a subject were presented with an array of stimuli made up of blue circles and green squares, a conjunction error would be reporting a blue square or a green circle. These types of errors (illusory conjunctions) are evidence that the features of objects are processed separately from one another and the process of conjoining the features is carried out subsequently. Conjunction errors have commonly been found in visual search studies that examine the spatial characteristics of attention (Treisman, 1977) and in studies that examine the temporal characteristics of attention (e.g., Botella, 1992; Botella & Eriksen, 1991; Botella & Eriksen, 1992; Botella, Garcia, & Barriopedro, 1992; Intraub, 1985).

More evidence for the parallel processing of basic features is provided by the speed with which these basic features are processed. When a single unique feature (i.e. a blue "X" among red "X"s) is used to define an item as a target, the search is carried out in parallel for that feature and reaction times do not tend to increase with the increase in distractor set size. On the other hand, when a target is defined by two features or a conjunction of features (e.g. a blue "X" among red "X"s and blue "O"s), the search time is slowed as the system examines each item serially until it finds a match for the two target defining features. This is an example of a serial search and takes much longer than parallel search. Serial search is sensitive to the number of distractors present; the more distractors, the longer the search time.

Some of Treisman's (Treisman, & Gelade, 1980) assumptions regarding the feature integration theory have been questioned by recent research. According to Treisman's feature integration theory, any time a conjunction is required the search would be a serial search and should be dependent on display set size. Using the visual search paradigm, Wolfe and colleagues (Cave & Wolfe, 1990; Wolfe, Cave & Franzel, 1989; Wolfe, Yu, Stewart, Shorter, Friedman-Hill, & Cave, 1990) found that when subjects had to perform conjunction searches where three features defined the target, their search times were independent of the display set size and were faster than standard two feature conjunction searches. They proposed a model of guided search where the preattentive, parallel processes "guide the spotlight of attention toward likely search targets" (Wolfe, Cave & Franzel, 1989 p. 420). The parallel processes pick out likely locations for the target based on the features that are processed. If a target is to be a 'blue X', then the preattentive parallel search would be able to guide the slower serial search process to the locations where only "blue" was detected rather than where the distractor color (e.g. red) is located.

Another theory that has been influential in the understanding of how attention is distributed through space is Duncan and Humphreys' (1989) Distractor Similarity Theory. This theory deals with the speed at which a subject is able to detect the presence of a target among distractors and is a function of the information carried by the target in relation to the distractors, and the distractors in relation to each other.

If the information carried by the target is unique relative to that carried by the distractors, the target will be detected quickly. This serves as a alternative explanation for the "pop-out" phenomena (Treisman & Souther, 1985) witnessed when the degree of dissimilarity between target and distractors is high. If a circle is to be detected among an array of straight lines, then the circle will appear to pop-out of the display, and mean reaction time to detect its presence is relatively fast. If, on the other hand, a number '1' were to be detected from among an array made up of number '2's, then the similarity of the target to the distractors would make it harder to detect, and the corresponding mean reaction time would be slower. Thus, the similarity of the target to the distractors plays an important role in the process of target detection in an array.

Another important aspect of the distractor similarity theory is the similarity among the distractors themselves. If the distractors are completely homogeneous then target stimuli departing from such homogeneity will be detected quickly. As an example, if the distractors (i.e. non-targets) are an array of 'T's, and the target is an 'O', then the target is easy to pick out. If on the other hand, the distractors are different letters of the alphabet, and the target is one of these letters (an 'O'), the target will be more difficult to detect. The lack of homogeneity among the distractors and the similarity between the target and the distractors (all alphabetic characters) underscores the interplay and interdependence of the target and distractor relationships. The more similar a target is to the distractors, the more difficult the target is to detect and the more similar the distractors are to each other, the more the target will stand out. See Duncan & Humphreys (1989) for a full explaination of this model.

Another finding in the spatial research that has assisted in understanding how attention can be focused is the benefit found through the use of Posner's cost/benefit paradigm (Posner *et al.*, 1980). The use of Posner's cost - benefit paradigm to study attention has uncovered some significant findings regarding how attention moves through space. The basic method involves a cue to alert the subject to a probable (typically a high probability of around 0.8) target location, and compare the benefit (as measured in faster reaction times) for the valid cues, which correctly predict target location, to the cost (slower reaction times) associated with the invalid cues, in which the cue incorrectly predicts target location.

Results from the findings employing this or a variant of this paradigm, have analogized spatial attention to a spotlight (Posner *et al.*, 1980) or a zoom lens (Eriksen & St. James, 1986) in how it can focus and move through space (Eriksen, & Murphy, 1987). Spatial attention can focus on a small area and provide a high resolution in the processing of small detail, or it can cover a broad area, taking in the grosser features, but without the high resolution that enables it to process the fine details of an object (Eriksen & St. James, 1986). Attention can move through space, and can, under certain circumstances, be directed by some internal mechanism, independent of movements of the fovea.

Experiments employing with the cost/benefit paradigm have shown that attention can be focused away from the fovea in a tightly controlled manner. There are efficient control mechanisms for spatial attention that allow it to be controlled and directed for our benefit. If there is a mechanism to focus attention spatially, it is logical to assume that attention should be able to be focused in a tightly controlled temporal manner as well. Findings supporting this claim have been found in studies examining vigilance and readiness (e.g., Klemmer, 1957; Smith, Warm & Alluisi, 1966; Warm, Epps, & Ferguson, 1974) and is one of the areas under investigation in this thesis.

Many of the mechanisms thought to underlie spatial attention may have analogous mechanisms in temporal attention. For example, Duncan & Humphrey's (1989) theories about the relationship between target and distractors should be directly applicable to items presented in a temporal array just as they apply to items presented simultaneously in a spatial array.

Temporal Attention

Rapid serial visual presentation (RSVP) is a paradigm used to study the temporal characteristics of attention. RSVP involves the sequential presentation of single items in rapid succession. The items are usually presented in the same spatial location, although some experiments may vary the location at which items are presented. The items used are typically words, digits, letters or pictures. The rates of presentation will vary from as few as six to as many as thirty items per second. The stimulus duration and the inter-stimulus-interval

(ISI) are varied along a continuum from simultaneous stimulus offset and onset to variable ISIs to yield different SOAs (stimulus onset asynchrony). A task that is typically used in RSVP research is either to identify or to detect the presence of one or more targets from among the stream items (e.g., Broadbent & Broadbent, 1987; Lawrence, 1971). The targets are delimited in some way (e.g. presented in a different color or shape) from the rest of the stimulus stream so that identification or detection can take place. When the target is completely defined (e. g. a white "X"), or partially defined along some dimension of the stimulus stream (e. g. the white letter), the task is a filtering task and whatever matches the filter or template is responded to or identified. A different target delimiter is one of a selection set (e. g. pick out the digit from among the letters) where the target is defined by the set to which it belongs.

Studies of temporal attention using RSVP techniques typically employ stimulus streams consisting of between 15 to 20 items. The items are normally not repeated in the stimulus stream (except in the studies of repetition blindness, e.g., Kanwisher, 1987). In research involving temporal attention, RSVP tasks are analogous to the visual search tasks used in the study of spatial attention. The difference is that in an RSVP procedure, the task is to pick a target out of a temporal array, whereas visual search tasks usually involve picking a target out of a spatial array (cf., Raymond, Shapiro & Arnell, 1992; Shapiro & Raymond, 1994). Because the items are presented in the same spatial location, the need for eye movements or attentional shifts is eliminated (Young, 1984).

Single Task RSVP

The earliest studies using the RSVP procedure were single-target RSVP studies. Lawrence (1971) reported that an item embedded in a stream is more difficult to identify than an item presented singly for the same amount of time. Even though the target task in an RSVP stream is more difficult than a single presentation, the error rates in identifying targets tends to be low. When errors are made, they are made in a systematic fashion. It has been found that when an error is made in a target identification task, on a high proportion of the trials, the reported item is a distractor item from the stream, otherwise known as an intrusion error. There are three patterns of intrusion errors reported: (1) pre-target intrusions where the item preceding the target by n items is reported as the target, (2) post-target intrusions where the item following the target by some n items is reported as the target and (3) a symmetrical pattern of approximately equal numbers of pre- and post-target intrusion errors (Broadbent & Broadbent, 1986). Which pattern of intrusion errors occurs is dependent on the task demands of the experiment that is being carried out.

The most common intrusion error observed is when the item intruded is from the first post-target, or +1 item (Lawrence, 1971; Mclean, Broadbent & Broadbent, 1982). This error occurs when the target defining characteristic is featural, as is the case when the task is to "name the red letter" (see Figure 1). The target defining feature is the color red, and the reported feature is the target identity. Post-target intrusion errors suggest a target identification process that extends for a longer time period than is available for each item in an RSVP task.

Figure 1

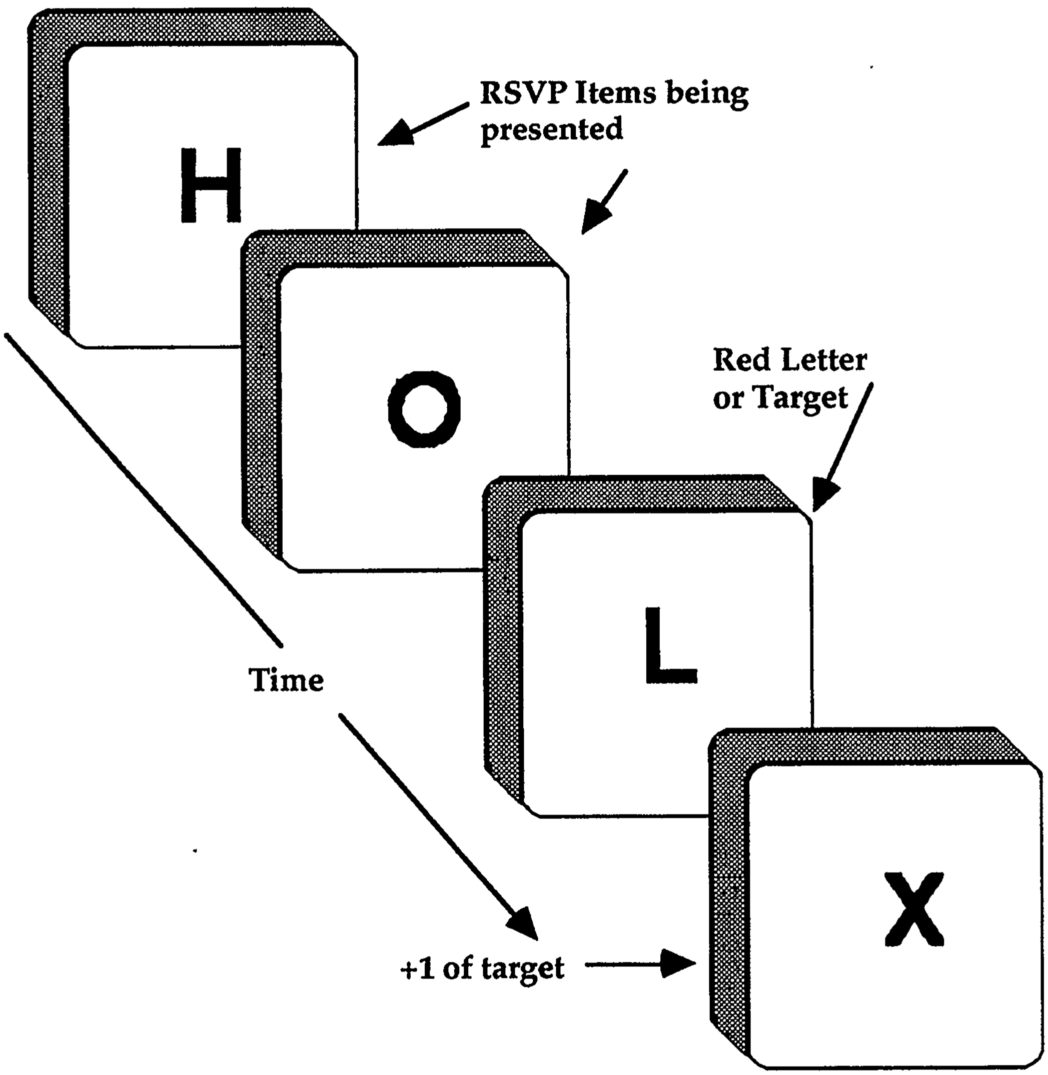


Figure 1: RSVP stream of letters with the target (red letter) being an 'L'. A target +1 intrusion error would be the reporting of the letter 'X' as the red letter. This type of intrusion error occurs when the target defining feature (the colour red) is mistakenly conjoined with the letter following the target.

Thus the process of identification extends beyond the target and is completed after the subsequent items have been processed. These results suggest a two stage, detect-then-identify model of processing. The first is a detection stage, where the target defining feature has been registered from among the stream items. The second stage is the identification stage where the feature to be reported is identified. If more items than the target are in the storage buffer, then there is a potential for an intrusion error to occur (Broadbent & Broadbent, 1986, 1987; Gathercole & Broadbent, 1984; Lawrence, 1971; McLean *et al.* 1982; Raymond *et al.* 1992).

Although the target +1 post-target intrusion errors are the most common errors observed, the pattern of symmetrical pre- and post-target intrusion errors also occurs, and is very difficult to explain. This pattern of errors has occurred in RSVP tasks involving pictures (Intraub, 1985), filtering (Botella & Eriksen, 1992), and selective sets (McLean *et al.*, 1982). The detect-then-identify model can not account for intrusion errors that involve the pre-target items. Another model that has been proposed to account for the findings is based on the speed of processing for the delimiting feature and the response feature. Keele & Neill (1978) proposed that different feature dimensions are processed at different speeds; as a result, the delimiting feature may be processed before the response feature. McLean *et al.* (1982) demonstrated that this is not the case when they reversed the role of the delimiting and the response features in their RSVP task. According to Keele & Neill (1978), there should have been post-target intrusion errors in one case, and pre-target intrusion errors in the other. Both tasks resulted primarily in post-target intrusion errors demonstrating that the feature dimensions themselves are not processed at different speeds, but that something else must account for the differential processing times. Another account of the processing times is one proposed by Duncan (1980) wherein the delimiting feature may always precede the response feature in visual short term memory (VSTM) where selection takes place. This account suggests that the demands of the task are responsible for the order of processing rather than the features themselves. The response feature, whatever it may be, might be processed more slowly than the delimiting feature (Shapiro & Raymond, 1994).

In an RSVP experiment involving selective sets or categorization, Gathercole and Broadbent (1984) found symmetrical patterns of intrusion errors. They proposed two separate mechanisms to explain the different patterns of errors, an early-selection mechanism (detect-then-identify model) for filtering tasks and a late-selection mechanism (a number of items in VSTM causing interference model) for set selection tasks. Shapiro and Raymond (1994) believe that this explanation lacks parsimony, as a single late selection mechanism can account for both kinds of errors.

The results of the single task RSVP studies have uncovered at least two findings of significance to this thesis: (1) the conjunction of the feature delimiting the item and the feature to be responded to must be complete by at least 100 ms as intrusion errors rarely occur outside the target ± 100 ms range, and (2) this processing requires attention (Raymond *et al.* 1992; Shapiro & Raymond, 1994). This would suggest that the processing mechanisms would be free to deal with subsequent items after 100 ms, but this appears not to be the case. Processing deficits have been found for up to 600 ms after a target is identified, as will be described below

Multiple Task RSVP Studies

Multiple task RSVP studies are used to track processing performance following the successful detection or identification of a target. In the earliest experiments carried out involving multiple tasks in RSVP paradigm there was a deficit in the processing of a second target (probe) subsequent to the successful processing of a first target. Broadbent & Broadbent (1987) asked subjects to detect the presence of two words in uppercase letters or flanked by hyphens (the target and the probe) in an RSVP stream of lowercase words being presented with an SOA of 80 ms (12.5 items per second). They found that when the two targets were temporally adjacent, or in close temporal proximity, subjects could correctly identify one, but not both. As the temporal distance between the target and the probe word increased, the probability for correct identification of both the target and the probe rose from a low of 0.1 when the temporal interval was less than 400 ms to about 0.7 when the intervals reached 720 ms or longer. On many of the trials where subjects mis-identified the probe, they indicated that they were guessing as they were completely unaware of the presence of a probe in the stream. Broadbent & Broadbent (1987) attributed their findings to their detect-then-identify model with the identification stage being a slower process that caused interference for later processing.

Using a multiple target RSVP paradigm, Weichselgartner & Sperling (1987) observed the same processing deficit following the successful identification of the first target. Their paradigm had subjects identify the four items immediately following the target. Their target consisted of either a white box surrounding a digit, or a highlighted digit in a stream of digits presented with SOAs of either 80 ms or 100 ms. Their subjects showed a bi-modal distribution of responses with little difficulty identifying the target and the item immediately following the target, but the next digit reported tended to be about 300 or 400 ms after the target. Their subjects tended to miss the two or three items that occurred between the immediate post-target item and the third or fourth item presented (300 or 400 ms later). Weichselgartner & Sperling (1987) suggested a dual-stage model of attention to account for their findings. The first stage consists of a fast process triggered by the detection of the target resulting in close to perfect identification of the target item and often the first item immediately following the target. The second stage is an effortful, slower attentive process that is able to be sustained for longer periods of time and takes time to become fully activated. The deficit was attributed to the falling off of the first mechanism before the second mechanism had been fully activated.

A series of experiments was undertaken by Raymond *et al.* (1992) to examine the nature of the processing deficit found in multiple task RSVP studies. After replicating the findings of Weichselgartner & Sperling (1987), they reduced the memory demands of the task from having to recall four items to having to recall two items in a stream of black letters: 1) the target or the identity of the white letter and 2) the presence of a probe (the letter "X") in any one of the eight post-target positions (see Figure 2). The results from these manipulations showed that there was still a processing deficit during the temporal interval of 100 to 500 ms following the successful processing of the target. Because the task involved the recall of only one letter and the detection of another, these findings suggest that the deficit is not related to a memory limitation, but must be due to either attentional or sensory factors (see Figure 3).

Figure 2

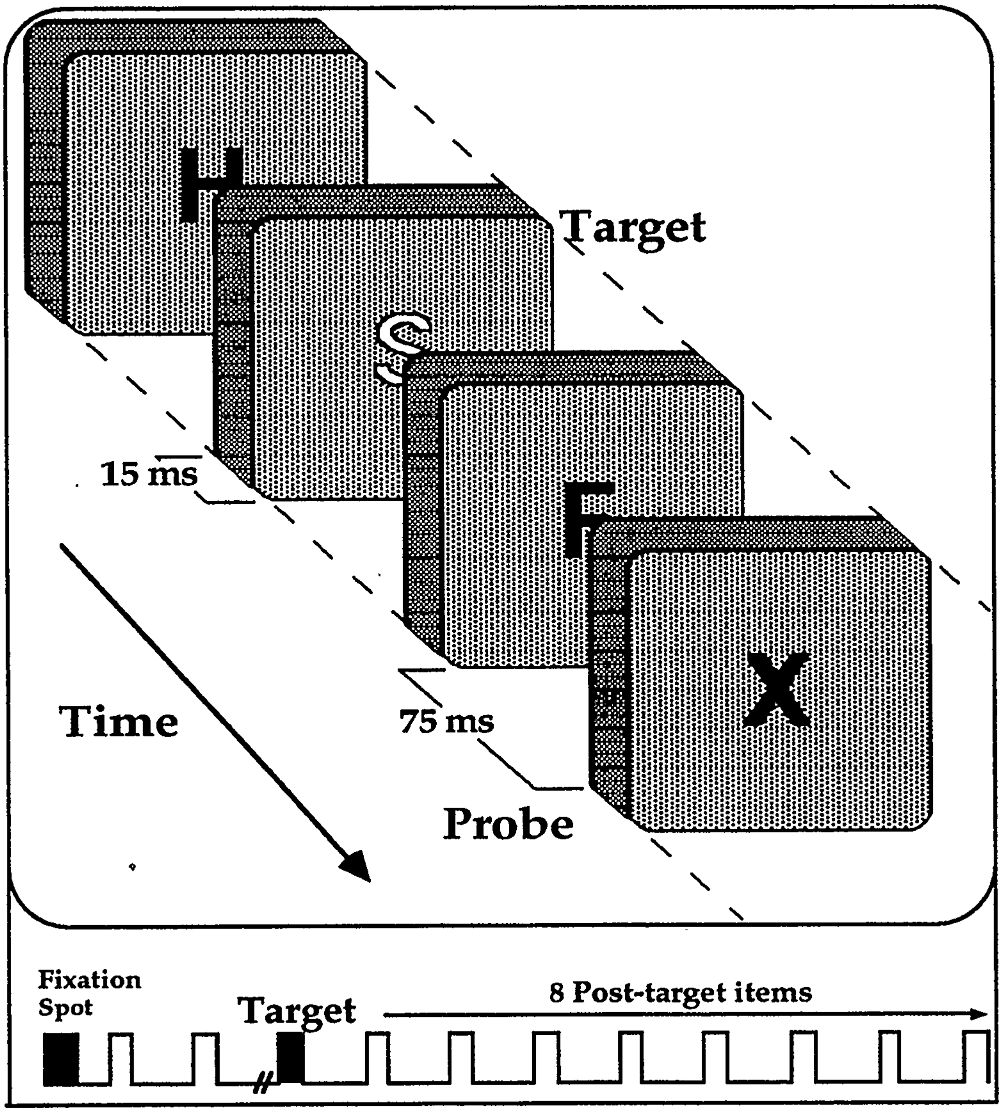


Figure 2: The top panel illustrates the typical RSVP stream with the target denoted by the color white and the probe being a specified letter ('X'). The bottom panel shows the temporal aspects of the typical RSVP experiment used by Raymond *et al.* (1992).

Figure 3

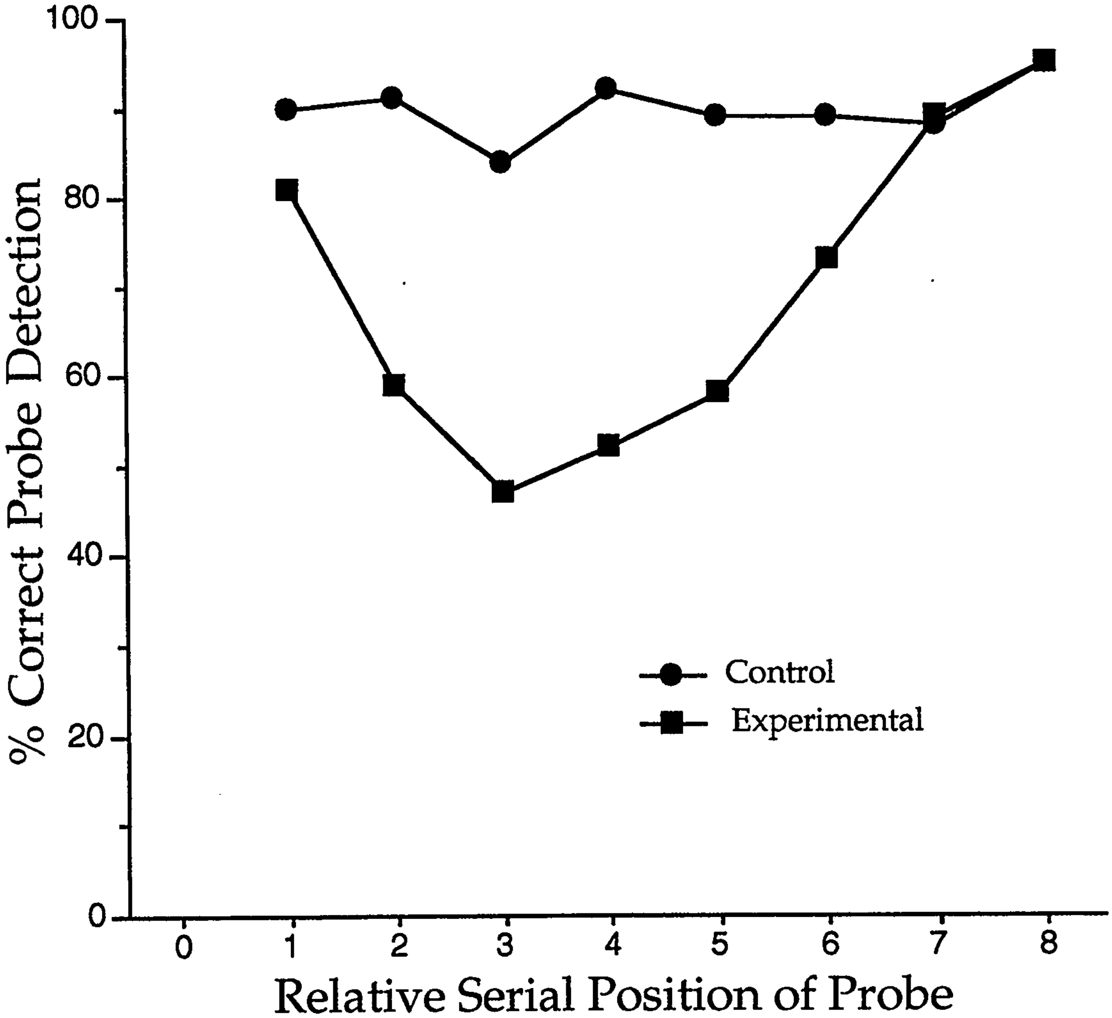


Figure 3: The group mean percentage of trials in which the probe was correctly detected as a function of the relative serial position of the probe. The data plotted is taken from Experiment 2 of Raymond *et al.* (1992). Circles represent the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected.

To examine whether the observed deficit was the result of a sensory related problem (e. g. masking), Raymond *et al.* (1992) had subjects ignore the target and then assessed their performance on probe detection. Since the actual perceptual elements present in the RSVP stream was held constant between the two conditions, if the observed deficit were perceptual it would still be present. The subjects had no difficulty in detecting the presence of the probe when the target was ignored. With evidence suggesting that it was neither a memory or a perceptual problem, Raymond *et al.* (1992) called the deficit which they were studying the "attentional blink" (AB). Using the basic paradigm of identifying the target and then detecting the presence of a probe, they commenced a series of experiments to understand the AB.

Weichselgartner & Sperling (1987) suggested a dual attentional process that may have been responsible for the observed deficit. Their model was one that relied on the ballistic nature of attention. It takes a certain length of time for the second, slower attentional mechanism to get started. Within the framework of this model, removing any of the items between the target and the probe should have no effect on the deficit. Raymond *et al.* (1992) tested this assumption by removing some of the stream items between the target and the probe. They found that when the target +1 item is removed and replaced by a non-patterned, blank space, there is no AB. These findings suggested that the target +1 item plays an important role in the AB. In contrast when the other, intervening items (the target +2 and target +3) are removed, they have no effect on the AB, as long as the target +1 item is present.

Raymond *et al.* (1992) postulated that the blink was a mechanism to minimize confusion among items brought into VSTM, and allow for better processing of targeted items. Because of the rapid presentation rates, the items from the stream that got into VSTM were the target and the target +1. The presence of multiple items that were similar enough to cause identity confusion in VSTM invoked an inhibitory mechanism that prevented other items from getting into the sensory buffer. Further investigation, however, uncovered certain shortcomings of this model.

In spatial search, increasing the difficulty of the target search task results in increased attentional demands on the processing system (Keele & Neill, 1978). Using this as a model for temporal search tasks, increasing or decreasing the target difficulty should be reflected in the AB magnitude. In dual-task RSVP, manipulations of target difficulty showed however that there is no relationship between target difficulty and probe performance (Shapiro, Raymond, & Arnell, 1994). The target task ranged from extremely difficult to very easy with the most difficult target task requiring discrimination of the duration of two temporal gaps in the stream. The results from this difficult target task was a mean probability of a target hit of 0.59 (FA (false alarms) = 0.24) and no AB. The easiest target task was to detect the presence of a white item in the stream with a mean probability of a target hit at 0.98 (FA = 0.03) yet an AB of normal magnitude. Because the 'gap' experiments contained no pattern information for the target, and yet were the most difficult target tasks, but revealed no blink, these findings led to the conclusion that the AB is an all-or-nothing mechanism that is initiated by the presence of pattern information in the target.

The model that emerged from this series of experiments is based on Duncan and Humphreys' (1989) distractor similarity theory. The distractor similarity theory is based on the interference that the items cause each other due to their perceived similarity. The target and the probe are both selected for processing in VSTM because they match some template for selection, and the target +1 and probe +1 items are also processed on the basis that they share a close temporal proximity to the items selected. The blink then, is a result of a difficulty in choosing from among the items in VSTM where the range of possible responses are stored. This model is called the interference model to differentiate it from the earlier, inhibitory model (Shapiro, & Raymond, 1994; Shapiro *et al.*, 1994).

More recent work on the role of the target +1 item (Raymond, Shapiro & Arnell, in press) has also supported this interference theory. By manipulating the similarity of the target +1 item to both the target and the probe, it was shown that as the featural similarity among the critical items decreases, the AB is attenuated. When the target +1 item was a pattern of dots, the manipulation with the least similarity to letter shapes, the AB was attenuated the most. When it was dissimilar on the basis of category, the target +1 was a digit rather than a letter, there was no difference between that AB observed in this experiment and the AB observed when the target +1 is a letter. From this experiment, the target +1 item's role appears to be one based on the physical pattern information that it carries rather than on the semantic information it contains. Where this interference takes place in the processing system is an important question which will be dealt with in the next section and the general discussion.

Practice & Attention

Selection Models (early vs. late)

Once information has entered the processing system, it must be selected for further processing. That there is a selection mechanism to reduce the amount of available information is generally accepted (e.g., Allport, 1989; Keele & Neill, 1978; Johnston & Dark, 1986). Where this selection takes place, or where the "bottleneck" occurs has given rise to two classes of theory, early- and late-selection. Is the information presented to the system selected for processing early in the system, before semantic analysis of the stimuli as Broadbent (1958) proposed in his original filter theory, or after the stimuli have undergone semantic analysis, much later in the system (Deutsch & Deutsch 1963)?

Early-Selection Models

The first models of attention were early-selection models with Broadbent's filter theory (1958) being the first such model to address attention in a mechanistic manner. He envisioned attention as analogous to an electromagnetic filter, much like the kind used in early telephone switching equipment. Since there is only one input channel to higher levels of processing in his theory, whatever input channel attention selects is the only channel to receive further processing (Broadbent, 1958).

Early selection models argue that selection of information for further processing occurs relatively early in the processing system. According to a general model of information processing, the earliest processing is a parallel or preattentive selection system based on the physical or sensory based attributes or features of the stimuli such as color, spatial location or orientation. After these physical features of the stimuli have been extracted, only a portion of what has been extracted can be passed on to receive further processing, and so there is a constriction or bottleneck in the information flow. Once the information reaches this point the stimuli that are to receive further processing are selected and passed on for categorization and semantic analysis. This is a much smaller sample than is processed early in the information processing system.

Evidence supporting early selection models is based on research comparing the efficiency of selection based on physical differences between targets and distractors (sensory selection) and selection based on semantic differences between targets and distractors (semantic selection). The selection based on physical differences (sensory selection) is more efficient, more accurate and requires less effort (Johnston & Dark, 1986). These differences provide evidence for an efficient selection mechanism at an early stage, suggesting that attention is working at this level. Strict early selection provides for information to be selected for further processing based on the physical features of the stimulus only.

Treisman's (1960) experiments led to some modifications of the early-selection theories. Using a dichotic listening paradigm, she had subjects shadow a passage presented to one ear, and told them to ignore what was presented to the other ear. As they shadowed a passage in the attended ear, a second, supposedly unattended passage was being presented to the unattended ear. The attended passage was then switched to the unattended ear, and a new passage was begun in the attended ear. According to the strict early selection views held at the time, the new passage should have been shadowed from the beginning, because it was being presented to the attended channel. This was not the case.

When the passage first switched, subjects followed the passage to the previously unattended ear for the first few words before realizing what they had done and switching back to the ear to which they were supposed to attend. These findings led to a modified early selection viewpoint and it was not until Deutsch & Deutsch (1963) presented their theory based on a late selection model, the early vs. late selection debate began.

Late Selection Models

Late selection theories contend that selection is not restricted to the early, sensory or physical based stages of processing. Evidence for this is based on findings that irrelevant stimuli are sometimes processed to the report stage. According to strict early selection theories, irrelevant stimuli are passed over at a purely physical code stage of processing and as a result, could not reach the report stage. Early-selection theorists contend that the distractors are excluded from further processing because the target or relevant stimulus has been selected as the item to receive further processing. Selection takes place before any semantic information has been extracted. As an argument against this position, there are a number of findings that provide support for semantic analysis of irrelevant stimuli, suggesting that at least some of the distractor information is processed at more than just a sensory level.

The earliest findings that supported a late selection mechanism were the works of Treisman (1960) mentioned earlier, and Moray (1959) who consistently found that a persons name spoken in the unattended ear during a dichotic listening task was attended. Based on this and the work of other researchers at the time (e.g., Gray & Wedderburn, 1960), Deutsch and Deutsch (1963) theorized that selection by attention did not take place until after all the inputs were analyzed to at least a semantic level. Much of the processing takes place unconsciously, and the processing bottleneck occurs later in the system when the processed information must be retrieved from memory. This does not mean that the physical characteristics of the stimuli are irrelevant in a late selection theory. These physical characteristics can cause interference at a late stage in processing.

There is evidence that supports both the early- and late-selection theories, suggesting more than one mechanism or process is involved in the selection process. Having more than one mechanism would provide both flexibility and efficiency to facilitate the information reduction required by the relatively slow, serial processing capability of the brain. The process used for selection would be related closely to the demands of the task rather than blindly, by some pre-set rules. In addition, neuro-physiological evidence suggests that the early vs. late distinction is not necessarily valid (*i.e.*, Mishkin, Ungerleider, & Macko, 1983). This evidence has shown that there are parallel processing channels going from the early visual centres to both the "what" and to the "where" information processing centers in the brain. The neuro-physiological evidence suggests that both types of information are being processed simultaneously, and that the task demands determine whether selection occurs early or late in the processing system.

Controlled versus Automatic processing.

As an explanation as to why the amount of information being processed can be increased, Shiffrin and Schneider (1977, Schneider and Shiffrin, 1977) introduced the concept of controlled and automatic processing. Based on a late-selection model of attention, their model focused on how the information processing system is controlled. The views of strict early- vs. late-selectionists suggested a passive mechanism where there is little or no control over the information that is either filtered, blocked or passed on for further processing. Shiffrin and Schneider (1977, Schneider and Shiffrin 1977), on the other hand, proposed that capacity limitations occurred after stimuli are fully processed by the perceptual system. These capacity limitations are the property of a control center under conscious control. This control system has the ability to accentuate certain information and block the processing of other information. The information in the system either can be processed in a controlled mode or in an automatic mode, depending on the task demands and the type of stimuli.

Shiffrin and Schneider (1977, Schneider and Shiffrin, 1977) carried out a series of experiments to examine the differences between controlled and automatic processes. They presented their subjects with letter displays on which they were required to perform a target search task. The total number of items (target and distractors) presented on each trial was one, two or four. Half the trials contained a target, chosen from a set size of one or a set size of four items. The SOA for the frames was 40, 80, or 120 ms. The relationship between the target set and distractor set (mapping condition) was either consistant or varied. In the consistent mapping condition, the items that made up the memory-set were never distractors and the distractors were never in the memory-set. In the varied mapping condition, when all the trials are considered, all the memory-set items were distractor items, and all the distractors were memory-set items. Subjects in this experiment participated in up to 10,000 trials each in order to assess the effects of practice on automaticity.

Subjects' performance was found to be better in the consistent mapping condition than in the varied mapping condition. The investigators also found that memory set-size effected the varied mapping condition, but it had no effect on the consistent mapping condition. Shiffrin and Schneider suggested that the difference in the two mapping conditions could be explained as being the result of two different processes. The consistent mapping condition, after many trials, became an automatic detection response. Because the stimulus never changed, and as the effects of long term practice took effect, the subjects were able to do the task with little (if any) reliance on attentional mechanisms. The stimulus/response linkage became automatic as it was placed in the long term memory store.

In the varied mapping condition, the stimulus/response linkage can not be automated because the relevant stimuli change from trial to trial. Such a lack of predictability (feature wise) forces the system to use attention as a controlling mechanism to respond in the correct manner. Because of the lack of consistency in the target set, the subjects must rely on their short-term memory capacity to perform the task. As a result, the task remains under the subjective control of the subject and the search is carried out in a serial manner.

The key feature to the theories proposed by Shiffrin and Schneider is the role that practice plays in automaticity. As subjects increasingly practice a task and the component processes that make up the task are transferred from short term memory to long term memory, the attentional demands are lessened and the task becomes automated. This dual processing mode allows us to direct our attention to novel tasks which must be performed in a slow, and careful manner, while allowing us to carry out some of the tasks that we do on a frequent and regular basis in a more automatic and efficient manner. A good example is found as humans learn to drive a car. When they are first confronted with the task there are many aspects that they must attend to and as a result it is difficult. As they gain experience in the task, it becomes easier and easier as the component processes become automatic until they reach a point where the actual operation of the vehicle requires little attention.

Experiments

The following set of five experiments examine two selection factors, temporal predictability and practice, for their effect on the AB. The first set of experiments examined the temporal predictability of the target and probe. This was done using the RSVP paradigm developed by Shapiro *et al.* (1994, Experiment 3a), where the target task was to detect the presence of a white letter (a white "S") and the probe task was to detect the presence of a black "X". These experiments were carried out both in the presence of the distractor stream and in the absence of the distractor stream. Experiment 1 replicated the findings of the Shapiro *et al.* (1994 Experiment 3a). Experiment 2a examined the effect of temporal predictability of the target on probe performance by fixing the temporal location of the target relative to the beginning of the stream.

Posner's (Posner *et al.*, 1980) cost-benefit paradigm used in spatial attention research has demonstrated the advantage of indicating the probable location of the target in space in target detection tasks. If the mechanisms involved in the control of temporal attention are similar to those used in the control of spatial attention, then there should be a measurable benefit in keeping the timing parameters constant. This should yield an attenuation of the AB.

Experiment 2b fixed the temporal predictability of the probe in relation to the target and Experiment 2c fixed the temporal position of both the target and probe relative to the beginning of the RSVP stream.

Both Experiments 1 and 2 (a, b, & c) were all carried out with the stream of distractors present. Experiment 3a reexamined Experiment 1, which was a replication of Shapiro *et al.* (1994) Experiment 3a, in the absence of a distractor stream, and Experiment 3b replicated Experiment 2c, where both the target and the probe had a fixed temporal position, but with the distractor stream removed. In both of these experiments, the target and the probe were masked with a pattern mask to limit the perceptual processing. If the non-target distractors are placing a load on the attentional system, then this load may prevent the subjects from using the predictability information provided by the manipulations in this series of experiments. By removing the non-target stream elements, this load should be removed, and it was hypothesized that the AB would be attenuated.

Experiments 4 a & b replaced the distractor stream with a constant element (the mask used in Experiment 3). This manipulation was designed to examine the effects of a constant distractor stream element on probe performance in both the temporally unpredictable (Experiment 4a) condition and the temporally predictable (Experiment 4b) condition. It was expected that a homogeneous distractor stream in place of the heterogeneous distractor stream would result in fewer items to be confused with the critical target and probe items. This would result in an attenuated AB.

Experiment 5 examined the effects of practice on the AB. Shiffrin and Schneider (1977, Schneider and Shiffrin, 1977) theorized that practice would lighten the attentional demands of a task by automated some of the aspects of the task. Since the AB has been shown to have an attentional aspect, practice should have the effect of attenuating the effect.

Experiment 1

Rationale

The first experiment was a replication of Shapiro *et al.* (1994) experiment 3A, in which the target task was the detection of the presence of a white letter (the letter 'S'), and the probe task was the detection of a specified black letter identity (the letter 'X') in a stream of black distractors.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as a second repeated variable, and probe position (positions 1 to 8) as the third repeated variable.

Subjects

Fifteen volunteers from the university subject pool were used. Before beginning the experiment, subjects filled out an informed consent form (see appendix 1), and the procedure was explained. Eight females and seven males, ranging in age from 18 to 23 years (mean = 20, SD = 1.3) participated.

Stimuli and Apparatus

The stimuli were presented with an Apple LC Macintosh computer and displayed on an Apple Macintosh 13" color monitor. The monitor resolution was 70 dots per inch while the horizontal screen refresh rate was 14.99 ms. The viewing distance for subjects was 35 cm with their heads stabilized on a chin rest. Responses were verbally reported and were recorded by the experimenter. The experimenter was blind to the correct responses.

Each trial consisted of a succession of capital letters presented on a uniform gray field (9.1 cd/m^2) which subtended 16.3° by 12.5°. The letters were 0.88° in height and 0.62° in width. All the letters were black with the exception of the target letter which was white (32.9 cd/m^2). The letters were from a custom made font in a block style. The stimuli and apparatus used in this experiment remained the same for Experiments 1, 2 and 5.

Procedure

Each subject participated in two experimental sessions consisting of 320 RSVP trials each. Each letter was displayed for 15 ms with an inter-stimulus intervals (ISI) of 75 ms for a stimulus onset asynchrony (SOA) of 90 ms (11.11 letters/sec). Each letter was presented at the same spatial location at the centre of the computer screen. The number of pre-target letters randomly varied from between 7 and 15 items allowing the target to occur within the temporal window extending from 630 ms to 1350 ms after the beginning of the RSVP stream. There were always eight post-target letters.

During the ISI, the subject viewed the uniform gray field. A small white fixation dot in the centre of the screen indicated that a trial could begin. Once the trial was initiated, by the subject pressing the mouse button, the fixation dot remained on the screen for 180 ms before the presentation of the letter stream. For each trial, the subject had two tasks. The first was the detection of the presence or the absence of a white letter (the target) in the stream. The white letter was always an 'S' so there was no need for identification. The second task was detecting the presence of the letter 'X' (the probe) in the stream. The other pre-target and post-target stream letters were randomly selected from the remaining 24 letters in the alphabet with the condition that no letter be presented twice in a trial.

In half of the trials, the target was presented, and in the other half, the target was absent. The probe was also presented on half of the trials in each of the eight post-target positions with the other half of the trials being probe absent trials. The presentation order was fully counterbalanced, and the order of the trial presentation completely random. The probe, when presented, always occurred in the last eight letters (the post-target stream). The probe was presented 10 times in each of the post-target positions for a total of 80 trials in each of the four possible target/probe combinations (target present/probe present, target absent/probe present, target present/probe absent, target absent/probe absent).

The trials that required probe detection in the absence of a target served as a control condition, giving an indication of the subjects performance on probe detection from among the stream item when there was no preceding (target) task. The probe was presented in all eight positions when the target was both present and absent, so the probe detection by position in the stream in the target present condition was compared to probe detection by position when the target was absent (see Table 1). The trials in which the target was present and the probe was absent were important to gauge the subject's false alarms on the probe task. This was necessary to obtain a' (a signal detection measure (Creelman, 1991; Donaldson, 1992) discussed in more detail below), which is useful in determining the difficulty of the task. The attentional blink is any differences found when subjects were required to do the dual task (target and probe) as compared to their performance on the single task (probe only).

Subjects were given between five and 20 practice trials in order to familiarize themselves with the task. They practiced until the experimenter was confident that they knew the procedure and understood the expectations of the experiment. When both the experimenter and the subject were comfortable with their practice performance, the experiment began. The subjects ran in two identical sessions to examine the effects of practice on the AB. The results from the practice manipulations will be discussed later.

Results and Discussion

The group mean percentage for correct probe detection trials plotted against the probe serial position is shown in Figure 4 for both the experimental condition and the control condition. The mean percent correct for the experimental group was calculated by dividing the number of trials that the target was correctly detected and the probe was shown by the number of trials where both the target and the probe were correctly detected. The control group shows the number of correct probe detections when the target was absent against the number of times the probe was presented when the target was absent (10 times). The experimental performance is plotted against the control performance in Figure 4. This method of calculating percent correct for the probe performance will be used throughout the thesis.

Table 1

Experimental Trial

Potential Probe False Alarm Trial

Target Present **Probe Present**	**Target Present** **Probe Absent**
Target Absent **Probe Present**	**Target Absent** **Probe Absent**

Control Trial

Figure 4

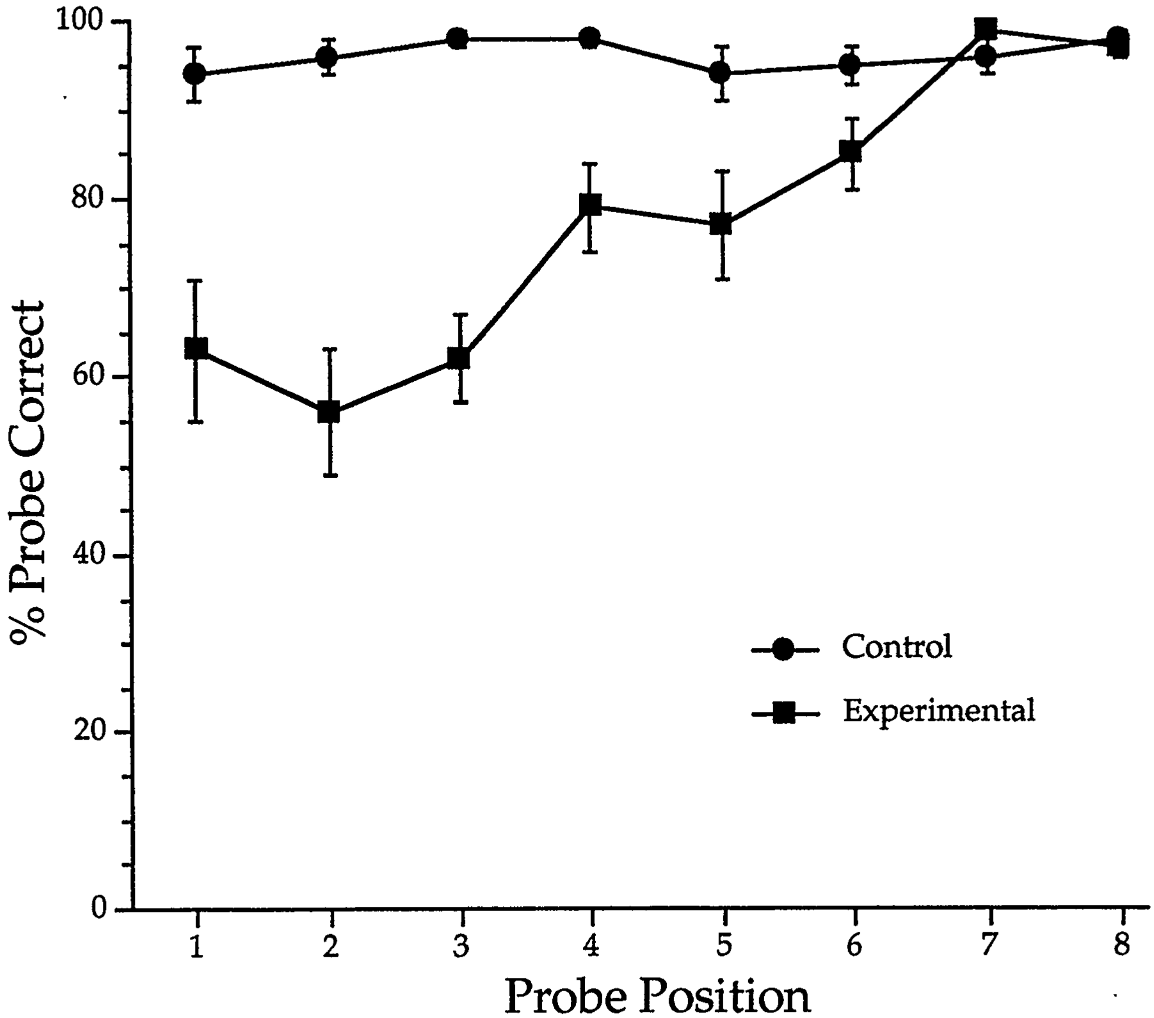


Figure 4: The group mean percentage of trials in which the probe was correctly detected as a function of the relative serial position of the probe for Experiment 1. Circles represent the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

The group mean percentage correct takes into account all of the correct hits and all of the misses, but fails to account for the false alarms or correct rejections. A signal detection measure was also used to account for these other possibilities. The traditional use of d′, a measure of the receiver operating characteristic (ROC) curve was rejected because of its lack of sensitivity when the data contains many extreme values. In its place, the a′ measure (Creelman, 1991; Donaldson, 1992) was adopted for use in this and the following experiments. It is a non-parametric measure of the area that falls under the ROC curve whereas d′ is a straight line that estimates the distance that the ROC curve is away from chance performance (see Figure 5). Figure 6 is a plot of the a′ measures of probe performance across the probe positions.

The principle analysis in this series of experiments is one used to determine whether there is an attentional blink or not. This analysis consists of comparing the results of the experimental condition for each experiment, against the control condition for that experiment. The main difference between the two tasks is that the experimental conditions have dual tasks, i.e., both a target task and a probe task. Since the AB is measured as the decrement in performance on the second task following the successful completion of the first task, the appropriate control condition against which to measure this deficit is one in which the items presented are exactly the same as those used in the experimental task, but with subjects only reporting on the second task, i.e., the probe.

Performance in the control conditions reflect the magnitude of visual masking as a result of items being presented in the RSVP stream. Visual masking

Figure 5
ROC Curve showing a' and d'

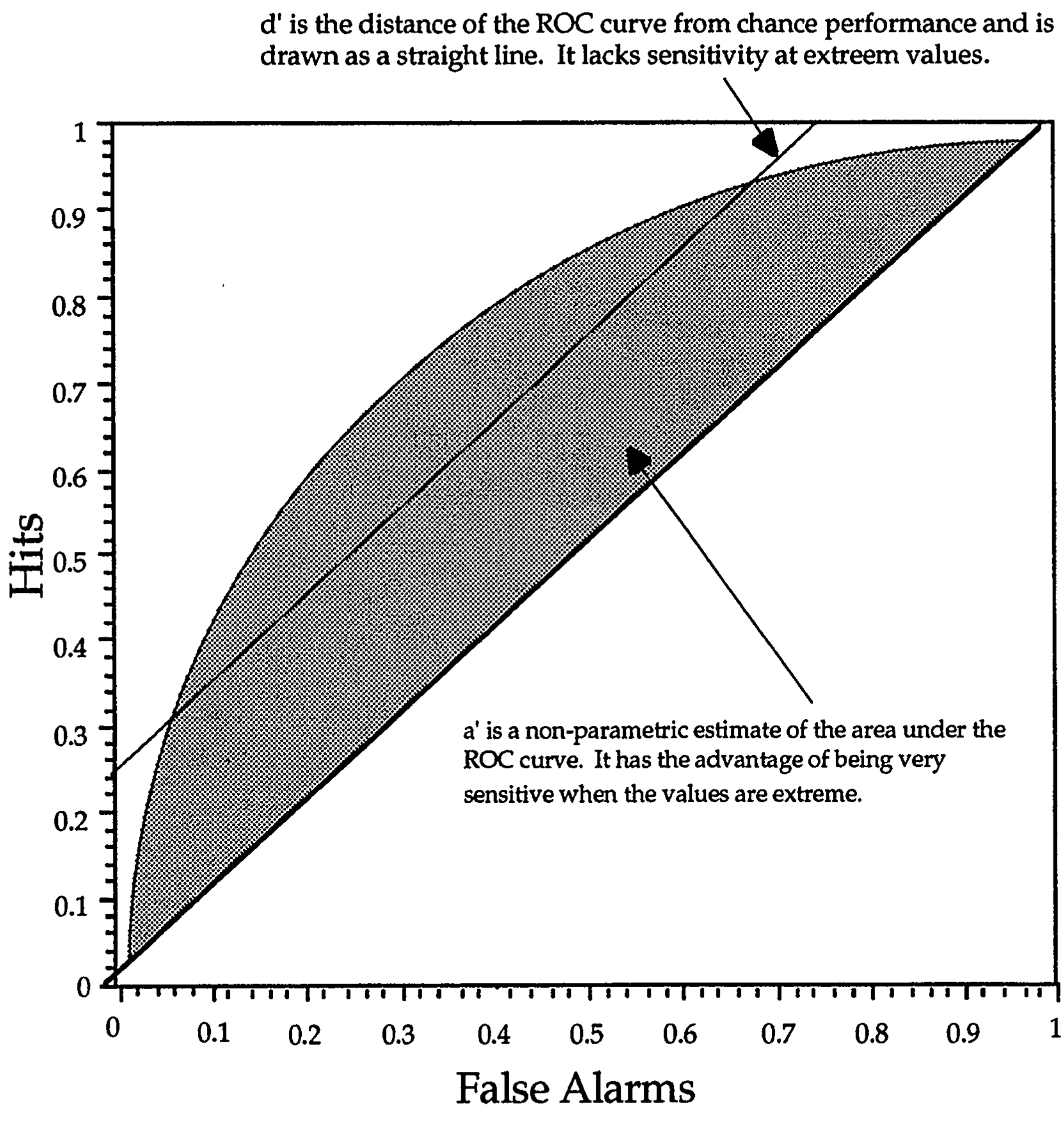


Figure 5: A figure showing the receiver operating characteristics (ROC) for a given performance. The probability of a hit is plotted against the probability of a false alarm. The shaded area represents the area under the ROC curve (a′) and the line represents the distance of the ROC curve from chance (d′).

Figure 6

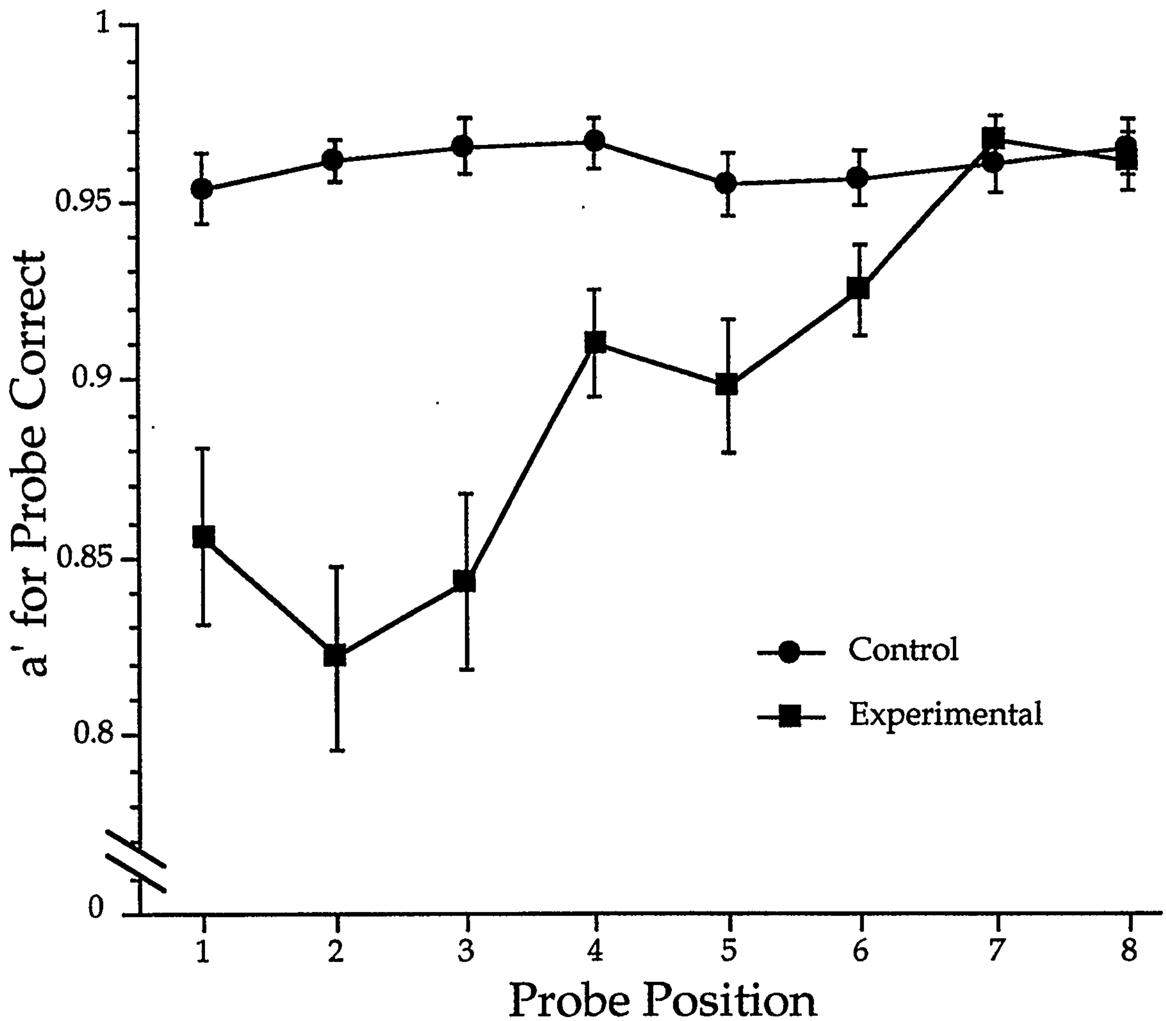


Figure 6: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative serial position of the probe for Experiment 1. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

is a function of both timing (SOAs) and the relative luminance of the mask as compared to the stimulus items (Felsten & Wasserman, 1980; Turvey, 1973). Since these are varied between the experiments, the control conditions will reflect different performance levels. Of critical importance is the comparison between performance in the single- versus dual-target conditions. The deficit seen in performance on the second task (probe detection) following the successful completion of the first task (target detection) is considered an attentional blink only if the performance is worse than when the same task is done in isolation. The cause for the poorer performance is the additional processing required for the first task, and is therefore an attentional or processing problem rather than a perceptual problem. When the experimental condition differs from the control condition in the critical temporal window, 150 ms to 400 ms after the target (serial positions two, three, and four) this is used as evidence for the attentional blink.

A two-factor (experimental condition X probe position) repeated measures univariate analysis of variance (ANOVA) was performed on both the percentage correct data and the a′ data from this experiment. Only data from the target correct trials was used in the experimental data. In all the analysis done for this experiment and in the ones to follow, a Huynh-Feldt epsilon adjustment is made to the degrees of freedom to correct for the use of univariate statistical procedures in repeated-measures designs. All the follow-up comparisons were corrected with the use of a Bonferroni adjustment to the critical alpha level. The alpha level reported is the critical alpha level, which is .05 unless the Bonferroni adjustments require otherwise.

Whether the percentage correct values or the a′ values are used, there was a significant main effect of experimental condition [percentage data ($F(1,14) = 38.7$, $p < .05$); a′ data ($F(1,14) = 39.73$, $p < .05$)], a significant main effect of probe position [percentage data ($F(7,98) = 11.81$, $p < .05$) a′ data ($F(7,98) = 11.99$, $p < .05$)], and a significant experimental condition by probe position interaction [percentage data ($F(7,98) = 12.87$, $p < .05$) a′ data ($F(7,98) = 13.22$, $p < .05$)]. The significant interaction indicates a difference between the probe positions across the experimental conditions. As Figures 4 and 6 indicate, the performance of the control group was consistently high for all the probe positions, while the experimental group showed the blink pattern with lower probe detectability for about the first 500 ms after the target and a gradual recovery as the time interval between the target and probe increased.

Using a pooled error variance technique, the probe positions were divided into two groups (first four positions and the last four positions). Performance in the first four probe positions in the experimental condition were compared to the first four probe conditions in the control condition and a significant difference was found [percentage data ($F(1,14) = 105.98$, $p < .025$) a′ data ($F(1,14) = 93.28$, $p < .025$)] indicating better performance in the control group. When the last four positions of the experimental group were compared to the last four positions of the control group, there was no significant difference [percentage data ($F(1,14) = 4.59$, $p > .025$) a′ data ($F(1,14) = 3.86$, $p > .025$)]. This analysis indicates that the differences between the experimental and control groups are found in the first four probe positions. Since this is the area where the blink is found, this difference indicates the presence of an attentional blink in this experiment. Thus

I have shown that my experimental conditions are similar to those used by Shapiro *et al.* (1994, Experiment 3c).

Experiment 2

Rationale

Experiment 1 replicated the findings of Shapiro *et al.'s* (1994) Experiment 3a and provides a baseline against which to judge various manipulations designed to investigate selection factors which may influence the AB. Experiment 2 employed three conditions of varying temporal predictability, manipulating the temporal predictability of the target and probe, in relation both to each other and to the beginning of the RSVP stream. Experiment 2a fixed the target in relation to the beginning of the RSVP stream, and the probe was then allowed to occur in any of the eight possible probe positions. Experiment 2b fixed the temporal relationship of the probe in relation to the target, but the target was allowed to vary from between positions seven and fifteen relative to the start of the stream. Experiment 2c fixed both elements in relation to the beginning of the stream. These manipulations were done to examine the effects of temporal predictability on probe performance. Temporal predictability should allow the subjects to be in a heightened state of readiness when the critical items are presented and was expected to attenuate the AB.

Experiment 2a

Rationale

Experiment 2a was the same as Experiment 1 except that the target was fixed in a temporal position (position 10). This manipulation was done to examine the effect of a fixed target, in relation to the beginning of the stream, on probe performance. It was the first step in the series of experiments that concluded with both the target and probe in fixed temporal positions.

Design

Experiment 2a employed a three-factor design with target present/absent as one repeated variable, probe present/absent as a second repeated variable, and probe position (positions 1 to 8) as a third repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Ten females and five males ranging in age from 18 to 39 years (mean = 21.1, SD = 5.06) participated.

Procedure

The procedure was similar to that used in Experiment 1. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of an 'X' (the probe). The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented ten times in each of the four possible combinations, in each of the eight possible probe positions, for a total of 320 trials per session. Two sessions were run to examine whether there was an effect of practice. The results from the practice manipulations will be discussed later.

The target was fixed relative to the beginning of the stream in the tenth position, making the time when the target appeared relative to the start of the stream predictable at 900 ms. The other RSVP stream parameters remained the same as those used in Experiment 1 (timing, target and probe identities, stimulus sizes and luminance), including the eight possible probe positions.

Results and Discussion

Figure 7 represents the percent correct data for experiment 2a and Figure 8 represents the a′ data for Experiment 2a. Once again we see the pattern of the attentional blink with the experimental condition showing lower performance for probe detection that gradually recovers to the level of control performance about 630 ms after the target. A two-factor (experimental condition X probe position) repeated measures univariate analysis of variance (ANOVA) revealed that there was a significant main effect of experimental condition [percentage data ($F(1,14) = 43.96$, $p < .05$) a′ data ($F(1,14) = 55.95$, $p < .05$)], a significant main effect of probe position [percentage data ($F(7,98) = 16.25$, $p < .05$) a′ data ($F(7,98) = 14.92$, $p < .05$)] and a significant experimental condition by probe position interaction [percentage data ($F(7,98) = 14.94$, $p < .05$) a′ data ($F(7,98) = 13.60$, $p < .05$)]. The significant interaction indicates a difference between the probe positions across the experimental conditions.

As in Experiment 1, a pooled error variance technique was used to analyze the first four probe positions and the last four probe positions. Performance in the first four probe positions in the experimental condition were compared to the first four probe conditions in the control condition and a significant difference was found [percentage data ($F(1,14) = 102.35$, $p < .025$) a′ data ($F(1,14) = 117.18$, $p < .025$)] indicating better performance in the control group. When the last four

Figure 7

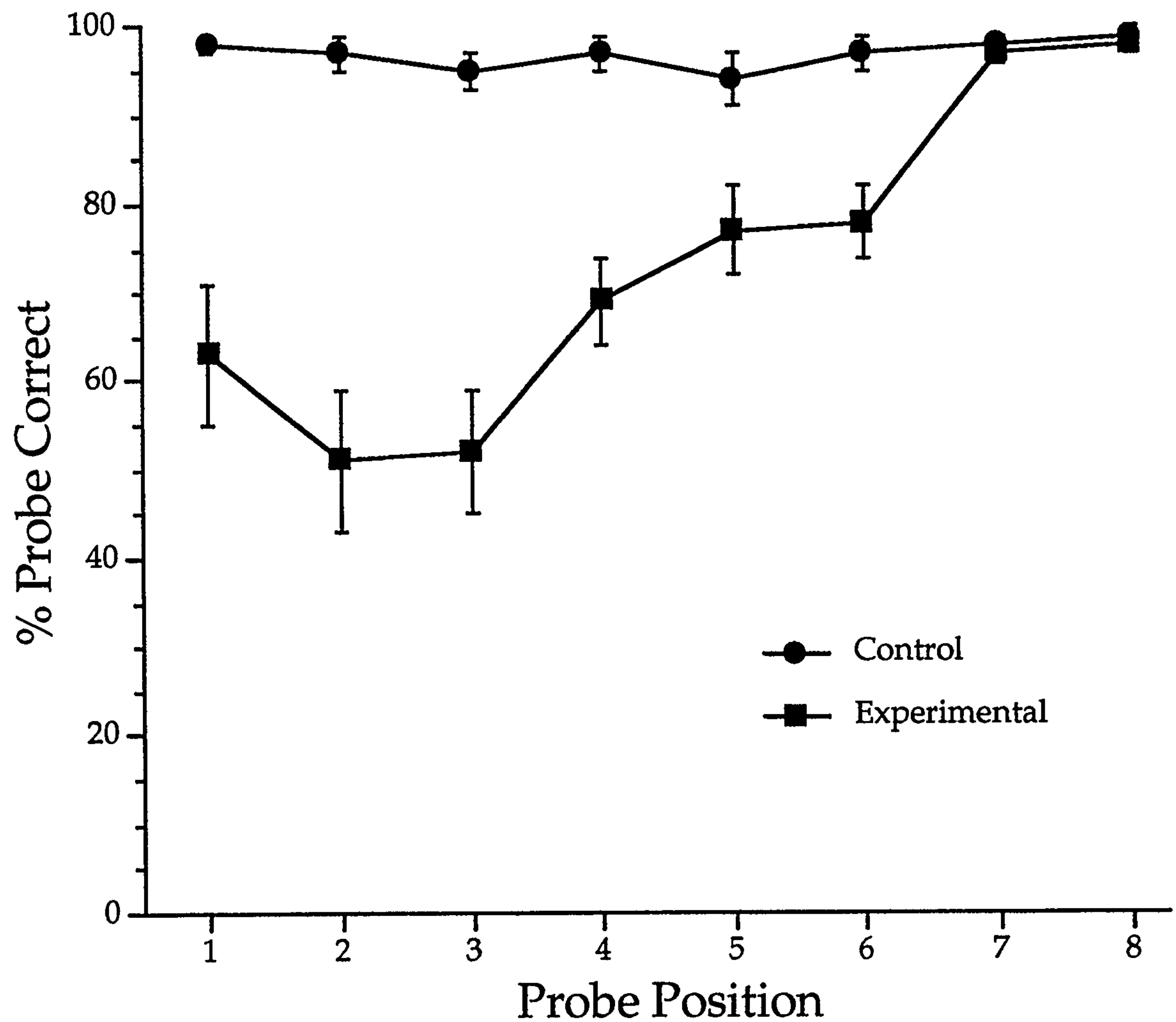


Figure 7: The group mean percentage of trials in which the probe was correctly detected as a function of the relative serial position of the probe for Experiment 2a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 8

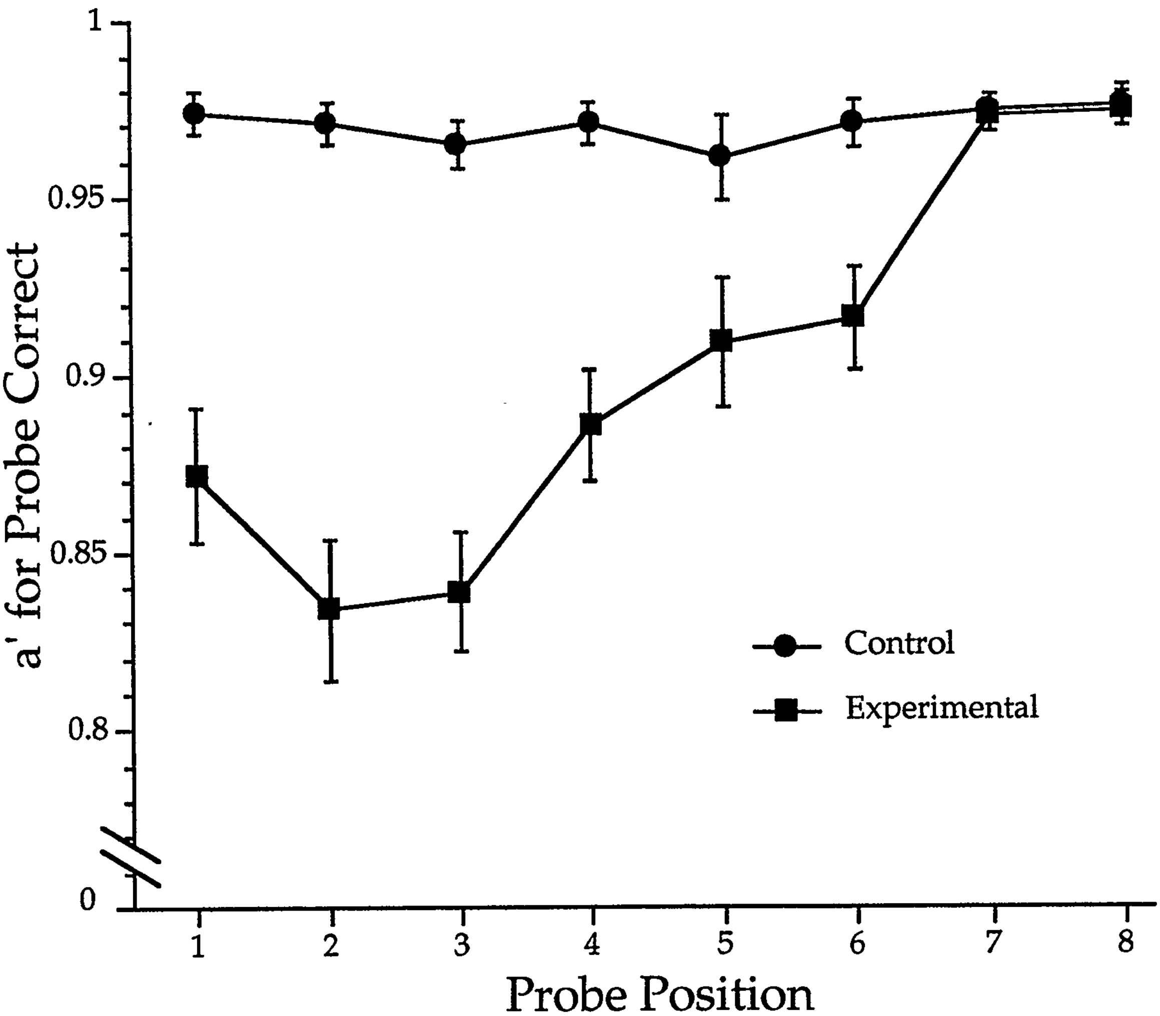


Figure 8: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative serial position of the probe for Experiment 2a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

positions of the experimental group were compared to the last four positions of the control group, there was no significant difference in the percent correct data ($F(1,14) = 5.95$, $p > .025$) but a significant difference was found in the a′ data ($F(1,14) = 6.94$, $p < .025$). A follow up to the a′ data revealed that positions five ($F(1,42) = 17.87$, $p < .00625$) and six ($F(1,42) = 19.75$, $p < .00625$) were significantly different from each other, but positions seven ($F(1,42) = 0.03$, $p > .00625$) and eight ($F(1,42) = 0.01$, $p > .00625$) were not. This analysis indicates that the differences between the experimental and control groups are found in the first six probe positions, but recovered for the last two positions. The difference between this experiment and Experiment 1 was that this experiment had a prolonged blink, extending all the way to position 6 or for 540 ms after the target. The differences found between the experimental and control group will be used to indicate the presence of an attentional blink in this experiment. Fixing the target in a temporally predictable place in relation to the beginning of the RSVP stream appears not to affect the attentional blink.

Experiment 2b

Rationale

Experiment 2b allowed the target to vary and fixed the probe (in position 3). This was done to examine the effects of temporal predictability of the probe on probe performance. Position 3 was chosen because that is the position usually revealing the lowest performance in the blink region. If temporal predictability was to have any effect, it was thought that it would be observable where probe performance is the lowest.

Design

Experiment 2b employed a two-factor design with target present/absent as one repeated variable, probe present/absent as a second repeated variable. The dependent measure was correct probe performance in probe position three.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Ten females and five males ranging in age from 18 to 40 years (mean = 24, SD = 7.08) participated.

Procedure

The procedure was similar to that used in Experiment one. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of an 'X' (the probe). The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. Two sessions were run to examine whether there was an effect of practice. The results from the practice manipulations will be discussed later.

The probe was fixed relative to the target in position three so that it always occurred 270 ms after the target. As in Experiment 1, the target was allowed to vary from position seven to position fifteen relative to the beginning of the stream (630 to 1350 ms). The other RSVP stream parameters remained the same as those used in Experiment 1 (timing, target and probe identities, stimulus sizes and luminance).

Results and Discussion

The data for Experiment 2b are presented in Figure 9 for the percent correct and Figure 10 for the a′ findings. Since the probe position was fixed in position three, there is only one position to compare. This graph shows the relatively poor probe performance in position three for the experimental condition as compared to the control condition. A one-way ANOVA revealed that there was a significant difference between the experimental probe performance and the control probe performance [percentage data ($F(1,9) = 21.72$, $p < .05$) a′ data ($F(1,9) = 20.07$, $p < .05$)]. This difference is used as evidence to indicate the presence of a processing deficit in position three which would be within the temporal window of the attentional blink if all eight probe positions had been investigated. Thus, similar to the findings in Experiment 2a, fixing the probe in a predictable temporal location in relation to the target occurrence does not remove, or even attenuate the attentional blink.

Experiment 2c

Rationale

Experiment 2c was the final one in the first set where temporal predictability was manipulated. Since fixing the target and the probe separately had no effect on the AB, it was thought that fixing them both temporally might reduce the effects of the blink. Experiment 2c fixed the target in the same position as Experiment 2a (position 10), and fixed the probe in the same position as Experiment 2b (position 3). It was predicted that by making all of the critical items fall at predictable times, there would be an attenuation of the AB.

Figure 9

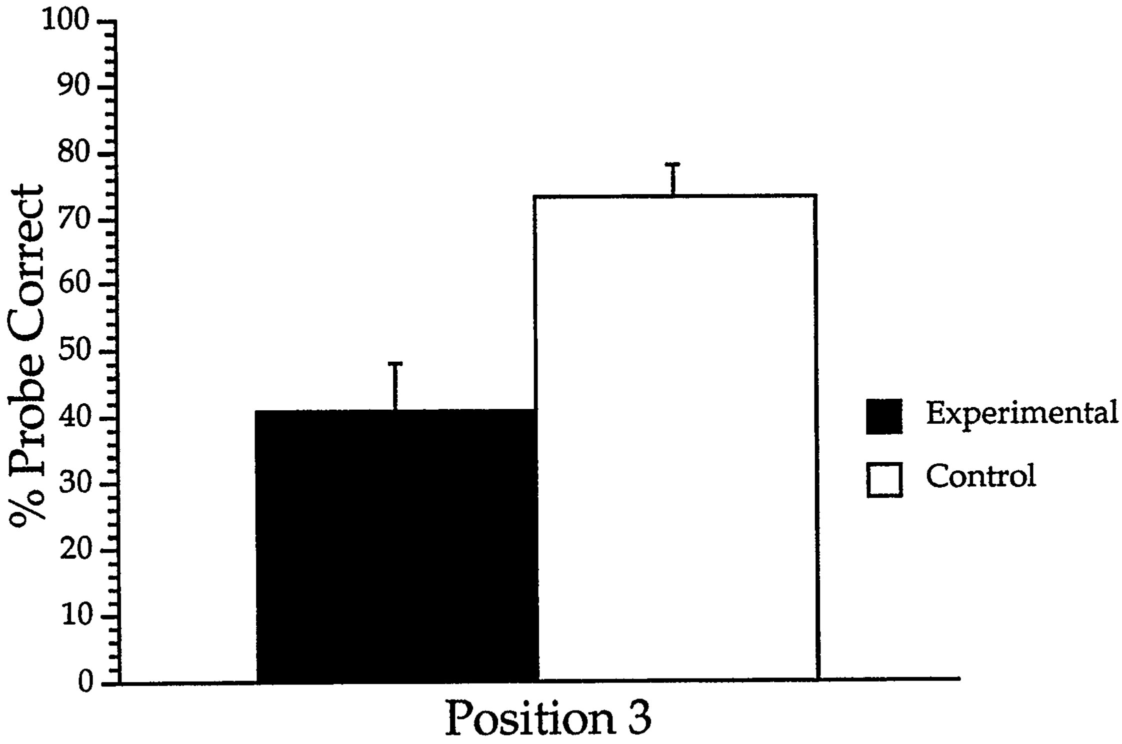


Figure 9: The group mean percentage of trials in which the probe was correctly detected for Experiment 2b. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 10

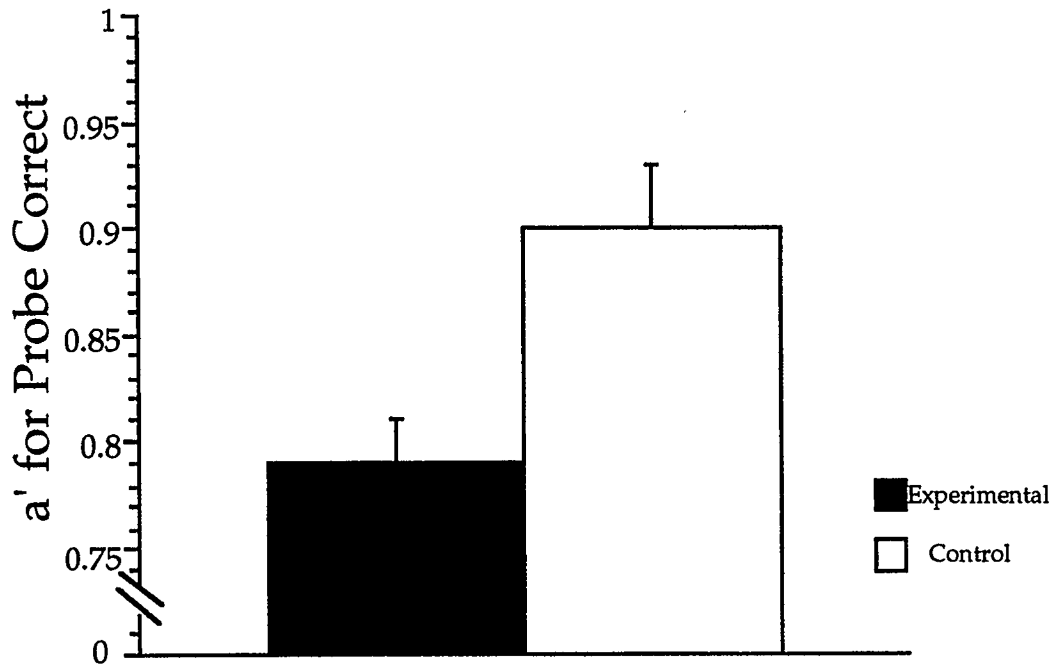


Figure 10: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection in Experiment 2b. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Design

This study employed a two-factor design with target present/absent as the first repeated variable, probe present/absent as the second repeated variable, and correct probe performance (position 3) as the dependent measure.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Seven females and three males ranging in age from 17 to 33 years (mean = 20.6, SD = 4.79) participated.

Procedure

The procedure was similar to that used in Experiment 2b. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of an 'X' (the probe). The target and probe were each presented on half of the trials for a total of four possible target/probe combinations for any given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. Two sessions were run to examine whether there was an effect of practice. The results from the practice manipulations will be discussed later.

This experiment combined the manipulations of the previous two experiments and fixed the temporal location of both the target and the probe. As in Experiment 2a, the target was fixed relative to the beginning of the stream in the tenth position, making the time when the target appeared relative to the start of the stream predictable at 900 ms. The probe was fixed relative to the target in position three so that it always occurred 270 ms after the target (1170 ms after the beginning of the stream); the same as had been done in Experiment 2b. The other RSVP stream parameters remained the same as those used in Experiment 1 (timing, target and probe identities, stimulus sizes and luminance).

Results and Discussion

The mean percent correct data from Experiment 2c are shown in Figure 11 and for a′ are shown in Figure 12. As in Experiment 2b, the probe position was fixed in position three and there is only one position to compare. This graph shows the relatively poor probe performance in position three for the experimental condition as compared to the control condition. A one-way ANOVA revealed that there was a significant difference between the experimental probe performance and the control probe performance [percentage data ($F(1,9) = 11.22$, $p < .05$) a′ data ($F(1,9) = 11.85$, $p < .05$)]. This difference indicates the presence of an attentional blink. Fixing both the target and the probe in a predictable temporal location in relation to the beginning of the RSVP stream appears to have no effect on the attentional blink.

Experiment 3

Rationale

Experiment 2 examined the effects of temporal predictability of the target and probe on probe performance. These manipulations appeared to have no effect in attenuating the AB. In a series of experiments run by Ward, Duncan & Shapiro (1992), these investigators found that removing the distractor items from the RSVP stream had no effect on attenuating the AB. Even though removing non-target items from the stream does not attenuate the AB, it is possible that the

Figure 11

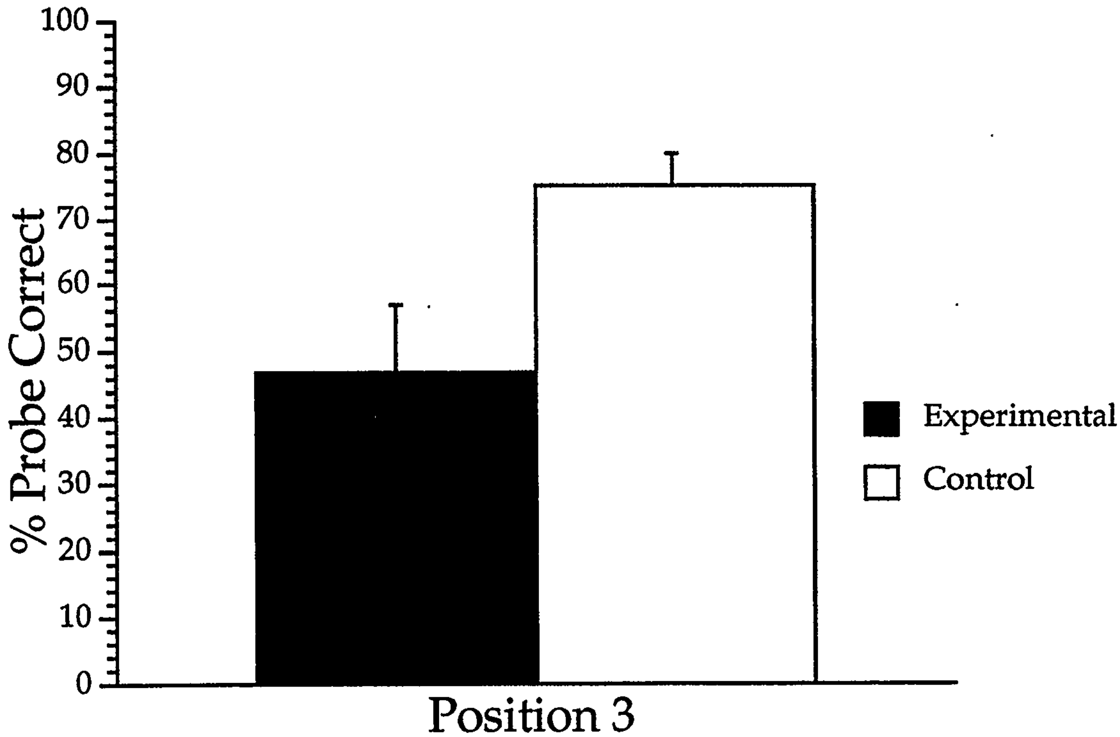


Figure 11: The group mean percentage of trials in which the probe was correctly detected for Experiment 2c. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 12

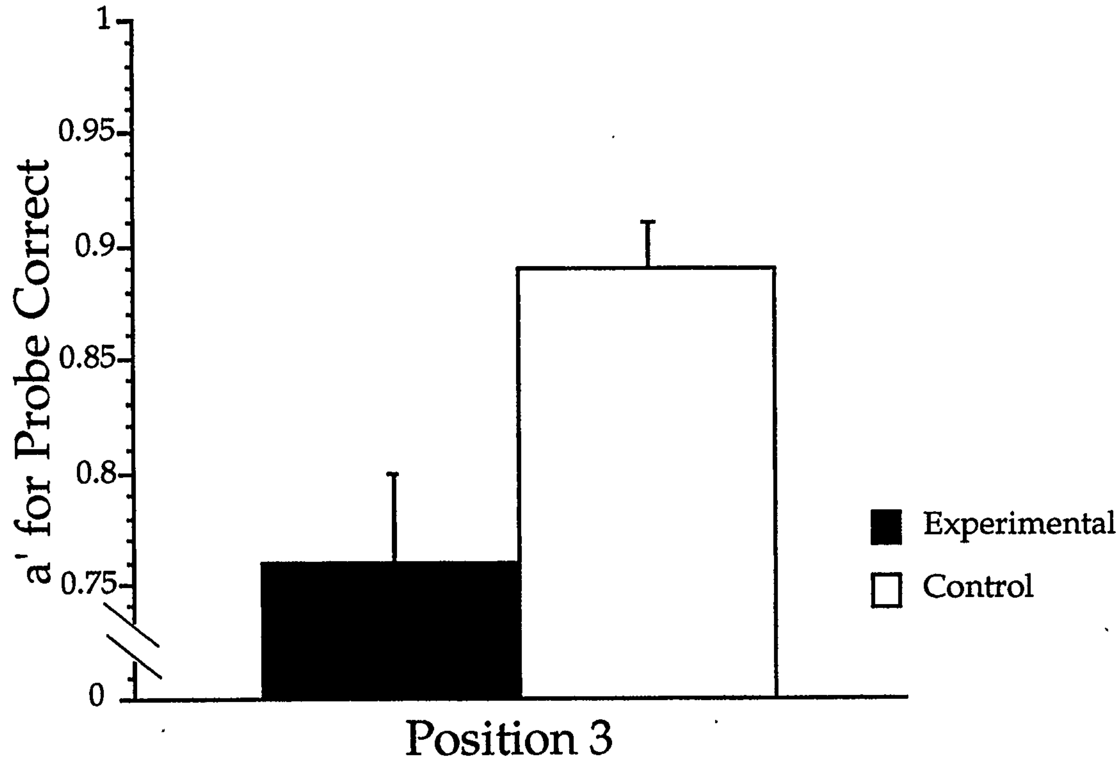


Figure 12: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection in Experiment 2c. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

level of noise in the system is reduced. The present experiment was based on the hypothesis that, if the presence of the distractor items adds noise to the attentional system, it could be that this noise is making it difficult to use the information carried by the temporal predictability. Thus, Experiment 3 examined the effects of temporal predictability on the AB in the absence of a distractor stream expecting that the lack of noise would allow the predictability information to be used by the subjects.

Experiment 3a

Rationale

Experiment 3a was similar to Experiment 1 where the target and the probe were allowed to appear in any of the possible stream positions, but without the non-target stream items. This experiment was done to see if the results of Ward *et al.* (1992) could be replicated. It was also necessary so that there would be an experiment against which to compare the predictable manipulation with no stream.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as a second repeated variable, and the timing of the probe onset (90 ms to 720 ms) as a third repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Six females and four males ranging in age from 18 to

34 years (mean = 21.5, SD = 4.64) participated in the experimental condition. Five females ranging in age from 19 to 28 years (mean = 23, SD = 3.7) participated in the control condition.

Stimuli and Apparatus

The apparatus was the same as was used in the previous experiments. A given trial consisted of a variable blank interval following the offset of the fixation stimulus. This interval was followed by a pattern-masked capital letter, followed by a variable blank interval, followed by another pattern-masked capital letter (see Figure 13). The letters were 0.88° in height and 0.62° in width and the mask was 0.88° in height and 0.88° in width. The mask was a series of straight lines in different orientations (see Figure 14). All the stimuli were black. Both the letter and the mask were displayed for 30 ms with an inter-stimulus intervals (ISI) of 60 ms between the letter and the mask for a stimulus onset asynchrony (SOA) of 90 ms. This change was necessary because of the poor performance for both experimental and control subjects run in the pilot studies. The stimuli were presented at the same spatial location at the centre of the computer screen. The stimulus onset for the first (target) item sequence randomly occurred in 90 ms intervals from 630 ms after the initiation of the trial to 1350 ms after the initiation of the trial. The onset of the probe sequence varied (in 90 ms intervals) from 90 ms after the target mask offset to 720 ms after the offset of the target mask. The stimuli and apparatus used in this experiment remained the same for Experiments 3 and 4.

Figure 13

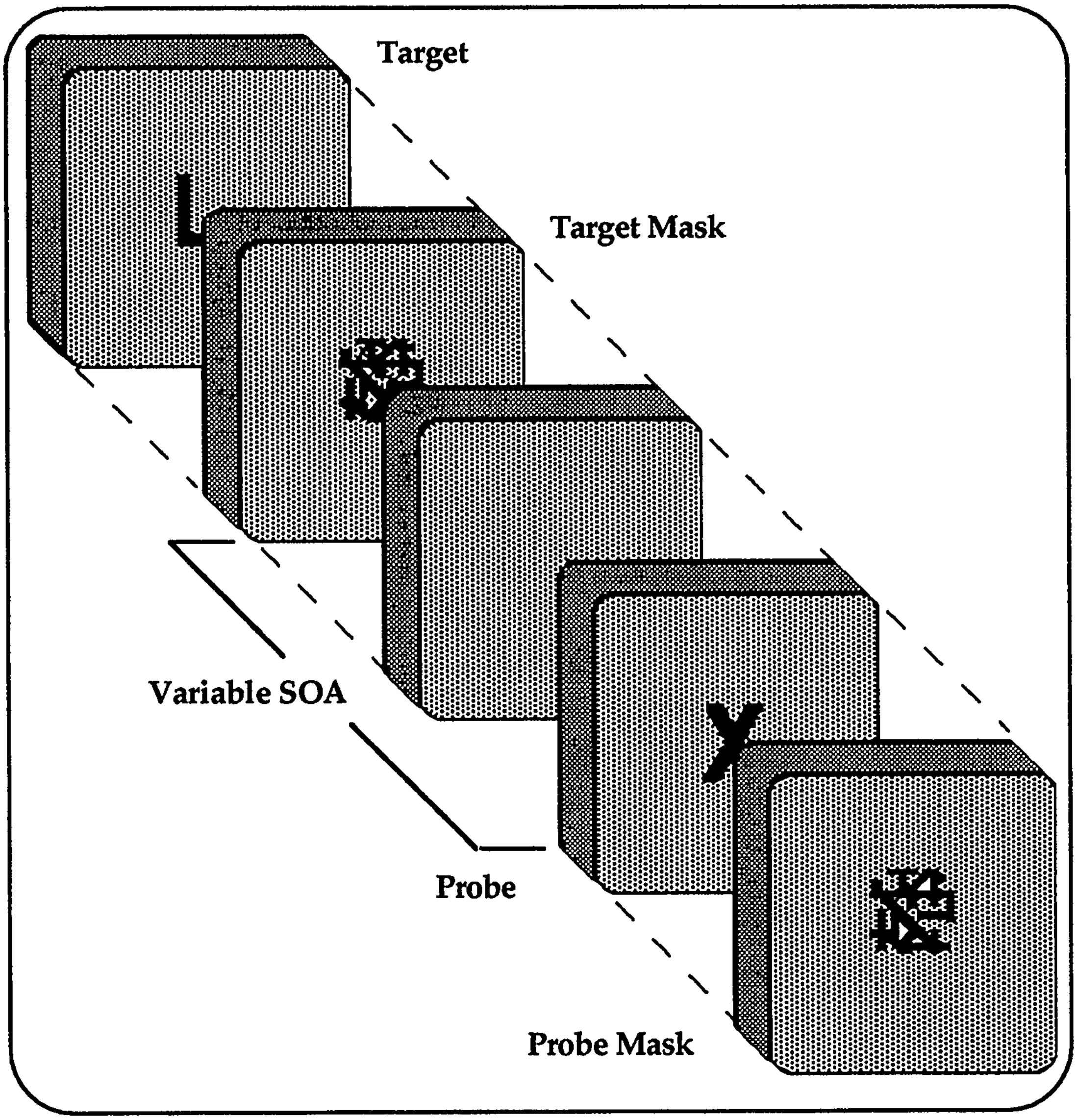


Figure 13: The presentation of items in Experiment 3 is illustrated. The target, target mask, probe and probe mask are all shown. The variable SOA is the variable blank interval between the offset of the target mask and the onset of the probe. This blank interval varied from 90 ms to 720 ms.

Figure 14

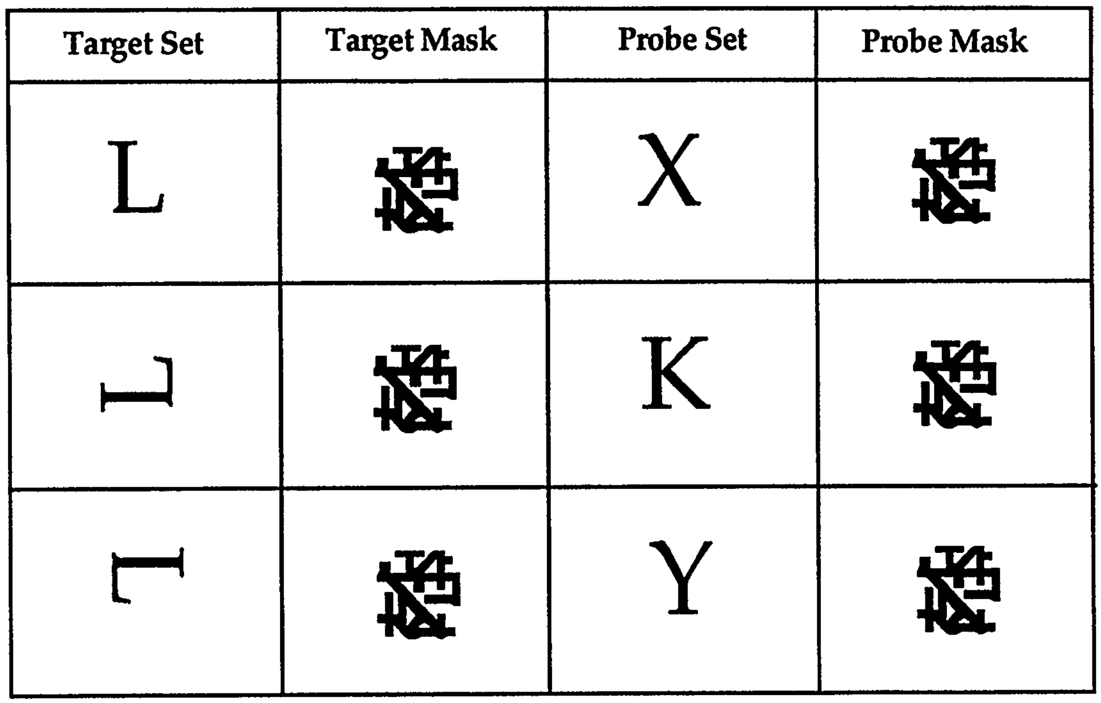


Figure 14: The target and probe set are illustrated here that were used in Experiment 3 and 4. The target was the upright letter 'L' and the probe was the letter 'X'. The other members of the sets were distractors to which the subjects responded that the target (or probe) was not present.

Procedure

Each subject participated in an experimental session consisting of 320 RSVP trials. A small white fixation dot in the centre of the screen indicated that a trial could begin. Once the trial was initiated, by the subject pressing the mouse button, the fixation dot remained on the screen for 180 ms before the trial began. For each trial, the subject had two tasks. The first task was the detection of an upright 'L' (the target). There were two target distractors, an 'L' laying on its front and an 'L' laying on its back (⊢, ⊣,L). Ninety milliseconds after the target was presented, the target mask was presented. After some variable interval, the next item presented consisted of the probe series which was made up of any one of the letters 'X', 'K', or 'Y', followed 90 ms later by the probe mask. The probe set was necessary, because an item needed to appear in the probe position when the 'X' was absent. The letters 'K' and 'Y' were chosen because of their similarity to the letter 'X'. The second task was detecting the presence of the letter 'X' (the probe) in the probe series (see Figure 14).

On half of the trials, the target was presented, and for the other half, the target was absent and one of the target distractors was presented. The probe was also presented on half of the trials in each of the eight 90 ms post-target intervals with the other half of the trials being probe distractor trials. The presentation order was fully counterbalanced, and the order of the trial presentation completely random. The probe was always presented after the target. The probe was presented 10 times in each of the eight post-target intervals for a total of 80 trials of each of the four possible target/probe combinations (target present/probe present, target absent/probe present, target present/probe absent, target absent/probe absent) (see table 1).

A separate control condition was run wherein subjects were instructed to ignore the first item, and only report the presence of an 'X' for a given trial. This allowed for a comparison between the dual task (target and probe) and the single task (probe only) in order to observe the presence or absence of a blink. This procedure was analogous to the full stream attentional blink experiment (e.g., Experiment 1) but with uniform gray blanks appearing in the non-target positions. The subjects practiced to the same extent in this experiment as they had in the previous experiments.

Results and Discussion

Figure 15 represents the percentage data for experiment 3a and Figure 16 represents the a′ data for Experiment 3a. In this experiment, we see that the control performance on probe detection starting out relatively low (57%) before reaching a relatively flat function (between 80 and 95 percent). This is generally seen in experiments that do not have pre-target stream and use a mask following the target items (i.e. Ward *et al.*, 1992) which could indicate an early alerting function that interferes with subsequent performance as a result of some processing that is automatically initiated when an event first starts. Regardless of the control performance, we see that the performance in the experimental condition initially reveals a lower percent probe detection when the first item must be processed to the level of report, and that recovery occurs about 360 ms after the target has been encountered. A two-factor (experimental condition X probe position) repeated measures univariate analysis of variance (ANOVA) revealed that there was not a significant main effect of experimental condition [percentage data ($F(1,13) = 2.88$, $p > .05$) a′ data ($F(1,13) = 0.0008$, $p > .05$)], but a

Figure 15

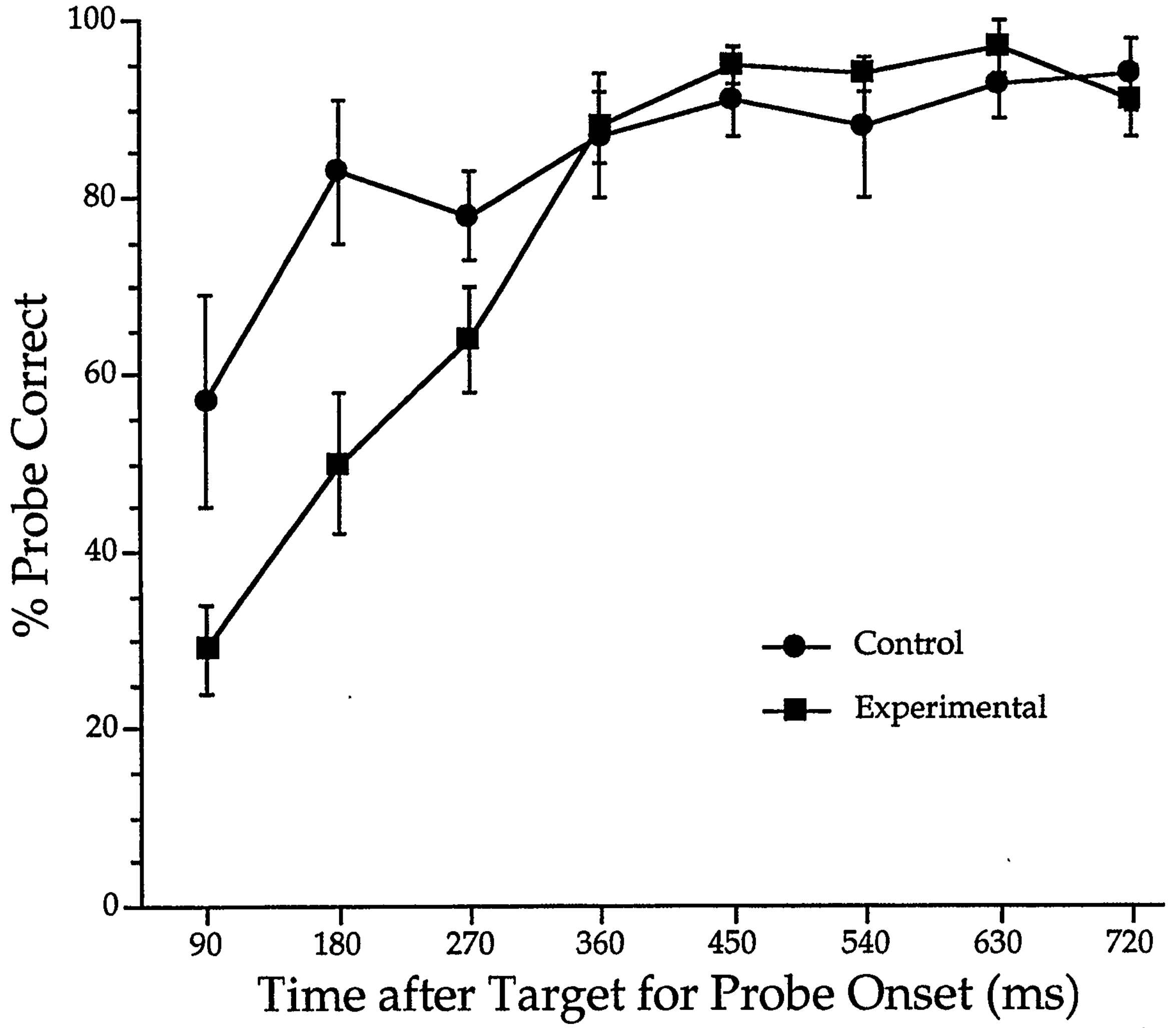


Figure 15: The group mean percentage of trials in which the probe was correctly detected as a function of the relative serial position of the probe for Experiment 3a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 16

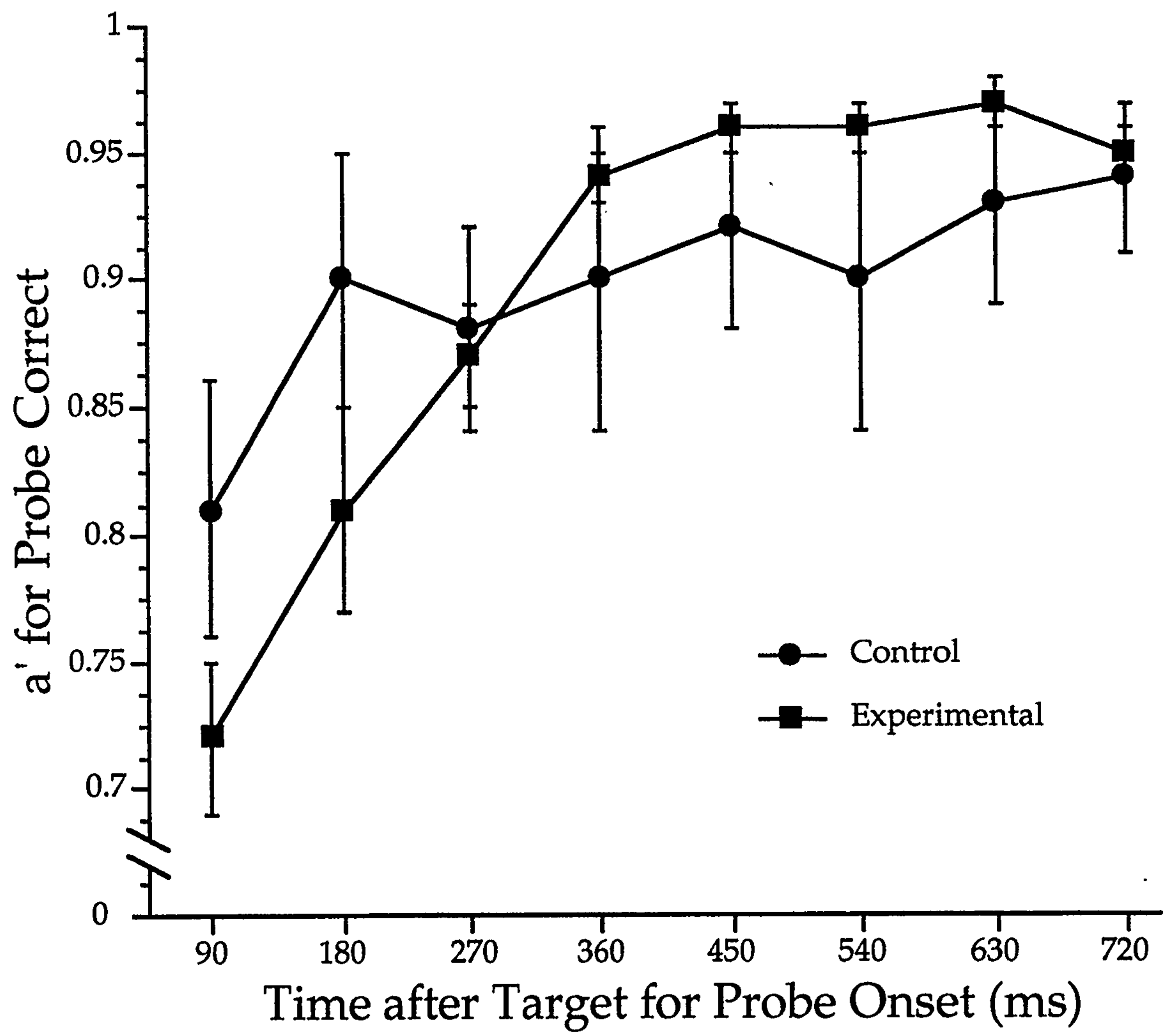


Figure 16: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative serial position of the probe for Experiment 3a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

significant main effect of probe position [percentage data ($F(7,91) = 26.68$, $p < .05$) a′ data ($F(7,91) = 18.24$, $p < .05$)] and a significant experimental condition by probe position interaction [percentage data ($F(7,91) = 4.60$, $p < .05$) a′ data ($F(7,91) = 3.80$, $p < .05$)]. The significant interaction indicates a difference between the probe positions across the experimental conditions.

A pooled error variance technique was used to analyze the first half of the positions and the second half of the positions to follow up the significant condition by probe position interaction. A significant half positions by experimental condition interaction [percentage data ($F(1,13) = 9.3$, $p < .025$) a′ data ($F(1,13) = 8.43$, $p < .025$)] was followed up by comparing the first four positions in the experimental group against the first four positions in the control condition and the last four positions in the experimental condition against the last four positions in the control condition. This comparison was made using separate error variances because of the difficulty in comparing parts of repeated measures between groups. For the first four probe positions no significant difference was found between the experimental and control conditions, once alpha level adjustments had been made [percentage data ($F(3,39) = 3.41$, $p > .012$) a′ data ($F(3,39) = 2.66$, $p > .012$)]. When the last four positions of the experimental group were compared to the last four positions of the control group, there was no significant difference found [percentage data ($F(3,39) = 0.83$, $p > .012$) a′ data ($F(3,39) = 1.69$, $p > .012$)]. Even though the follow-up tests fail to indicate the exact differences found in the significant interactions, a significant attentional blink will be assumed in this experiment for the following reasons: (1) there is a significant condition by probe position interaction, (2) there is a significant half positions by condition interaction, (3) the specific follow-up tests showed the pattern that would indicate a blink, but when the critical alpha levels are adjusted for the follow-up tests, they only reach marginal levels of significance. Since an attentional blink is demonstrated in this experiment, then the removal of the non-essential stream distractors in the absence of any temporal predictability is not enough to eliminate the attentional blink.

Experiment 3b

Rationale

Experiment 3b fixed both the target (position 10) and the probe (position 3) in a temporal position to examine the effects of temporal predictability in the absence of the non-target stream items. If the non-stream items introduce noise into the attentional system that interferes with a subjects ability to use temporal predictability, then this experiment should yield a reduced blink.

Design

This study employed a two-factor design with target present/absent as one repeated variable, probe present/absent as the second repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Four females and six males ranging in age from 19 to 23 years (mean = 20.6, SD = 1.34) participated in the experimental condition. Three females and two males ranging in age from 19 to 22 years (mean = 20.8, SD = 1.3) participated in the control condition.

Procedure

The procedure was similar to that used in Experiment 3a. Subjects detected the presence of the letter "L" (the target) which was followed by a pattern mask, and then detected the presence of an 'X' (the probe) which was then followed by the same pattern mask. The target and probe were each presented on half of the trials for a total of four possible target/probe combinations for any given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. Three sessions were run so that the probe could be examined in three temporal locations.

This experiment fixed the temporal location of both the target and the probe (as in Experiment 2c). The target was fixed relative to the beginning of the stream at 900 ms. The probe was fixed relative to the target in the depth of the blink (270 ms after the target), in the recovery period (450 ms after the target) and after the blink has recovered (630 ms after the target). The three temporal locations of the probes were blocked in the three sessions, one session having the probe occur at 270 ms, one session having the probe occur at 450 ms and one session having the probe occur at 630 ms. The order that the sessions were presented to the subjects was randomized. The other RSVP stream parameters remained the same as those used in Experiment 3a (timing, target and probe identities, distractor identities, mask, stimulus sizes and luminance).

Results and Discussion

The data for Experiment 3a is graphically represented in the two graphs, Figure 17 (for percent correct data) and Figure 18 (for the a' data). In this

Figure 17

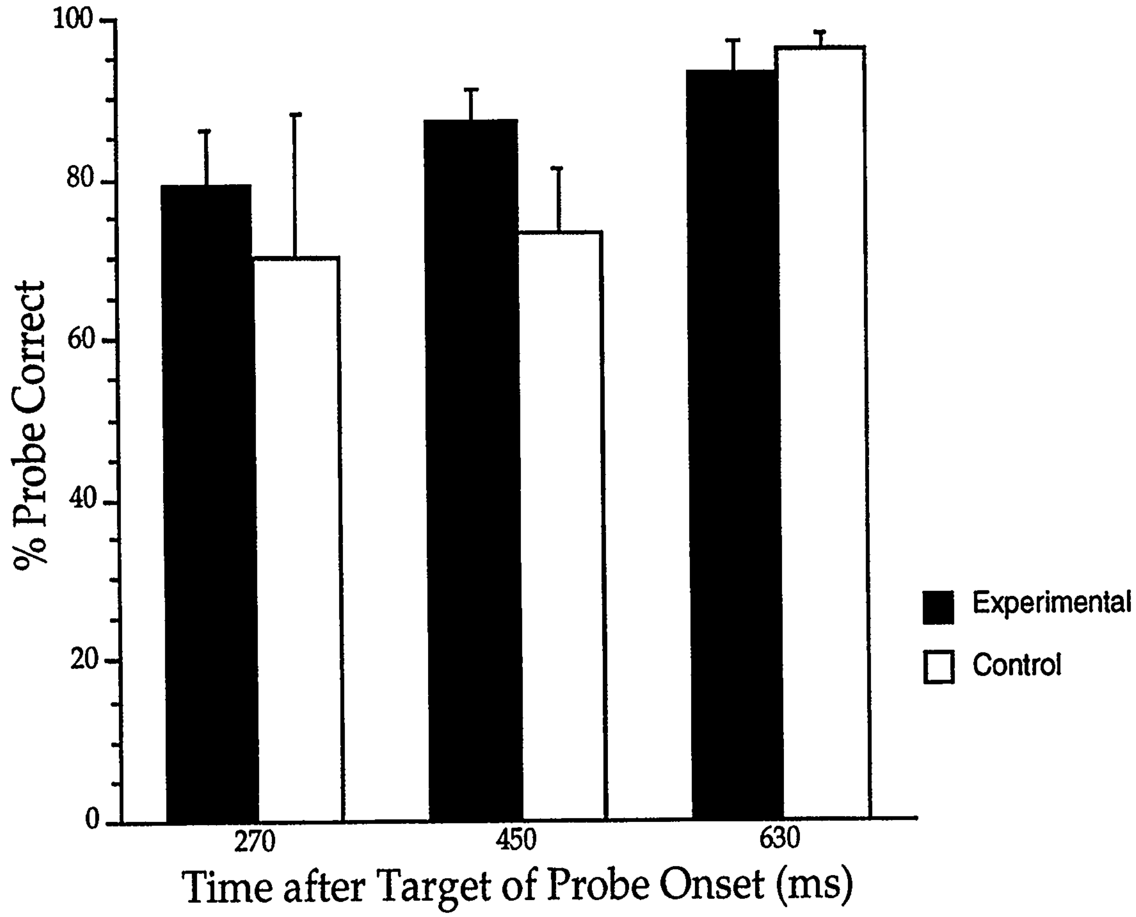


Figure 17: The group mean percentage of trials in which the probe was correctly detected as a function of the relative time after the onset of the target for Experiment 3b. The gray columns represents the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

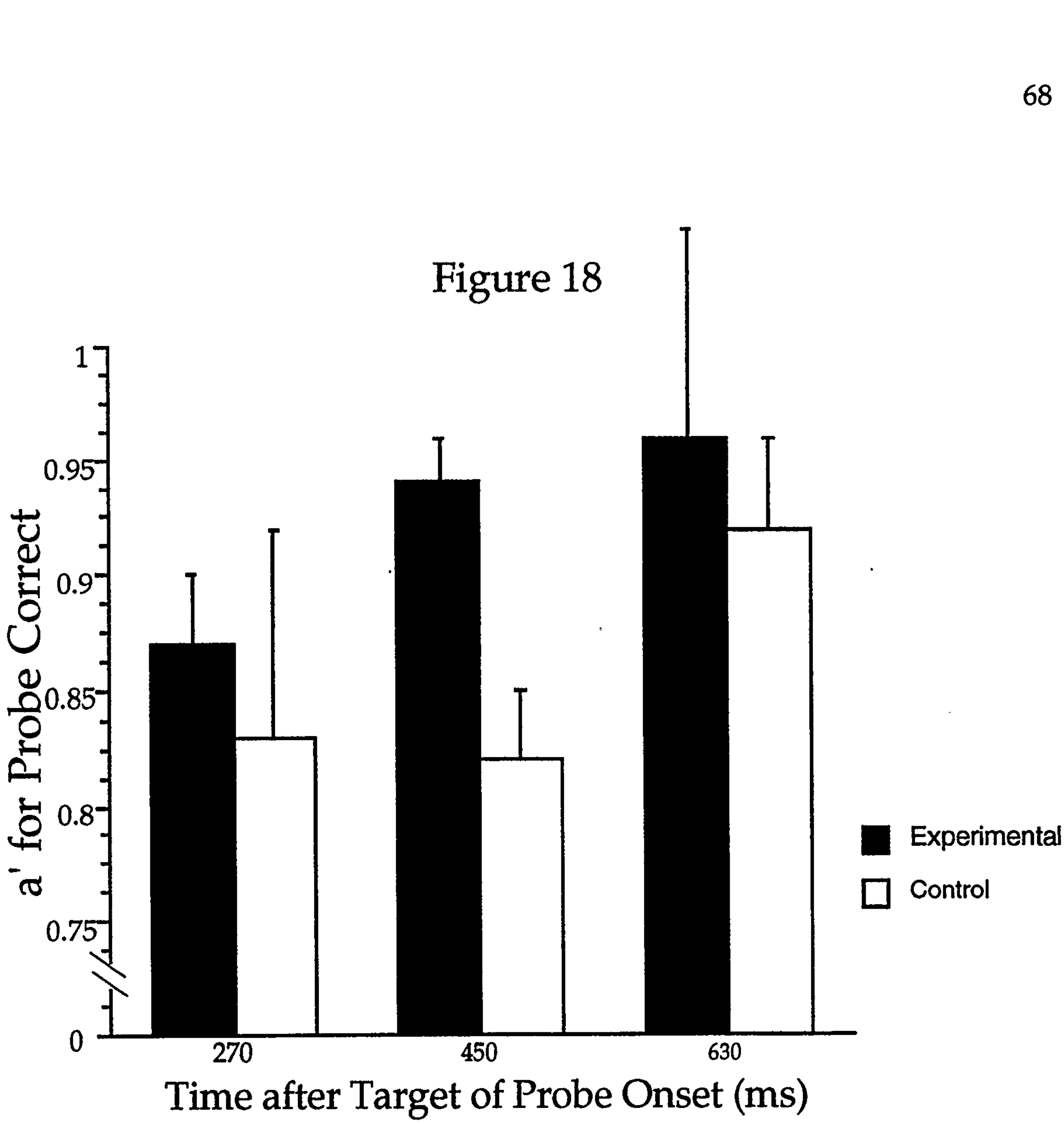


Figure 18: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative time after the onset of the target for Experiment 3b. The gray columns represents the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

experiment, control performance on probe detection initially was lower than in the experimental condition. This would seem to indicate the lack of an attentional blink. A two-factor (experimental condition X probe onset) repeated measures univariate analysis of variance (ANOVA) revealed that there was not a significant main effect of experimental condition [percentage data ($F(1,13) = 0.69$, $p > .05$) a′ data ($F(1,13) = 1.75$, $p > .05$)], that there was a significant main effect of probe onset [percentage data ($F(2,26) = 5.55$, $p < .05$) a′ data ($F(2,26) = 6.25$, $p < .05$)] and no significant experimental condition by probe onset interaction [percentage data ($F(2,26) = 1.07$, $p > .05$) a′ data ($F(2,26) = 1.83$, $p > .05$)]. The lack of both a significant interaction and a significant experimental condition main effect indicates that there is no significant difference between the two groups (control and experimental). This lack of a difference between experimental and control performance is taken as evidence that there is no attentional blink in this experiment. It appears that temporal predictability can be used to attenuate the attentional blink, but only when the interference caused by stream distractors is reduced. This finding will be discussed further in the general discussion.

The repetition of the mask (target +1 and probe +1 item) raised the possibility that 'repetition blindness' (Kanwisher, 1987) was an explanation for the lack of an AB. If the second occurrence of the mask (probe +1) item was suppressed as a result of 'repetition blindness', then the probe would, in effect, be unmasked. When the results of Experiment 3a are considered, this possibility is weakened. If the results of Experiment 3b were because of 'repetition blindness', then Experiment 3a should also lack an AB. Because there was an AB in Experiment 3a, it can safely be assumed that RB was not the cause of the results in Experiment 3b.

Experiment 4

Rationale

Experiment 3 indicates that there is an attenuation of the attentional blink when the target and probe are both fixed in temporal relation to the onset of the trial, but only when the distractor stream items have been removed. A question raised about these findings is centred on the lack of distractor items. Is it the complete lack of distractor information that allows the subjects to make use of the temporal information available? Or is it the lack of new pattern information that allows for the use of the temporal information? In Experiment's one and two the distractor stream was made up of all the letters of the alphabet not used as either the target or the probe. Experiment 3 reduced the amount of distractor information that could be potentially confused with the target and probe information to a single item, the pattern mask. It could therefore be argued that it was the reduction in the amount of information to be processed and sorted to find the target (or probe) and distractor, and that this allowed for the use of the temporal information to attenuate the blink in Experiment 3b. Intraub (1984) found that when repeated items were presented between target items, memory for the target items was better than when new (and meaningful) information was used. Thus it was predicted that if a repeated item is used as the distractor stream, the results will be similar to Experiment 3 where no items were in the distractor stream, than when the whole distractor stream was used as in Experiments 1 and 2. Experiment 4 was conducted with the same parameters as Experiment 3, but with a distractor stream made up of the pattern mask being repeated instead of new items being displayed every 90 ms.

Experiment 4a

Rationale

Experiment 4a was similar to Experiments 1 and 3a. The target and the probe were both temporally unpredictable. The main difference from Experiment 3a was that there was a stream of non-targets, but they were composed of the same stimuli (the mask used in Experiment 3), and repeated in every position.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as a second repeated variable, and probe position (1 to 8) as a third repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Seven females and three males ranging in age from 20 to 41 years (mean = 27.2, SD = 7.9) participated in the experimental condition. Five females ranging in age from 21 to 37 years (mean = 29.6, SD = 6.35) participated in the control condition.

Procedure

This experiment used the same task as Experiment 3a, where the subjects had to detect the presence of an 'L', and then detect the presence of an 'X'. The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented ten times in each of the four possible combinations for a total of 320 trials per session. After each trial was initiated there was a variable length of time (630 ms to 1350 ms) when the screen was the uniform gray color before the target, or a target distractor, was displayed. The probe, or probe distractor, was presented in one of the eight possible probe positions (90 ms or 720 ms) after the target. The other seven items that made up the probe stream were repetitions of the same item, the pattern mask (see Figure 13 above). The other RSVP stream parameters remained the same as those used in Experiment 3a (timing, target and probe identities, target and probe distractor identities, pattern mask, stimulus sizes and luminance).

Results and Discussion

Figure 19 represents the percentage data for Experiment 4a and Figure 20 represents the a′ data for Experiment 4a. The control condition in this experiment is lower than in the previous experiments, indicating a difficult task. Even though the performance is lower, when a regression line is plotted over the percent correct data points, it indicates a flat function with a very small slope ($fX = 0.845(X) + 71.0$). The experimental condition has a steeper slope ($fx = 83.9(X) + 34.3$) indicating that performance gets better as a function of probe position. In a

Figure 19

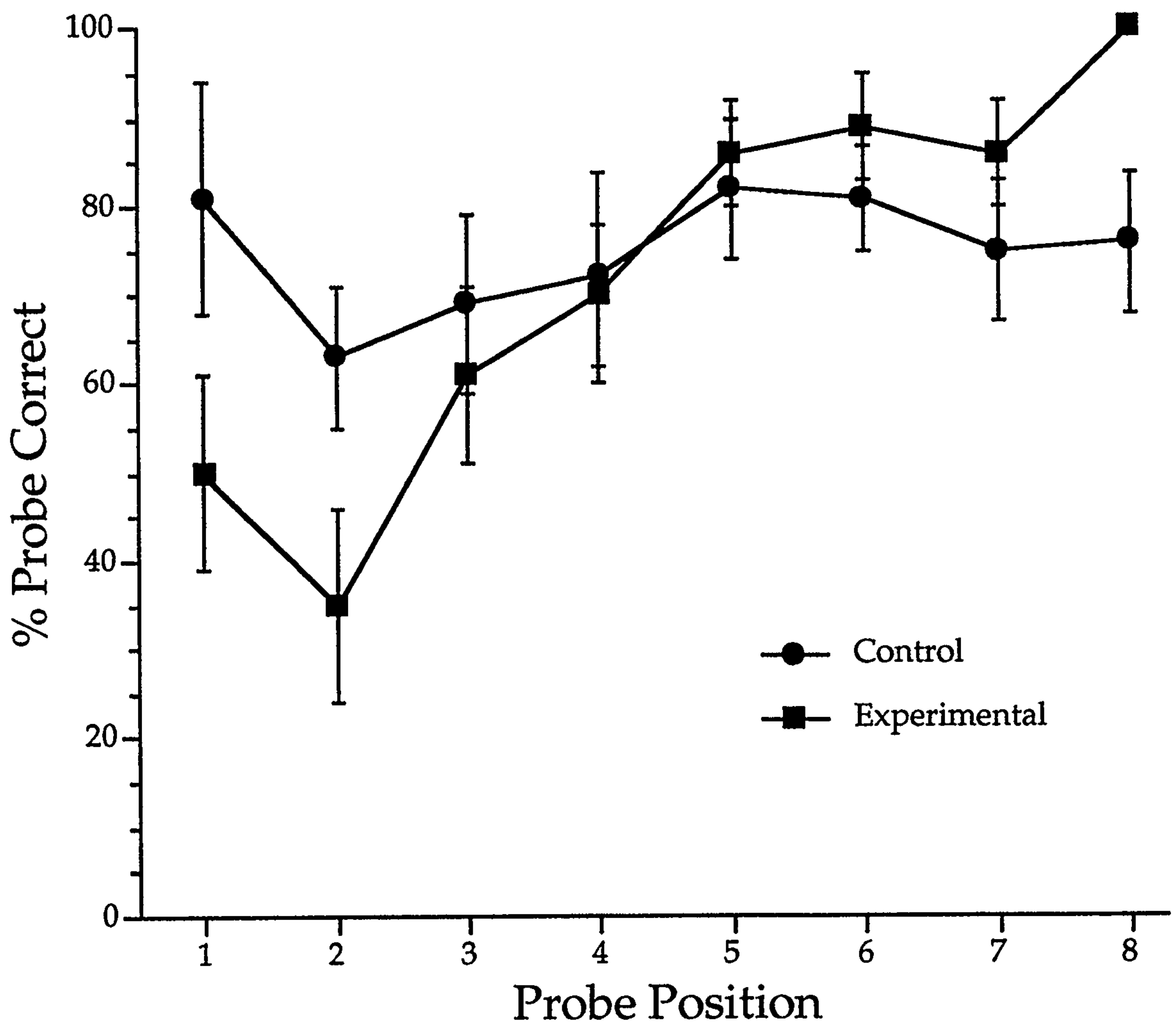


Figure 19: The group mean percentage of trials in which the probe was correctly detected as a function of the relative serial position of the probe for Experiment 4a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 20

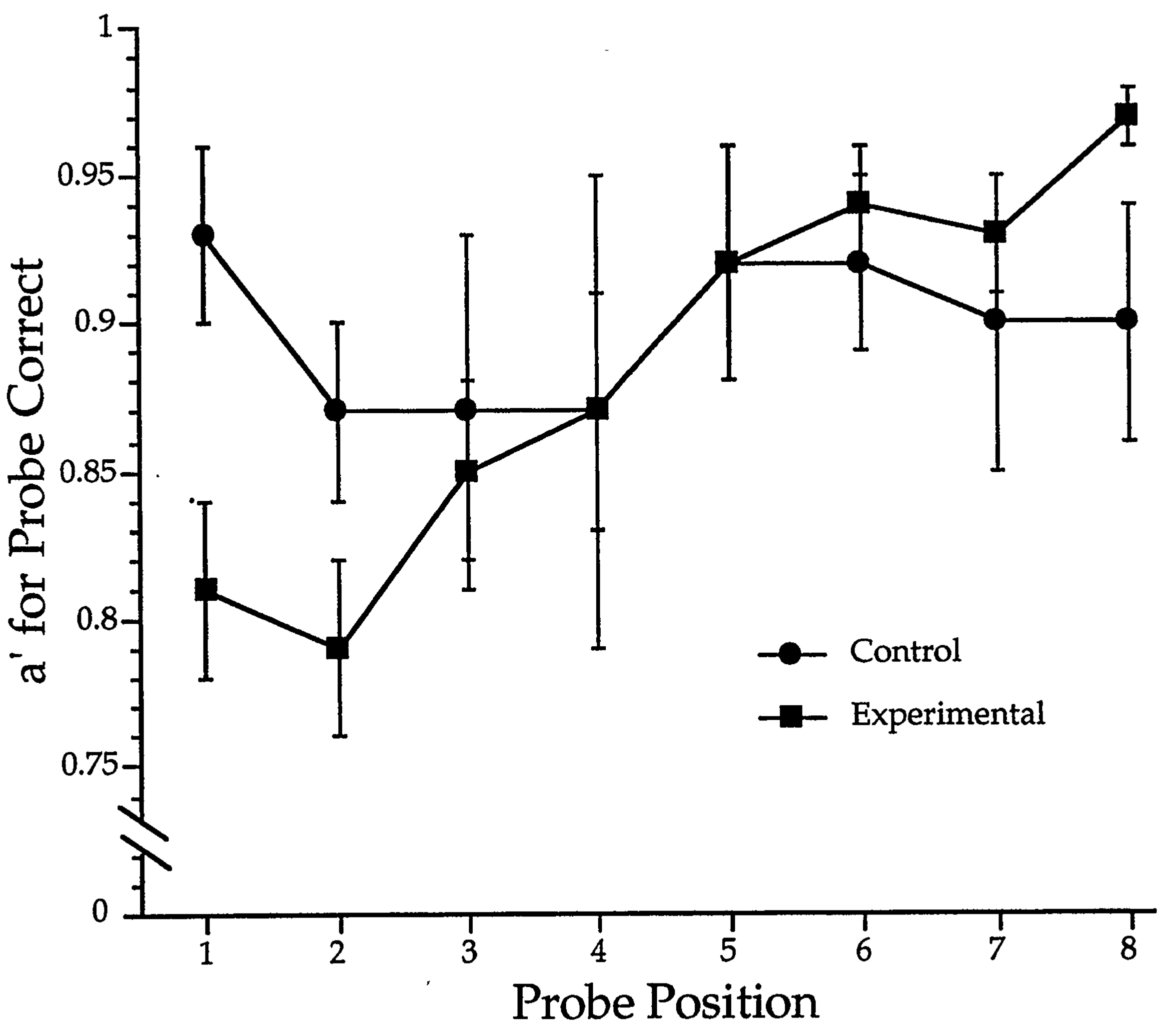


Figure 20: The group a' scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative serial position of the probe for Experiment 4a. Circles represents the control condition in which there was no target presented for the subjects to respond to. The squares represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

quick visual comparison of the percent data between this control group and the control group in Experiment 3a (position one must be disregarded in Experiment 3a, as the target was always followed by a mask in that experiment while in Experiment 4a, the probe could immediately follow the target) the lower performance is again observed that may be due to the automatic processing of an initial item for an event. A two-factor (experimental condition X probe position) repeated measures univariate analysis of variance (ANOVA) revealed that there was not a significant main effect of experimental condition [percentage data ($F(1,13) = 0.08$, $p > .05$) a′ data ($F(1,13) = 0.09$, $p > .05$)], but a significant main effect of probe position [percentage data ($F(7,91) = 7.53$, $p < .05$) a′ data ($F(7,91) = 4.81$, $p < .05$)] and a significant experimental condition by probe position interaction [percentage data ($F(7,91) = 3.83$, $p < .05$) a′ data ($F(7,91) = 3.09$, $p < .05$)]. The significant interaction indicates a difference in the probe positions between the two conditions.

A pooled error variance technique was used to analyze the first half of the positions and the second half of the positions to follow up the significant condition by probe position interaction. A significant half positions by experimental condition interaction [percentage data ($F(1,13) = 8.39$, $p < .025$) a′ data ($F(1,13) = 8.47$, $p < .025$)] was followed up by comparing the first four positions in the experimental group against the first four positions in the control condition and the last four positions in the experimental condition against the last four positions in the control condition. This comparison was made using separate error variances because of the difficulty in comparing parts of repeated measures between groups. For the first four probe positions no significant difference was found between the experimental and control conditions, once alpha level adjustments had been made [percentage data ($F(3,39) = 1.83$, $p > .012$) a′ data ($F(3,39) = 1.76$, $p > .012$)]. When the last four positions of the experimental group were compared to the last four positions of the control group, there was no significant difference found [percentage data ($F(3,39) = 2.05$, $p > .012$) a′ data ($F(3,39) = 1.65$, $p > .012$)]. When each of the eight positions were examined individually, using a separate error term, no significant differences were found after adjustments were made. Even though the follow-up tests fail to indicate the exact differences found in the significant interaction, a significant attentional blink will be assumed in this experiment for the following reasons: (1) there is a significant condition by probe position interaction, (2) there is a significant first half - last half by condition interaction. Since an attentional blink is demonstrated by this experiment, then interpolating a stream of repeating stimuli does not attenuate the blink.

Experiment 4b

Rationale

Experiment 4b fixed both the target (position 10) and the probe (position 3) in a temporal position to examine the effects of temporal predictability. The non-target stream items were the same as those used in Experiment 4a, the repeating pattern mask. It was predicted that the repeated item would show an attenuated blink when the target and the probe were temporally fixed.

Design

This study employed a two-factor design with target present/absent as one repeated variable, probe present/absent as the second repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Five females and five males ranging in age from 19 to 38 years (mean = 24.9, SD = 6.4) participated in the experimental condition. Three females and two males ranging in age from 23 to 45 years (mean = 30.2, SD = 8.5) participated in the control condition.

Procedure

The procedure was similar to that used in Experiment 4a. Subjects detected the presence of the letter 'L' (the target) and then detected the presence of an 'X' (the probe) from among a stream made up of a repeated pattern mask. The target and probe were each presented on half of the trials for a total of four possible target/probe combinations for any given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. Three sessions were run so that the probe could be examined in three probe positions.

This experiment fixed the temporal location of both the target and the probe (as in Experiment 3b). The target was fixed relative to the beginning of the stream at 900 ms. The probe was fixed relative to the target in the depth of the blink (position 3 or 270 ms after the target), in the recovery period (position 5 or 450 ms after the target) and after the blink has recovered (position 7 or 630 ms after the target). The other RSVP stream parameters remained the same as those used in Experiment 4a (timing, target and probe identities, target and probe distractor identities, mask, stimulus sizes and luminance).

Results and Discussion

The data for Experiment 4b is graphically represented in the two graphs, Figure 21 (for percent correct data) and Figure 22 (for the a′ data). For the three positions plotted, the experimental condition is lower than the control condition for both sets of data (percent correct and a′). A two-factor (experimental condition X probe position) repeated measures univariate analysis of variance (ANOVA) revealed that there was no significant main effect of experimental condition when the percent correct data was examined ($F(1,13) = 2.38$, $p > .05$) but the a′ data revealed a significant difference ($F(1,13) = 10.60$, $p < .05$). It also revealed a significant main effect of probe position [percentage data ($F(2,26) = 4.09$, $p < .05$) a′ data ($F(2,26) = 4.41$, $p < .05$)] and no significant experimental condition by probe position interaction [percentage data ($F(2,26) = 0.11$, $p > .05$) a′ data ($F(2,26) = 0.29$, $p > .05$)]. The presence a significant experimental condition main effect indicates that there is a significant difference between the two groups (control and experimental) across the positions measured. This can be seen in both Figures 21 and 22. This difference between experimental and control performance is taken as evidence that there is an attentional blink in this experiment, or that when subjects are required to perform two tasks in an RSVP stream (experimental task), their performance is significantly lower than if they only have a single task to perform (control task). Even though it was predicted that this experiment would show an attenuated blink, it appears that temporal predictability can not be used to attenuate the attentional blink in the presence of

Figure 21

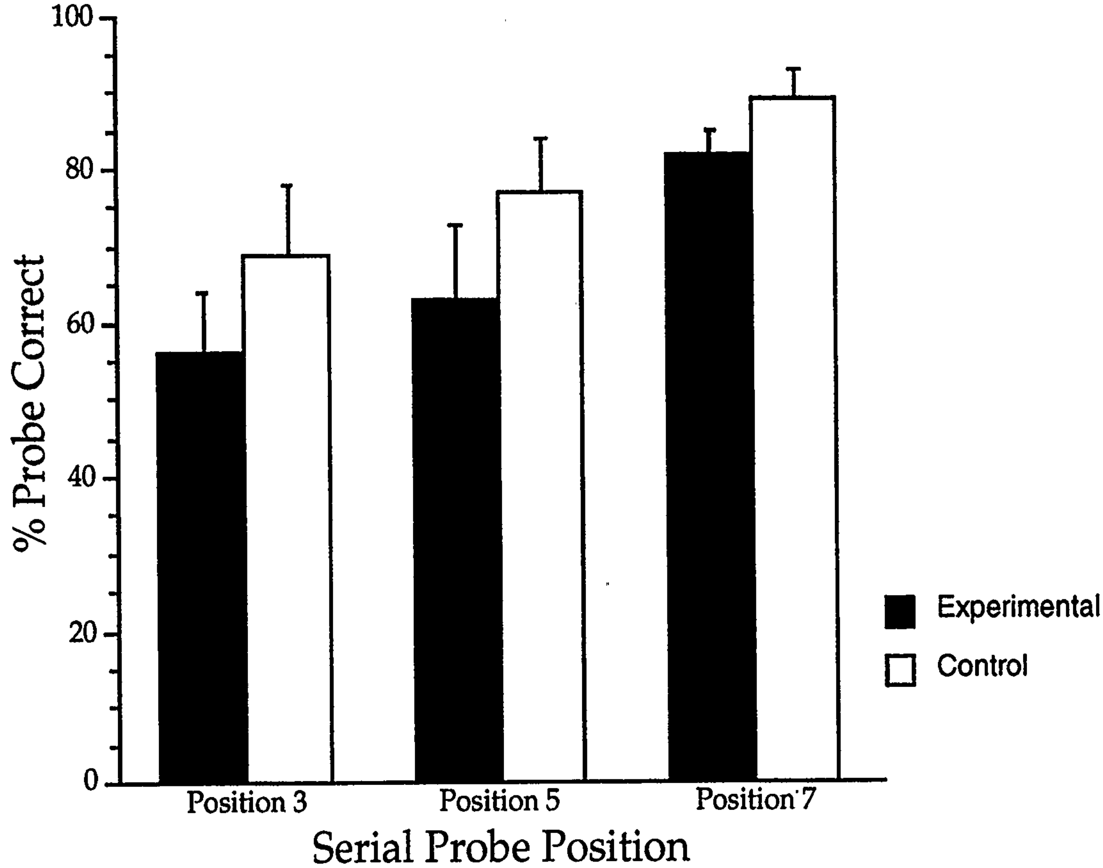


Figure 21: The group mean percentage of trials in which the probe was correctly detected as a function of the relative time after the onset of the target for Experiment 4b. The gray columns represents the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 22

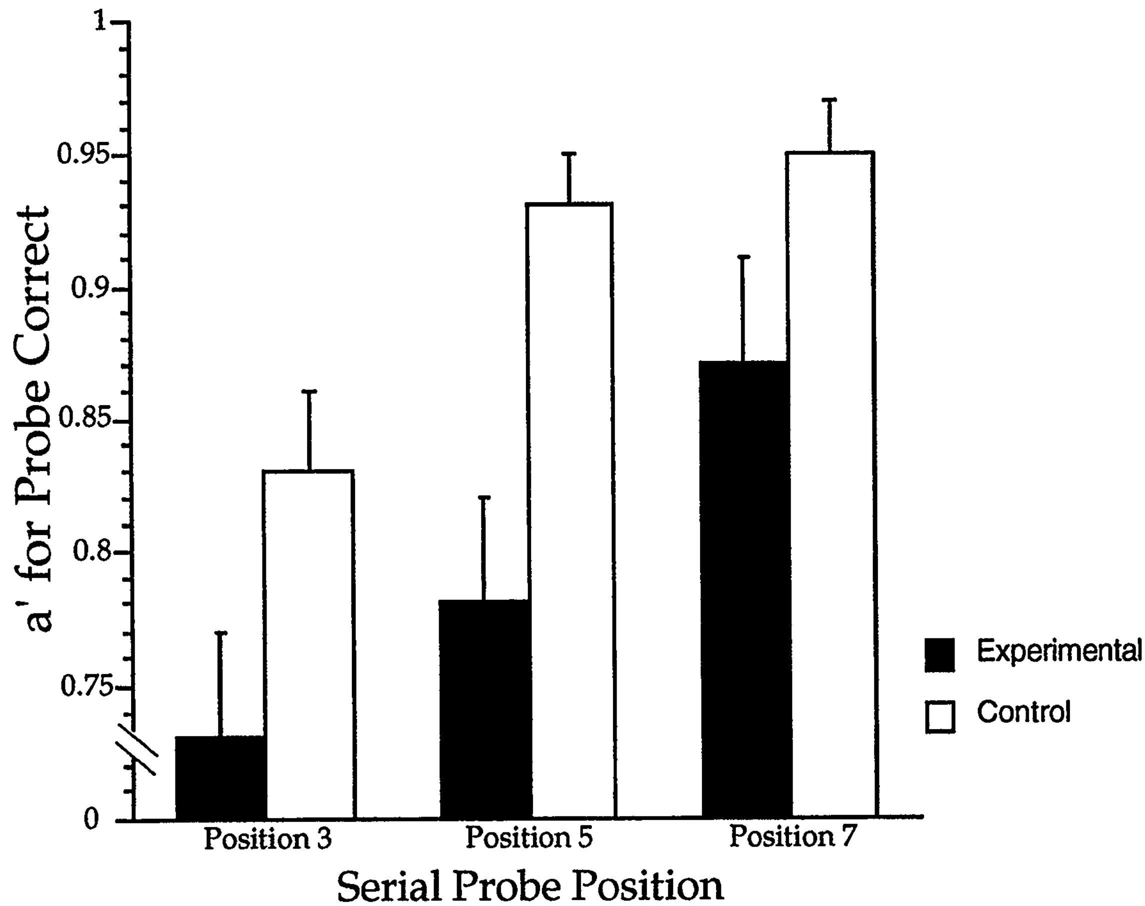


Figure 22: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection as a function of the relative time after the onset of the target for Experiment 4b. The gray columns represents the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

a stream of repeated items. The presence of the noise caused by the processing of the items in the stream, whether repeated or not, appears to be enough to prevent the subjects from using temporal predictability in the task.

Results and Discussion of Experiments 1 to 4

Experiments 1 to 4 examined the effects of both target and probe (temporal) predictability on probe report performance during the critical temporal window of the attentional blink. In the first part of the present section, the results of the general target and probe performance will be reported. The second section will focus on the results of the inter-experimental analyses of probe performance.

General Target and Probe Results

When the percent correct target errors for the first four experiments were analyzed, a significant difference was found ($F(7,82) = 2.394$, $p < .05$). Fisher's least square difference (LSD) post-hoc all pairwise comparisons revealed the following significant differences (at the $p < .05$ level of significance) in the percent target correct scores: Experiment 4a performance was lower than that of Experiments 1, 2c and 3b, and Experiment 4b was lower than Experiment 2a. As seen in Figure 23, the target errors for these two experiments (4a and 4b) were lower than the other experiments. This suggests that the target task of identifying an upright 'L' from among its distractors is a difficult task when the mask is repeated in every probe stream position (Experiments 4a and 4b).

Taking the target false alarms into account (which were not found to be

Figure 23

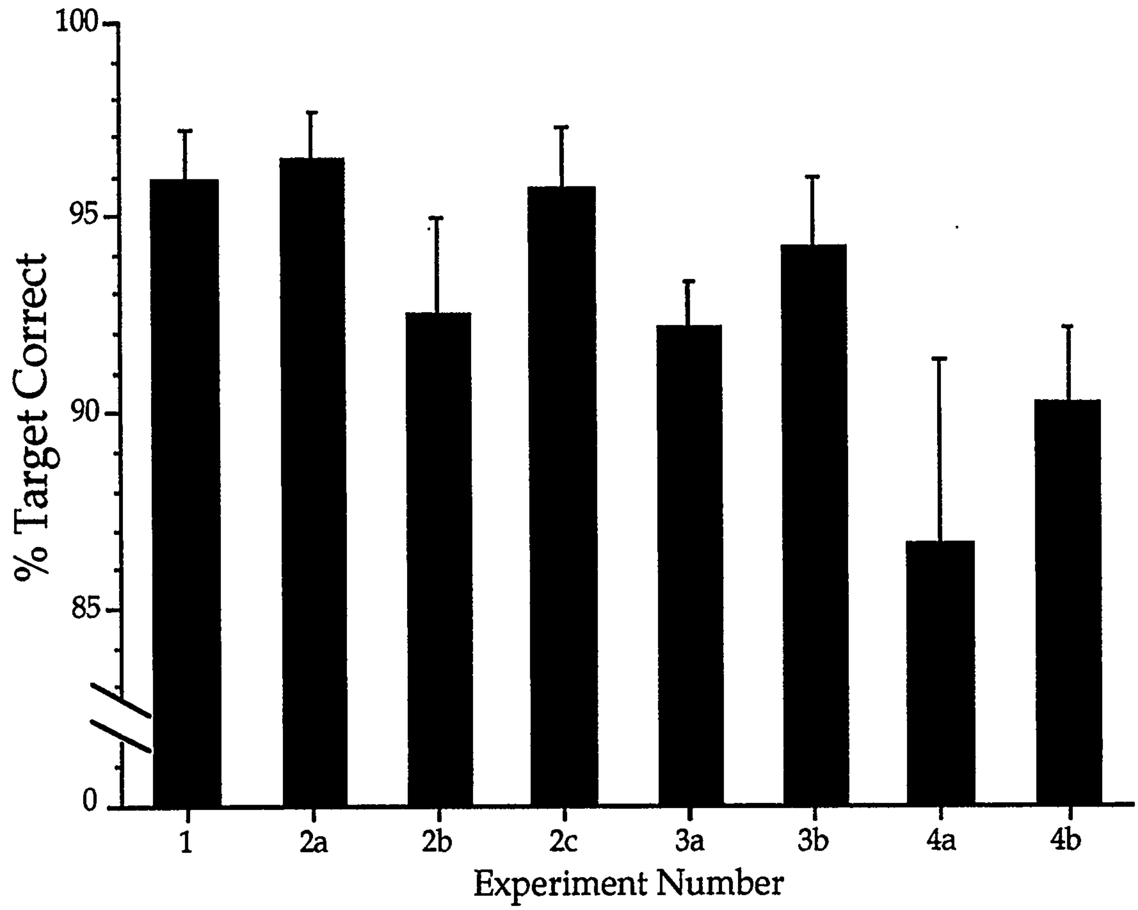


Figure 23: The mean percentage of trials in which the target was correctly detected in the different conditions of Experiments 1 to 4. Vertical bars represent ±1 standard error of the mean.

significantly different from each other ($F(7,82) = 1.55$, $p > .05$)) the target a' scores were examined next. There was a significant difference between target a' scores ($F(7,82) = 2.71$, $p < .05$) for all the experiments. Fisher's LSD post-hoc all pairwise comparisons revealed the following significant differences (at the $p < .05$ level of significance) in the target a' scores: Experiments 4a and 4b were both lower than Experiments 1, 2a and 2c, showing once again that the task difficulty for Experiment 4 in general was higher.

The overall probe false alarm scores were examined next, but were done so with an emphasis on caution. The false alarm scores are computed in different manners for different experiments. It must be recalled that different experiments had different numbers of probe positions contributing to these data. Experiments 1, 2a, 3a and 4a all had eight probe positions contributing to overall probe correct totals while Experiments 3b and 4b both had three probe positions contributing to the totals, and Experiments 2b, and 2c only had a single probe position to be taken into account. The experiments using eight positions must rely on the assumption that the false alarm scores would be evenly distributed across all eight probe positions, while the other experiments, which were run in blocked sessions have exact false alarm scores for the probe position. The problems with this assumption are discussed below in the section dealing with between experiment comparisons of probe performance. With regard to overall probe false alarms, it is important to state the underlying assumptions, which in turn, have consequences for interpretation of the results.

A significant difference was found when the false alarm rates for all four experiments were analyzed ($F(7,82) = 2.22$, $p < .05$). Fisher's LSD post-hoc all pairwise comparisons revealed the following significant difference (at the $p < .05$

level of significance) in probe false alarms: Experiment 4b was higher than every other experiment. An explanation for this may lie in the fact that Experiment 4, in general, had a difficult task associated with it (as is evidenced by the higher target errors), and that Experiment 4b specifically examined probe performance in specific positions. When the probe false alarms for Experiment 4b are examined by position (possible because the probe positions three, five and seven were blocked in sessions), it was found that there were no significant differences in the probe false alarm rates between the positions ($F(2,18) = 0.54$, $p > .05$). The best explanation is that the task is an extremely difficult task, which is supported by the next analysis performed on the overall probe a' data.

The overall probe a' analysis is the final analysis performed in this section. A significant difference was found between the probe a' scores for the experiments ($F(7,82) = 7.11$, $p < .05$). Fisher's LSD post-hoc all pairwise comparisons revealed the following significant differences (at the $p < .05$ level of significance) in probe a′ scores: Experiment 4b was lower than all the other experiments, Experiment 2c was lower than Experiments 1, 2a, 3a, and 3b, Experiment 2b was lower than Experiments 1, 2a and 3b, and Experiment 4a was lower than Experiment 2a (see Figure 24). This pattern of results must be interpreted with the same caution as was mentioned above. With that in mind, the fewer the probe positions examined, the more difficult the probe task appears. This makes a certain amount of intuitive sense as well. Without the improved performance of the probe positions that fall outside of the AB area accounted for in the experimental results, the task should appear more difficult.

Figure 24

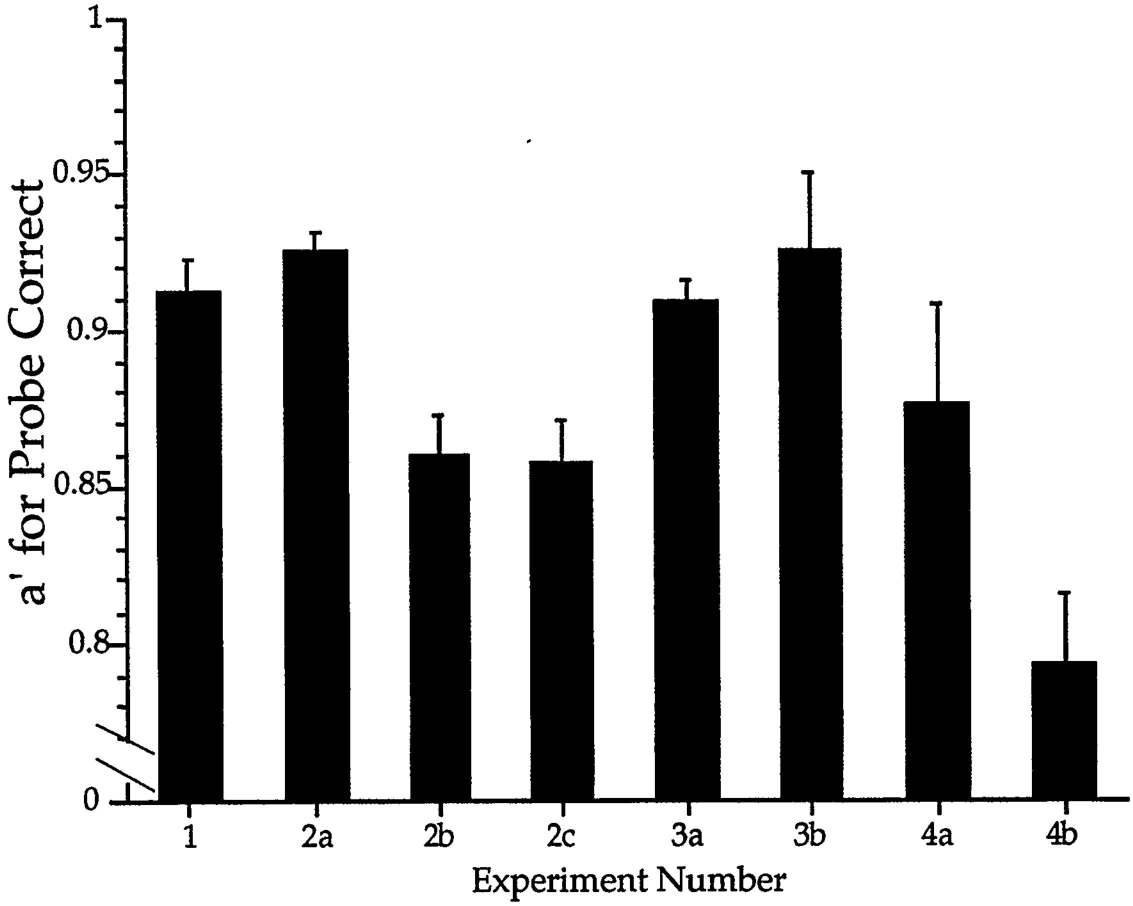


Figure 24: The a′ scores taking into account both the percent correct and the false alarms for the probe detection in the different conditions of Experiments 1 to 4. Vertical bars represent ±1 standard error of the mean. The a′ scores shown are not conditional on correct target identification, but reflects overall performance.

This would effect the experiments where only a single probe position (the position where probe performance is commonly the lowest) was examined (Experiments 2b, and 2c) and to a lesser extent, the experiments that only examined three probe positions (Experiments 3b and 4b).

Inter-experimental Probe Performance

One of the assumptions made in calculating a' (or d') scores for the individual probe positions in many of the experiments conducted in this area is the assumption that the false alarms recorded are evenly distributed across all possible probe positions. This assumption may or may not be valid. I feel that analyses performed between conditions of the same experiment are robust to violations of this assumption. The assumption being made is equally applicable to both conditions being examined; therefore, the distribution of false alarms will be consistent across the conditions. When comparisons between experiments are made, the possibility of violations to this assumption are more serious. An experiment examining all eight possible probe positions, and which therefore needs to rely on this assumption, is not directly comparable to an experiment examining only one probe position at a time and thereby getting exact false alarm data for that position. For this reason, in the following section when probe performance by positions are compared across experiments, a' data will be reported, but the a' data results will not elaborated on.

The only analysis that can be performed that will take into account the data from all the experiments is an analysis of the probe performance in position three. An analysis of variance (ANOVA) was conducted that examined the experiment as the independent variable and used the percent probe correct in position three as the dependent variable. There was a significant difference ($F(7,82) = 2.22$, $p < .05$) (marginally significant in the a′ data ($F(7,82) = 1.87$, $p < .10$). Fisher's LSD post-hoc all pairwise comparisons revealed the following significant differences (at the $p < .05$ level of significance) in position three probe performance: Experiment 3b was higher than Experiments 2a, 2b, 2c and 4b, and Experiment 3a was higher than Experiment 2b (see Figure 25). Experiment 3b was marginally higher (at the $p < .10$ level of significance) than Experiments 1 and 4a. The results were similar for the a′ data with Experiment 3b performance significantly higher than Experiments 2c, 4a and 4b, marginally higher than Experiment 2a, and not significantly different than either Experiment 1 or Experiment 3a.

Experiment 3b is the critical experiment, as it is the only one that did not have an AB associated with it when examined by conventional standards (experimental group versus control group performance). By this standard, and when the results reported in the section above are considered, it would appear that there is no attentional blink revealed in Experiment 3b, and that its performance is higher than that of the other experiments examined (except Experiment 3a). When the individual subjects data for Experiment 3b are examined, it should be noted that out of the ten subjects involved, the performance of only three of them was less than 87 percent of the probes correct presented in position three, and of those three, two scored 40 percent correct, and one scored 57 percent correct. This poor performance by a subset of subjects suggests that either the individual subjects 'blink' when the temporal parameters are kept constant in the absence of a distractor stream, or they do not blink in

Figure 25

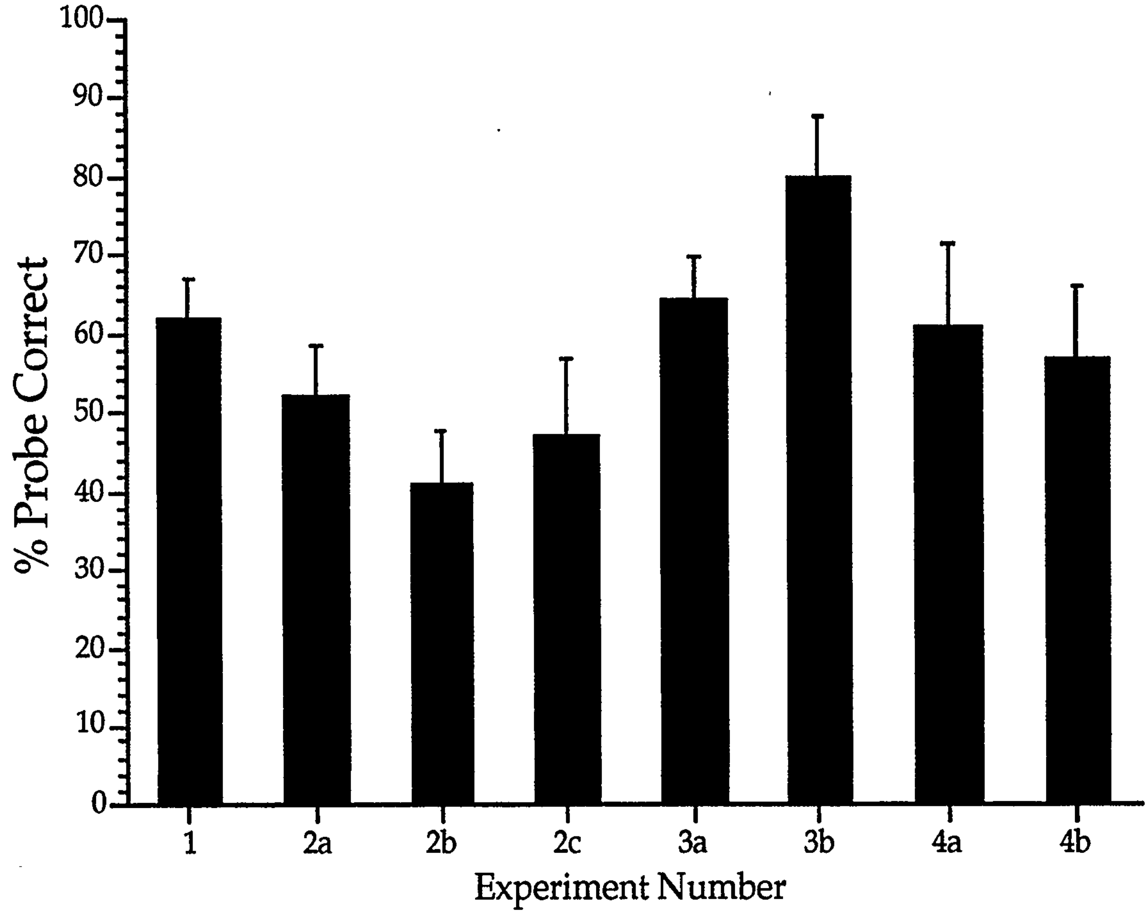


Figure 25: The mean percentage of trials in which the probe was correctly detected in position three across the different conditions of Experiments 1 to 4. The columns represent the dual-target task where both the target and the probe were detected, and only show the probe performance when the target was correctly detected. Vertical bars represent ±1 standard error of the mean.

those conditions. This is a question that needs to be addressed by running a greater number of subjects in this condition to determine if there is a truly bi-modal distribution, or if the subjects in this experiment perform that way by chance.

Practice and the Attentional Blink

Experiments 1 and 2 required subjects to perform two sessions to examine the attentional blink as a result of the manipulations of the temporal predictability of the target and probe. There was a difference in the session effects (with session two being better than session one) of Experiments 1 and 2a, but there was not a significant interaction. A significant interaction between predictability and session would indicate that the predictability manipulation did not have the same affect on the second session in Experiment 1 and Experiment 2a. The difference in the session effect was that the improvement shown in session two of Experiment 1 was only marginally significant (see results below), while the improvement in session two for Experiment 2a was significant (see results below). This difference showed that the practice manipulations were sensitive to temporal manipulations (to be discussed in the general discussion), but after the first condition (Experiment 1), which had only a marginal difference between session one and session two, every other experiment showed a significant session effect. It appeared that the effects of practice were too robust and lacked the sensitivity needed to measure differences in the temporal manipulations, and so for this reason, it was decided not to conduct the remainder of the experimental conditions (Experiments 3 and 4) in two sessions. In an analysis of variance performed on the two sessions of

Experiments 1 and 2, the following was found; Experiment 1 had a marginally significant session effect ($F(1,14) = 4.16$, $p = .06$) (see Figure 26), Experiment 2a had a significant attenuation between sessions ($F(1,14) = 13.39$, $p < .05$) (see Figure 27), Experiment 2b had a significant attenuation between sessions ($F(1,9) = 12.33$, $p < .05$) (see Figure 28), and Experiment 2c had a significant attenuation of the blink between sessions ($F(1,9) = 11.36$, $p < .05$) (see Figure 29).

Figure 26

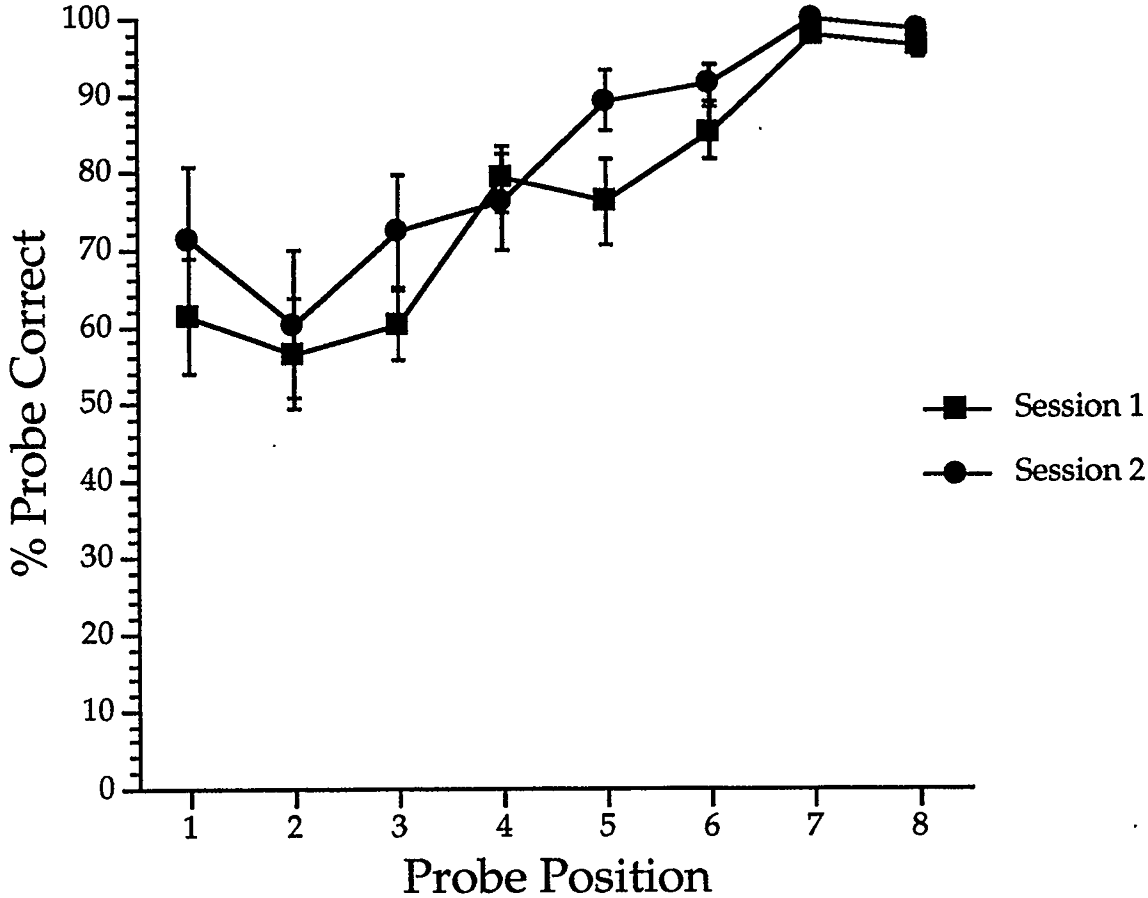


Figure 26: The group mean percentage of trials in which the probe was correctly detected as a function of probe position after the target for Experiment 1. The squares represent performance in session 1 of the task, and the circles represent performance in session 2 of the task. Both sessions were the experimental or dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 27

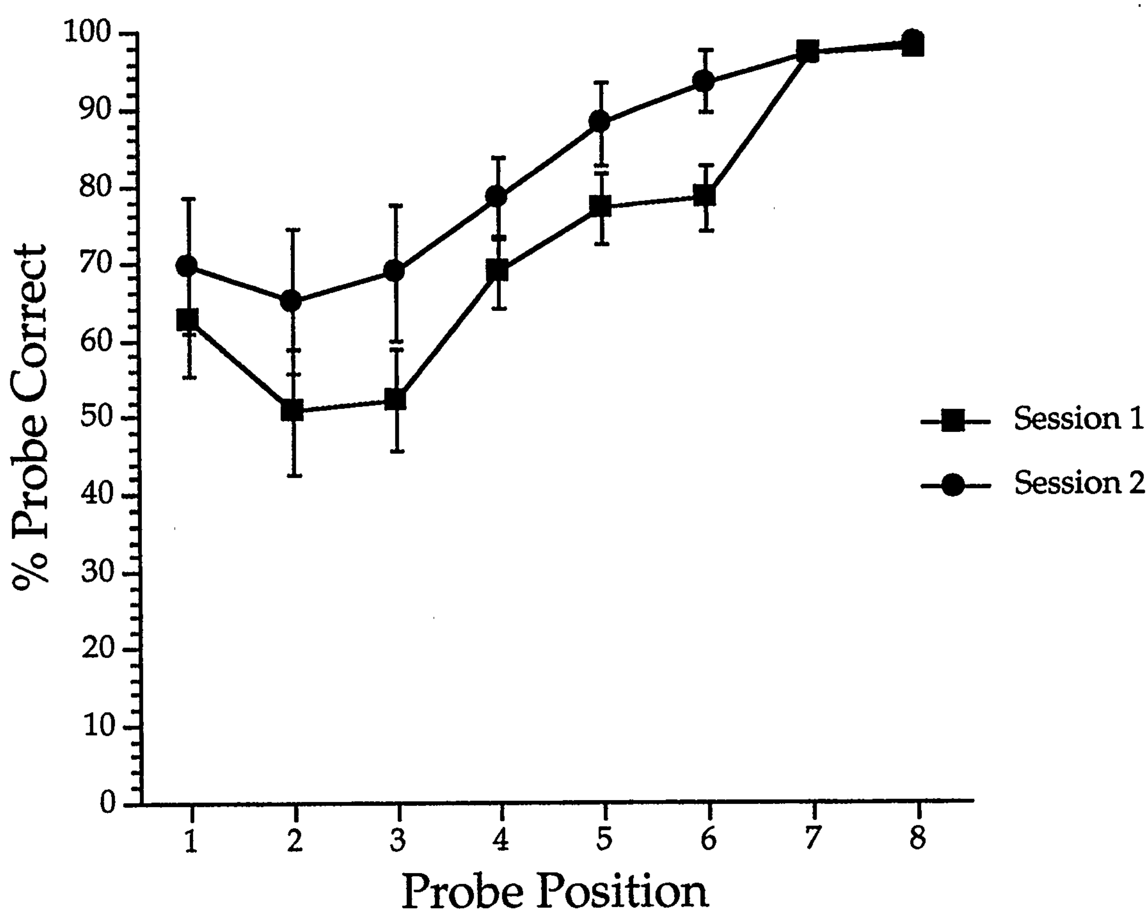


Figure 27: The group mean percentage of trials in which the probe was correctly detected as a function of probe position after the target for Experiment 2a. The squares represent performance in session 1 of the task, and the circles represent performance in session 2 of the task. Vertical bars represent ±1 standard error of the mean. Both sessions were the experimental or dual-target task where both the target and the probe were detected.

Figure 28

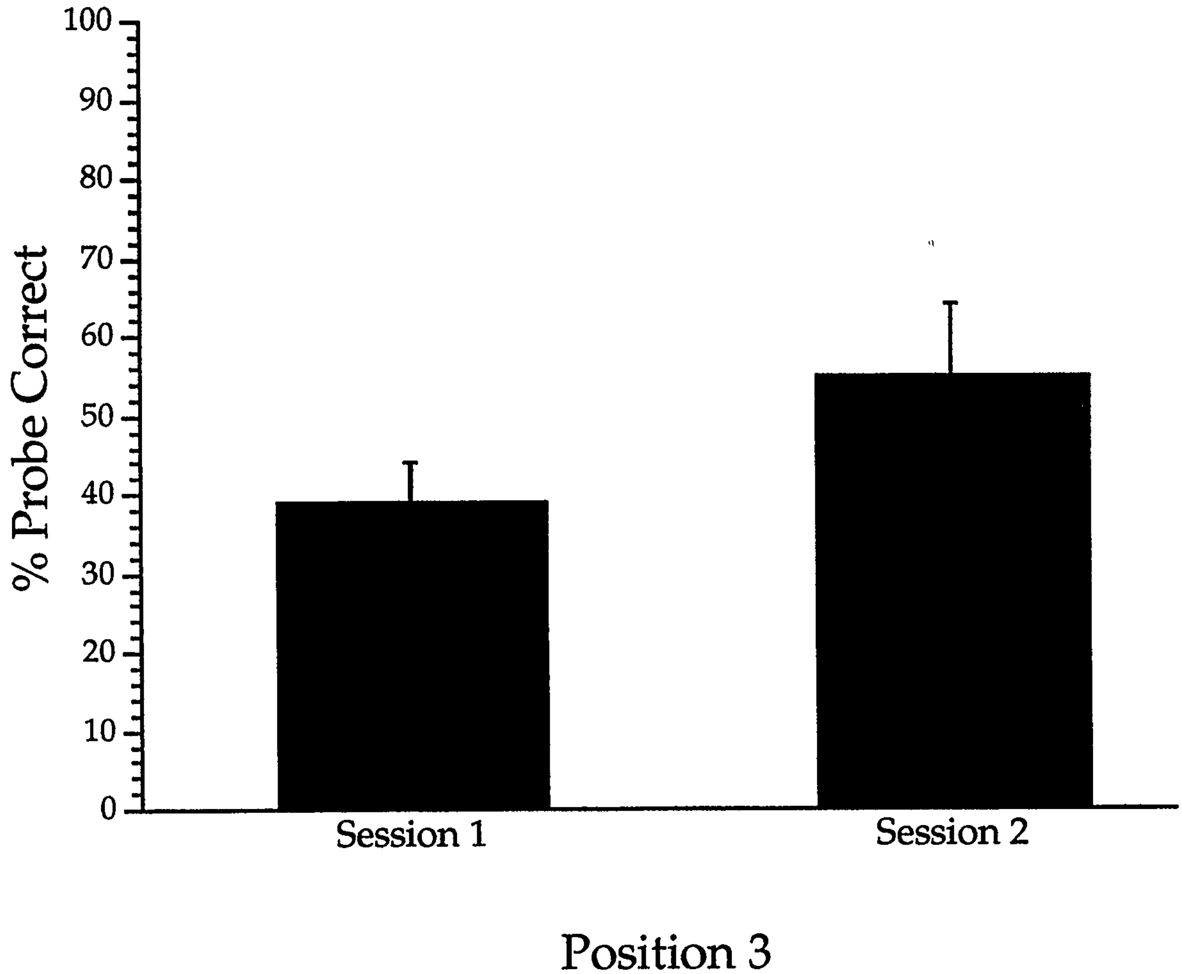
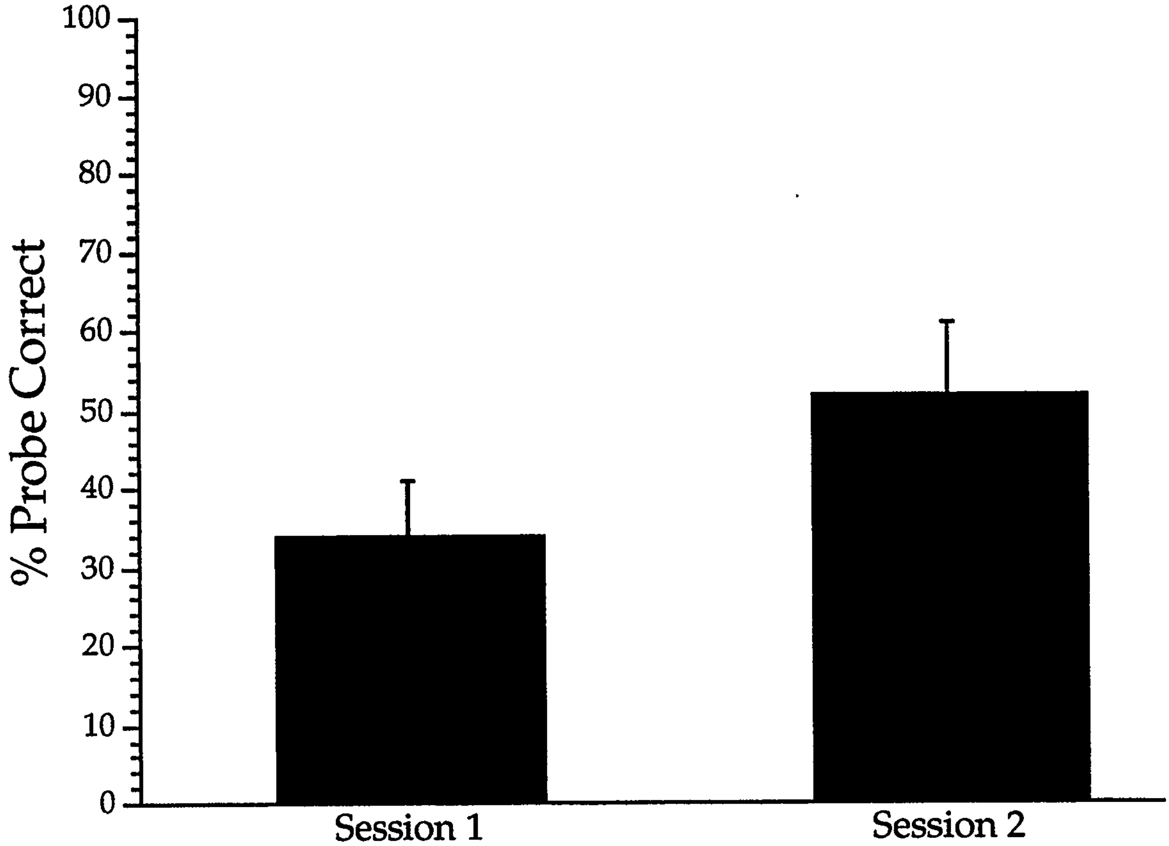


Figure 28: The group mean percentage of trials in which the probe was correctly detected in position three for Experiment 2b. Both sessions were the experimental or dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Figure 29



Position 3

Figure 29: The group mean percentage of trials in which the probe was correctly detected in position three for Experiment 2b. Both sessions were the experimental or dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean.

Experiment 5

Rationale

In the previous experiments, temporal predictability was manipulated as a means to attenuate the AB. Experiment 5 was designed to examine the specific effects of practice on subject's probe performance that had been found in Experiments 1 and 2. Experiment 5 was designed to examine whether this practice effect was due to a sharpened template for the probe (as the same probe was used in every session studied so far). Or, was it the result of a more general effect of practicing that affected the whole task? This was accomplished by manipulating the identities of both the target and the probe across experimental sessions.

Experiment 5a

Rationale

Experiment 5a was conducted to examine the effects of subjects participating in a third session when the identity of the probe remains the same between sessions two and three. The effects of two sessions have already been demonstrated, so it was necessary to see what happened in the third session when the stimuli were kept constant.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as the second repeated variable, and three sessions as the third repeated variable.

Subjects

The same procedure was used to select and prepare the subjects in this experiment as was used in Experiment 1. Four females and six males ranging in age from 18 to 31 years (mean = 20.7, SD = 3.9) participated in this experiment.

Procedure

The procedure was identical to that used in Experiment 2b, but with the addition of a third session. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of an 'X' (the probe). The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. The target was allowed to occur in any of the positions from 7 to 15 (630 ms to 1350 ms) relative to the beginning of the stream. The probe was fixed (as in Experiment 2b) in position three (270 ms), after the target. Three sessions were run to determine the effect of probe identity in the third session (for a total of 240 trials). The first two sessions were a repeat of Experiment 2b, and a third session was then run to see if the practice effects continued to attenuate the blink further. The experimental condition is measured as probe performance when the target is correctly identified and the control performance is measured as probe performance when the target was absent.

Results and Discussion

The data collected for this experiment are represented in Figure 30 (for the percent correct on probe performance) and Figure 31 (for the a' values). The

Figure 30

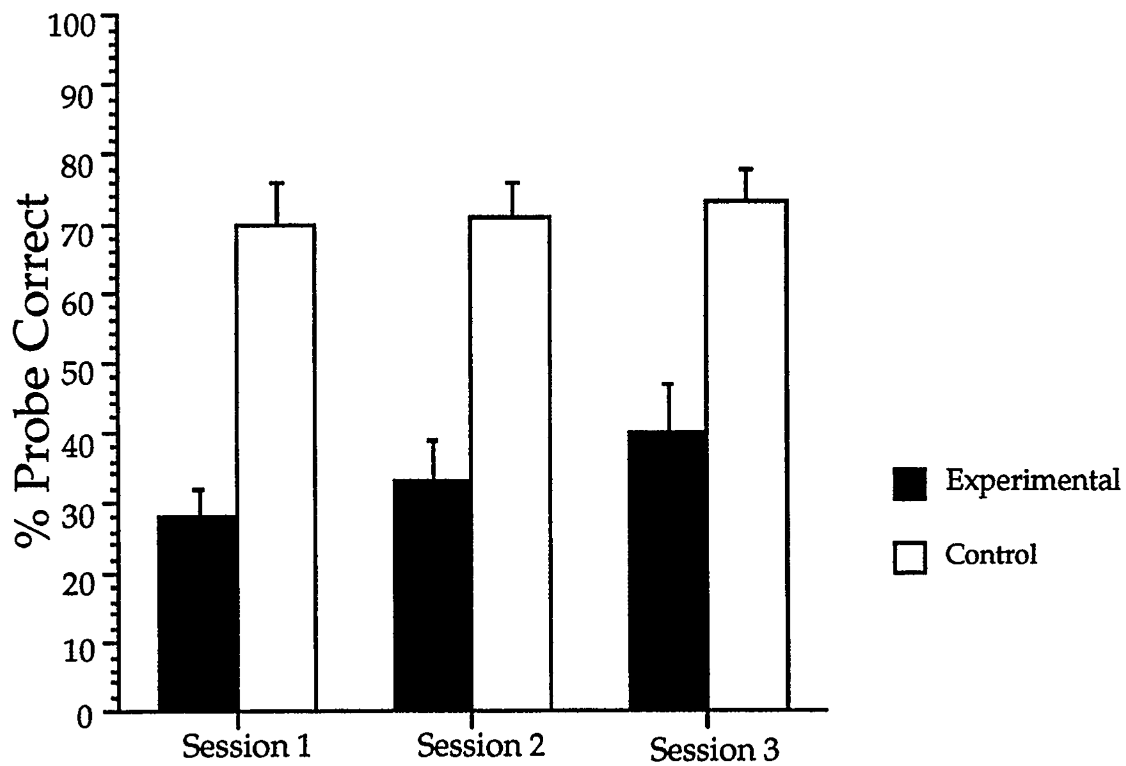


Figure 30: The group mean percentage of trials in which the probe was correctly detected for all three sessions of Experiment 5a. The white columns represent the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 31

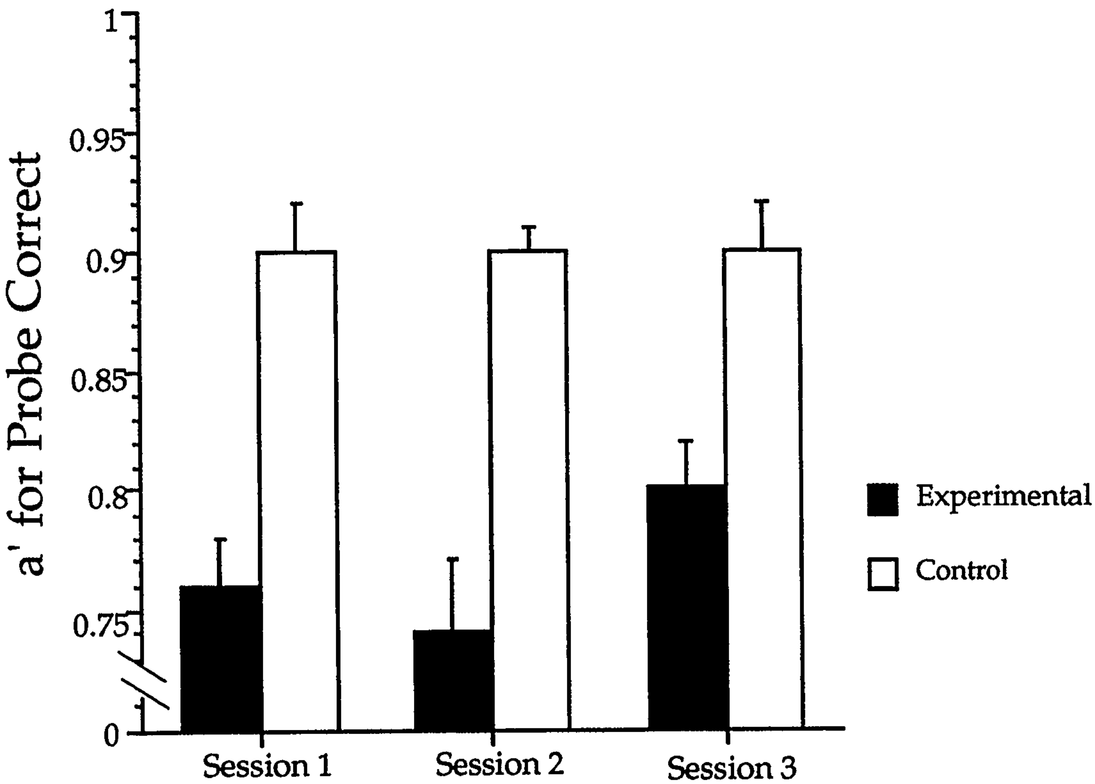


Figure 31: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection for all three sessions in Experiment 5a. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

probe performance for probe position three across the three sessions is what is shown for both the control condition and the experimental condition. The graph illustrates the improved probe performance in the experimental condition from session one to session three, but increased variability is also observed. A two factor (experimental condition by session) repeated measures univariate analysis of variance (ANOVA) revealed that there was a significant main effect of experimental condition [for percentage data ($F(1,9) = 57.91$, $p < .05$), for a' data ($F(1,9) = 42.42$, $p < .05$)], but there was no significant effect of either the session manipulation [for percentage data ($F(2,18) = 1.41$, $p > .05$), for a' data ($F(2,18) = 0.87$, $p > .05$)] or the experimental condition by the session interaction [for percentage data ($F(2,18) = 0.84$, $p > .05$), for a' data ($F(2,18) = 1.71$, $p > .05$)]. Using a separate error term, session one of the experimental data was compared against session two of the experimental data to see if the results were consistent with the session data found in Experiment 2c. The two session effect was not significant for either the percentage data ($F(1,18) = .64$, $p > .025$) or the a' data ($F(1,18) = .38$, $p > .025$). This could be the result of three of the subjects who had much worse performance in sessions two and three. With the small sample sizes used ($n = 10$), the performance of three of the subjects could have the effect of decreasing mean performance and increasing the variability enough so that no session effect was found. Regardless of the outcome of this experiment, the support for a session effect found in Experiments 1 and 2 was used as rationale to continue the investigation into the identity of the probe and its effect on practice.

Experiment 5b

Rationale

Experiment 5b examined the effects of changing the identity of the probe. The observed practice effects were an improvement in the probe detection task between sessions. It was thought that this improved performance might be as a result of a sharpened template for being able to detect an 'X' (the probe) in the stream. If this were the case, then changing the probe identity in the third session should result in much lower performance for the final session. If, on the other hand, the level of probe performance did not decrease (or in the case that performance even improved), it could be argued that the practice effects observed were more of a generalized learning of the experimental task, rather than an improved ability to detect a specific probe.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as the second repeated variable, and three sessions as the third repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Seven females and three males ranging in age from 18 to 42 years (mean = 25.2, SD = 6.6) participated in this experiment.

Procedure

The procedure was similar to that used in the Experiment 5a. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of another letter (the probe). The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. The target was allowed to occur in any of the positions from 7 to 15 (630 ms to 1350 ms) relative to the beginning of the stream. The probe was fixed (as in Experiment 5a) in position three (270 ms), relative to the target. Three sessions were run to determine the effect of probe identity in the third session. The identity of the probe for the first two sessions remained constant (an 'X') but was changed for the third session (a 'T'). The experimental condition is measured as probe performance when the target is correctly identified and the control performance is measured as probe performance when the target was absent.

Results and Discussion

The data collected for the probe performance across the three sessions in Experiment 5b are represented in Figure 32 (for the percent correct on probe performance) and Figure 33 (for the a' values). The graph shows improved probe performance from session one to session three along with reduced variability across the sessions. Probe performance in session three of the experimental condition appears to be identical to that of the control condition, suggesting that the blink may be attenuated to the point of being gone after the three sessions of

Figure 32

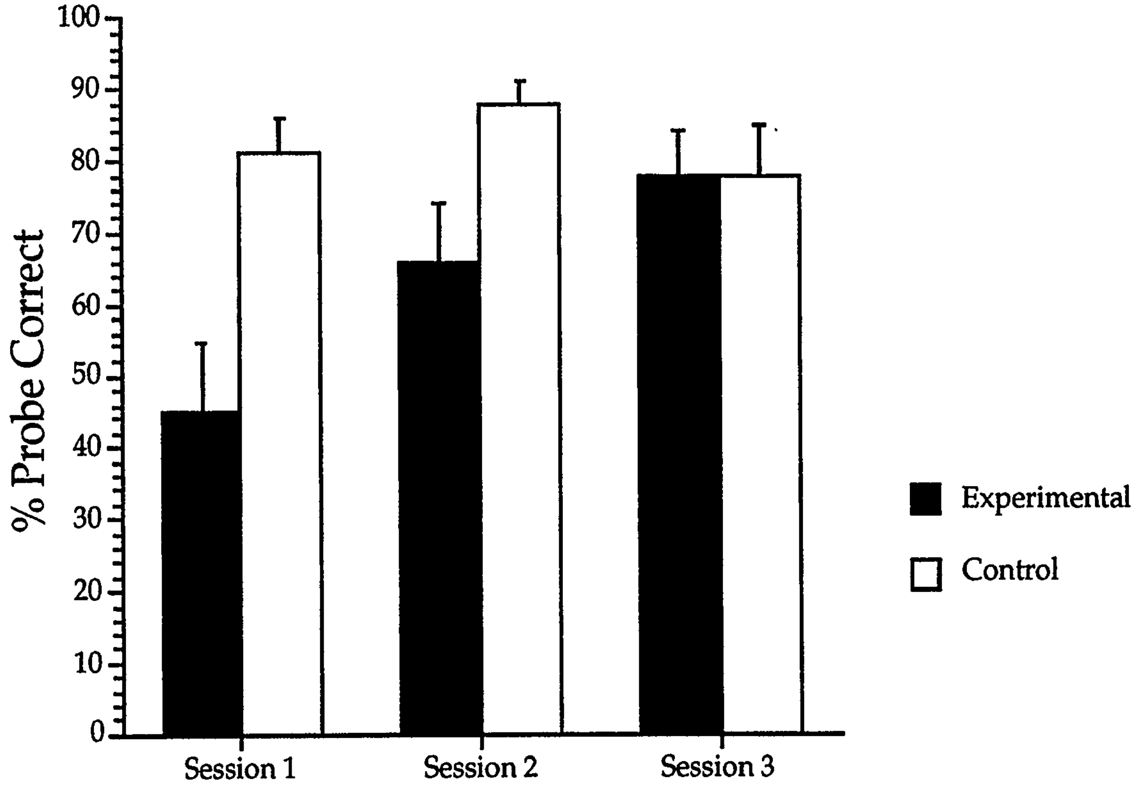


Figure 32: The group mean percentage of trials in which the probe was correctly detected for all three sessions of Experiment 5b. The white columns represent the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 33

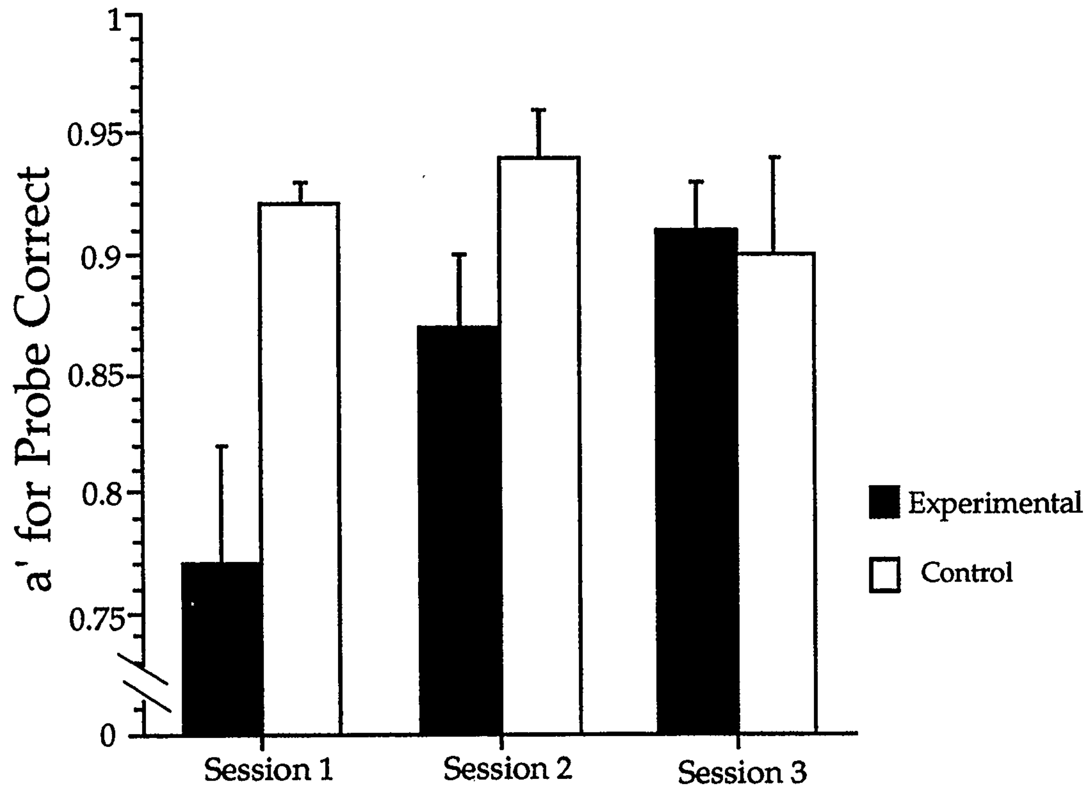


Figure 33: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection for all three sessions in Experiment 5b. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

practice. A repeated measures analysis of variance (ANOVA) revealed that there was a significant main effect of condition [for percentage data ($F(1,9) = 10.13$, $p < .05$), for a' data ($F(1,9) = 8.25$, $p < .05$)] a non-significant main session effect [for percentage data ($F(2,18) = 3.58$, $p > .05$), for a' data ($F(2,18) = 2.52$, $p > .05$)] and a significant experimental condition by session interaction [for percentage data ($F(2,18) = 9.79$, $p < .05$), for a' data ($F(2,18) = 8.51$, $p < .05$)]. Using a pooled error variance approach, the experimental and control conditions were compared for session three, as that is where the differences between the two conditions appears to have disappeared, and there was no difference found [for percentage data ($F(1,18) = 0.02$, $p > .025$), for a' data ($F(1,18) = 0.36$, $p > .025$)]. As there is no difference in the experimental and control performance in the final session, and the definition of the attentional blink is a significant difference between experimental and probe performance, then the conclusion drawn by this experiment is that on the third session probe performance has improved to the point where there is no blink. This experiment shows that changing the identities of the probe did not remove or decrease the effect of practice, suggesting that the practice effects observed are due to a general improvement in task performance rather than a sharpened ability to detect a specific probe identity.

Experiment 5c

Rationale

It was found in Experiment 5b that changing the identity of the probe on the third session did not reduce the effects of practice. In this experiment the blink had disappeared by the third session. An alternative hypothesis to the one just advanced is that this could have been a result of the ease of identifying the 'T' as the probe when compared to the 'X' as the probe. To test for this possibility, Experiments 5a and 5b were repeated with the probe identities switched. In Experiment 5c, Experiment 5a was replicated, but with all three sessions having a 'T' as the probe. Experiment 5d replicated Experiment 5b but had a 'T' as the probe for the first two sessions and an 'X' as the probe for the third session.

Design

This study employed a three-factor design with target present/absent as one repeated variable, probe present/absent as the second repeated variable, and three sessions as the third repeated variable.

Subjects

The same procedure was used to prepare the subjects in this experiment as was used in Experiment 1. Seven females and three males ranging in age from 18 to 29 years (mean = 20.1, SD = 3.41) participated in this experiment.

Procedure

The procedure was identical to that used in the Experiment 5a except for the identity of the probe used. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of the black letter 'T' (the probe) among the stream items. The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. The target was allowed to occur in any of the positions from 7 to 15 (630 ms to 1350 ms) relative to the beginning of the stream. The probe was fixed (as in Experiment 5a) in position three (270 ms), relative to the target. Three sessions were run to determine the effect practice in the third session. The experimental condition is measured as probe performance when the target is correctly identified and the control performance is measured as probe performance when the target was absent.

Results and Discussion

The data collected for the probe performance across the three sessions in Experiment 5c are represented in Figure 34 (for the percent correct on probe performance) and Figure 35 (for the a' values). The graph shows improved probe performance from session one to session three in both the percent data and the a' data. A repeated measures analysis of variance (ANOVA) revealed that there was a significant main effect of condition [for percentage data ($F(1,9) = 17.88$, $p < .05$), for a' data ($F(1,9) = 14.5$, $p < .05$)] a significant main effect for session [for percentage data ($F(2,18) = 15.63$, $p < .05$), for a' data ($F(2,18) = 7.85$, $p < .05$)] and a significant experimental condition by session interaction [for percentage data ($F(2,18) = 5.48$, $p < .05$), for a' data ($F(2,18) = 6.11$, $p < .05$)]. Using a pooled error variance approach, the experimental and control conditions were compared for session three to see if a difference between the experimental and control groups is still found. There was no difference found [for percentage data ($F(1,18) = 2.78$, $p > .025$), for a' data ($F(1,18) = 3.44$, $p > .025$)] indicating that the blink is attenuated to the point of being non-existent after three sessions of practice. This

Figure 34

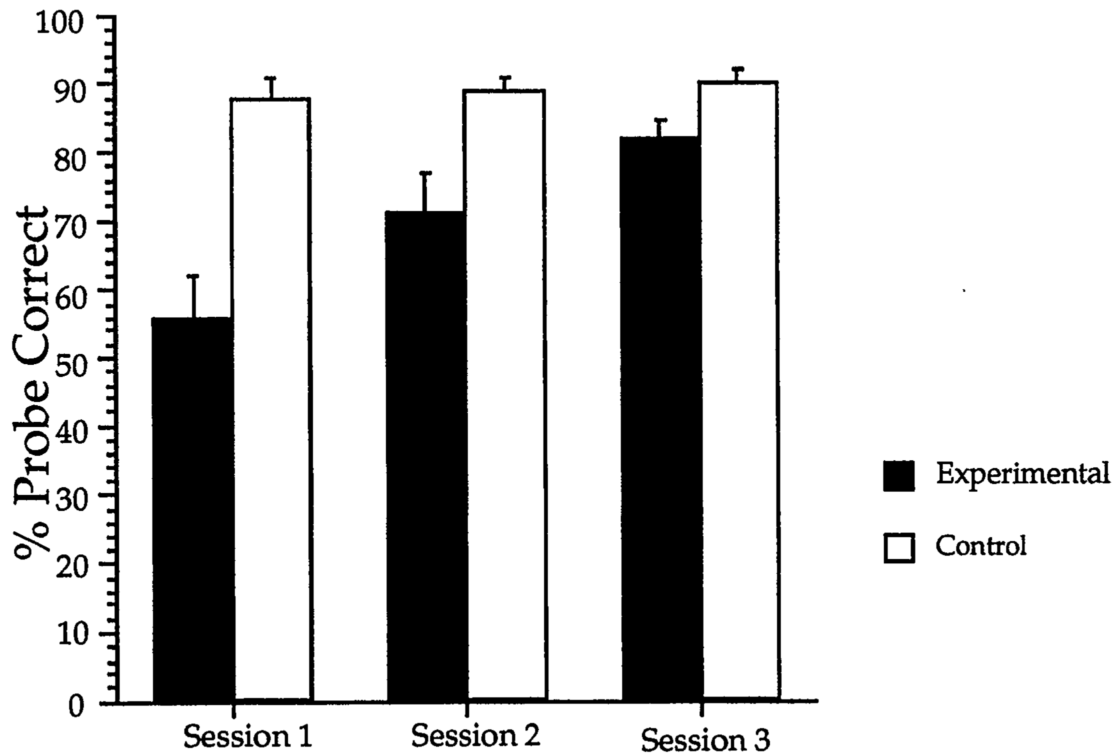


Figure 34: The group mean percentage of trials in which the probe was correctly detected for all three sessions of Experiment 5c. The white columns represent the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 35

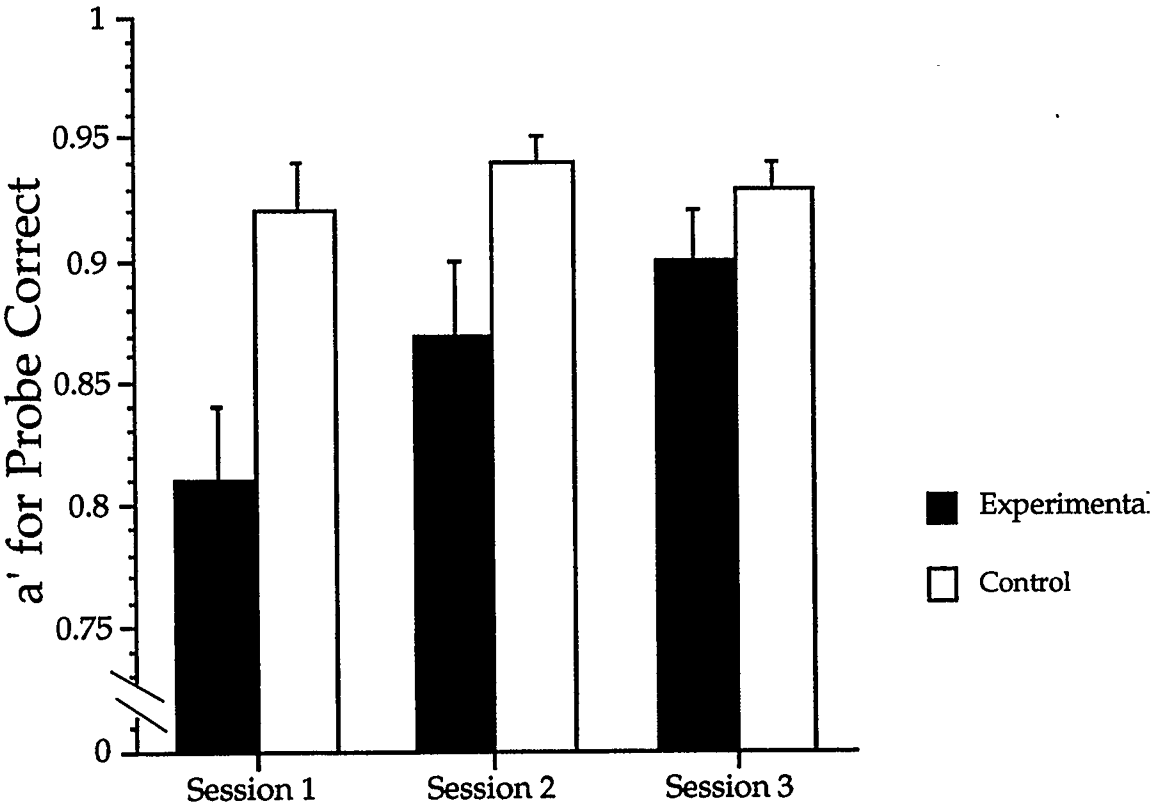


Figure 35: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection for all three sessions in Experiment 5c. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

experiment demonstrates that the identity of the probe may make a difference in the attentional blink. In this case, it may be that 'T's are easier to process within the blink area than 'X's.

Experiment 5d

Subjects

The same procedure was used to select and prepare the subjects in this experiment as was used in Experiment 1. Eight females and two males ranging in age from 18 to 30 years (mean = 20.4, SD = 3.62) participated in this experiment.

Procedure

The procedure was identical to that used in the Experiment 5b except for the identity of the probe was changed. Subjects detected the presence of a white letter, always an 'S', (the target) in the stream, and then detected the presence of a black letter (the probe) from among the stream items. For the first two sessions, a 'T' was used as the probe, and in the third session the probe was an 'X'. The target and probe were each presented on half of the trials for a total of four target/probe combinations on a given trial. The probe was presented twenty times in each of the four possible combinations for a total of 80 trials per session. The target was allowed to occur in any of the positions from 7 to 15 (630 ms to 1350 ms) relative to the beginning of the stream. The probe was fixed (as in Experiment 5a) in position three (270 ms), relative to the target. Three sessions were run to determine the effect switching the identity of the probe in the third session. The experimental condition is measured as probe performance when the target is correctly identified and the control performance is measured as probe performance when the target was absent.

Results and Discussion

The data collected for the probe performance across the three sessions in Experiment 5d are represented in Figure 36 (for the percent correct on probe performance) and Figure 37 (for the a' values). The graph shows improved probe performance from session one to session two (when the 'T' was the probe) in both the percent data and the a' data, but a drop in performance in session three (when the probe was changed to an 'X') for both measures. A repeated measures analysis of variance (ANOVA) revealed that there was a significant main effect of condition [for percentage data ($F(1,9) = 37.61$, $p < .05$), for a' data ($F(1,9) = 34.07$, $p < .05$)] a significant main effect for session [for percentage data ($F(2,18) = 4.72$, $p < .05$), for a' data ($F(2,18) = 5.55$, $p < .05$)] and a significant experimental condition by session interaction [for percentage data ($F(2,18) = 4.07$, $p < .05$), for a' data ($F(2,18) = 4.85$, $p < .05$)]. As can be seen by Figures 36 and 37, when the third session was run using a different probe, this time an 'X', performance dropped to a level similar to that of the first session. This confirms what was found in Experiment 5c, that the identity of the probe does make a difference in processing during the attentional blink. In other words, the subjects found it easier to report the 'T' as a probe within the critical blink area than an 'X' as a probe.

Results and Discussion of Experiment 5

In comparing between the conditions of Experiment 5, general target and

Figure 36

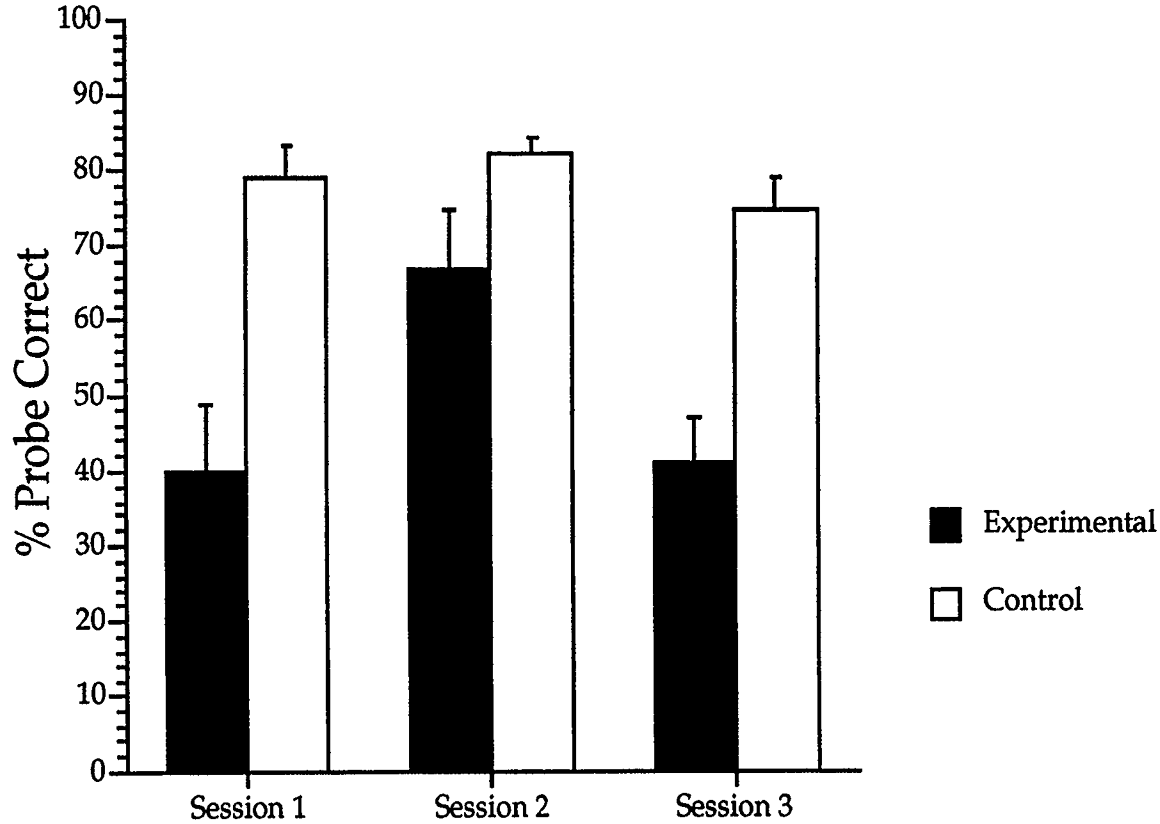


Figure 36: The group mean percentage of trials in which the probe was correctly detected for all three sessions of Experiment 5d. The white columns represent the control condition in which there was no target presented for the subjects to respond to. The black columns represent the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

Figure 37

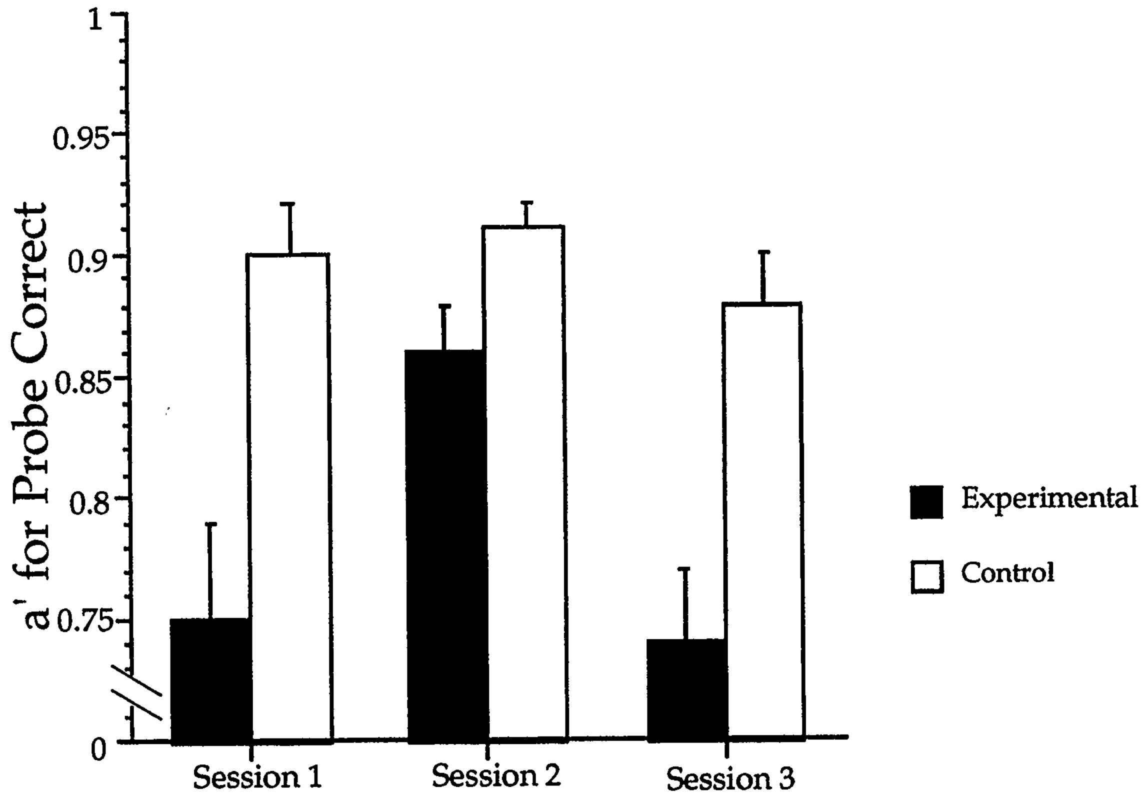


Figure 37: The group a′ scores taking into account both the percent correct and the false alarms for the probe detection for all three sessions in Experiment 5d. The white column represents the control condition in which there was no target presented for the subjects to respond to. The black column represents the experimental, dual-target task where both the target and the probe were detected. Vertical bars represent ±1 standard error of the mean. Since there was only one probe position examined, only that position (position 3) is shown.

probe performance will be discussed There were no overall differences between the experimental conditions in the percent target correct performance ($F(3,36) = 0.994$, $p > .05$), the target false alarms ($F(3,36) = 0.43$, $p > .05$), or the target a' scores ($F(3,36) = 1.19$, $p > .05$). There were, however, differences in probe performances for the different groups. There was a significant difference in the control performance ($F(3,36) = 6.09$, $p < .05$) when the only task was to detect the presence of the probe. Fisher's LSD post-hoc all pairwise comparisons revealed the following significant differences (at the $p < .05$ level of significance) in percent probe correct performance in the control conditions: Experimental condition 5a (XXX) was lower than the 5b (XXT) or 5c (TTT) conditions and was marginally ($p < .10$) lower than the 5d (TTX) condition. This suggests that the subjects in the first condition had more difficulty with the task as a group and this could be the reason that there was no session effect found in the analysis of the data for that experiment (Experiment 5a) specifically.

There was a significant main effect of group in overall probe correct performance [percent data ($F(3,36) = 8.56$, $p < .05$), a' data ($F(3,36) = 4.48$, $p < .05$)], a main effect of session [percent data ($F(2,72) = 16.09$, $p < .05$), a' data ($F(2,72) = 10.68$, $p < .05$)], and a session by group interaction [percent data ($F(6,72) = 3.96$, $p < .05$), a' data ($F(6,72) = 4.76$, $p < .05$)] (see Figure 38). This would be expected as the results of the individual conditions have already pointed toward this result.

Figure 38

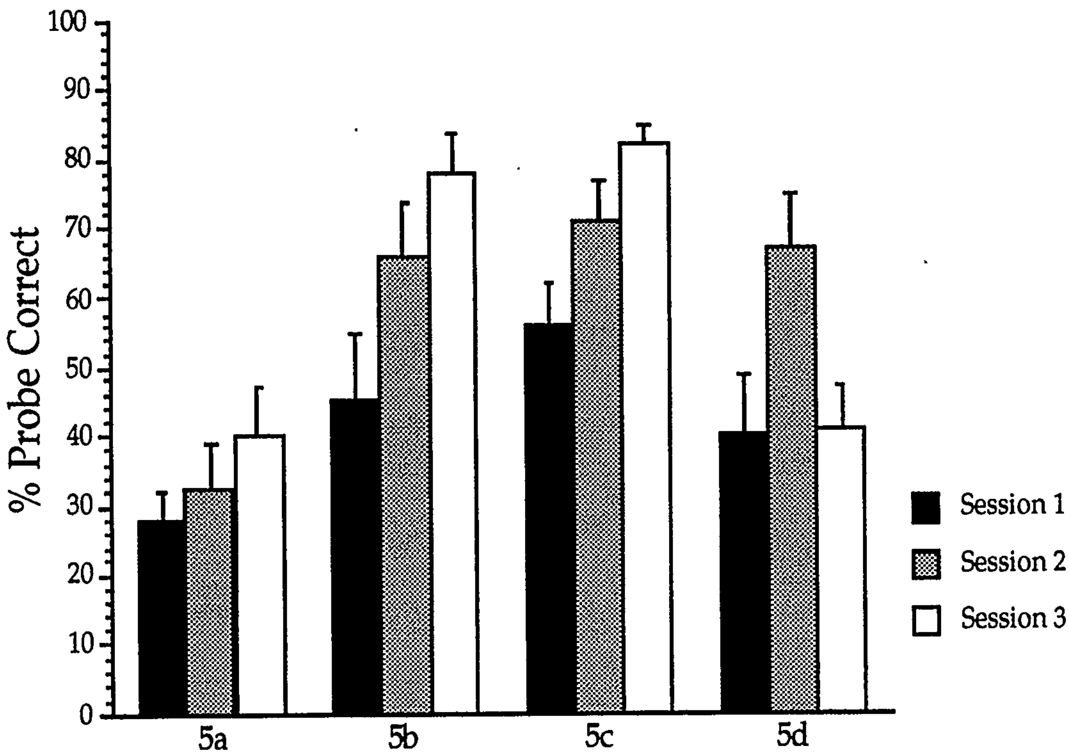


Figure 38: The mean percentage of trials in which the probe was correctly detected across the three sessions for the different conditions of Experiment 5. The black columns represent session 1 performance, the gray columns represent the session 2 performance, and the white columns represent the session three performance. Vertical bars represent ±1 standard error of the mean. All of the data plotted here represent the dual-target task where both the target and the probe were detected, and only show the probe performance when the target was correctly detected. Experiment 5 only measured probe performance in position three and as a result, only position three is shown.

General Discussion

The experiments presented here can be divided into two general categories. The first set (Experiments 1 to 4) have dealt with the effects of temporal predictability on the attentional blink. The second set (Experiment 5) addresses the effect of practice on the attentional blink. The first part of the general discussion will deal with the findings of the first set of experiments, and the second part will deal with the practice effects. Table 2 gives a brief outline of the experiments, a general description of the manipulation used, and the general results of the manipulation (see Table 2).

Temporal predictability and the Attentional Blink

The first set of experiments (Experiments 1 to 4) manipulated various aspects of temporal predictability to see if there was a measurable benefit of knowing "when" an item might occur. Experiments 1 and 2 showed that the temporal predictability of target and probe within an RSVP stream in and of itself, is not enough to provide a measurable benefit. The critical experiment was Experiment 3, in which the temporal predictability of the target and probe was combined with the removal of the non-target elements, and these two factors together produced a significant attenuation of the blink. The possible mechanisms whereby temporal predictability attenuates the AB will be discussed next, followed by a discussion of potential mechanisms underlying visual information processing.

The findings from Experiments 1 to 4 show that there can be measurable benefits in having an item occur at a temporally predictable time, but only under

Table 2

Experiment Number	Exparimental Manipulation	Outcome
Experiment 1	Replication of Shapiro (*et al.'s* 1994) Experiment 3a. Unpredictable target and probe	Blink
Experiment 2a	Predictable target	Blink
Experiment 2b	Predictable probe	Blink
Experiment 2c	Predictable target and probe	Blink
Experiment 3a	Non-target stream removed Unpredictable target and probe	Blink
Experiment 3b	Non-target stream removed Predictable target and probe	**No Blink**
Experiment 4a	Repeated mask as stream Unpredictable target and probe	Blink
Experiment 4b	Repeated mask as stream Predictable target and probe	Blink
Experiment 5a	Practice with XXX as probe *	Blink
Experiment 5b	Practice with XXT as probe	**No Blink**
Experiment 5c	Practice with TTT as probe	**No Blink**
Experiment 5d	Practice with TTX as probe	Blink

* XXX refers to the identity of the probe in three different sessions. The predictability parameters were the same as those for Experiment 2b.

specific circumstances. An analogy to spatial attention are the benefits which arise from the valid trials in Posner's cost/benefit paradigm. When a subject knows where an item is to occur in space, there is a measurable reaction time benefit, and when that item does not occur at the predicted spatial location, there is a reaction time cost associated with it. For the analogy to be fully realized, some of the trials presented in the temporally predictable experiments reported above should have been invalid, or been unpredictable so that the costs associated with the loss of predictability (within a given session) could have been analyzed. Instead, this was carried out as a between groups manipulation with the groups having either 100% predictability or 100% unpredictability. The costs or benefits were then examined based on the group performance.

Temporal predictability may provide a benefit for a subject by allowing them to ready themselves for the presentation of the critical items within a specific temporal region. Performance enhancement has been found in tasks that require attention through a mechanism described as perceptual readiness or response readiness. Readiness implies that "less information input and less attention" (Kahneman, 1973, p. 193) will be needed to accomplish the task. Readiness can only be accomplished when a degree of temporal certainty is available (or present) (e.g., Klemmer, 1957; Smith, Warm & Alluisi, 1966; Warm, Epps, & Ferguson, 1974). By fixing the temporal location of the items in the RSVP stream (and removing the non-target distractor stream), a high degree of temporal certainty was introduced. Thus, a potential mechanism to explain the benefit accruing from temporal predictability is that the attentional demands and amount of information needed for the task may have been reduced because of subject readiness.

To put the readiness mechanism into a more attentional framework, Duncan's integrated competition hypothesis (Duncan, in press) is relevant. Duncan postulates that when an object is primed in a particular brain system (e.g. where, what), the target object receives an advantage within that system, and that the integration provided by attention (across the different systems) will provide a more generalized advantage to the other systems that are necessarily involved. In other words, by giving the probe a primed temporal window, the attentional system coordinates and guides the activities of the other systems involved in the task (the detection of an occurrence). Fixing the temporal parameters of the task (and maximizing that predictability by removing the distractor stream), and therefore heightening a subject's readiness results in less informational input and less attention being required to complete the task. As a direct result of this, subjects' performance improves.

When a subject's readiness is heightened and less information is required to complete the task, two distinct possibilities as to how this information reduction takes place are possible. In a strict early-selection framework, the information selected for processing at an early stage would be the only information passed through the processing system (the target or probe in these experiments). As a result, this information would be the only information to arrive at the output stage. The other (i.e., late-selection) possibility is that the threshold for entry into the output stage is lowered for items encountered within the "readiness" temporal region. Other processes, such as familiarity could then be used to try to identify what the incomplete stimulus is at that stage in order to complete the task and report the item.

To understand whether the appropriate mechanism is an early-selection or a late-selection one, it is important to carefully look at the evidence as to where the problems associated with the AB occur. Information processing involves several stages which include an input or encoding stage, a processing stage, and an output stage. These three stages are only a gross division of all of the component process that are involved in the successful detection of a target object. The results of three studies will be discussed as evidence that the information processing deficits in the blink period are a result of a late-selection mechanism.

The first study to be taken as evidence of a late-selection mechanism being involved in the blink is by Hamm & Taylor (1994). In this study, the conceptual categorization of the probe item produced an attenuation of the blink. The investigators found that when the target and the distractor stream were in the same category (all letters) and the probe was from a different category (a digit) the AB was attenuated. When the digit used was the digit zero (0), there was an attenuation of the blink (presumably because the digit '0' and the letter 'O'' have the same physical shape), but when the digit used was a six (6), there was no blink at all. This study shows that categorically dissimilar information within the blink region is processed to the report stage.

The second study favoring late-selection mechanisms examined the relationship of another temporal attentional phenomenon (cf. repetition blindness, Kanwisher, 1990) to the attentional blink (Shapiro, 1993). This study employed a three target task examining the effects of performance on the second target (presented in the normally blinked region) on the performance of the third target (presented outside the normally blinked region). The finding that has direct implication to this thesis, is that when subjects failed to report the second target, priming was found for the third target. Even though the second item was not reported, it affected the performance on the third item, suggesting that the second item was processed to a level where it had an impact on a later occurring item.

The final study used to support the idea that the attentional blink is a late-selection processing deficit is a study by Shapiro, Caldwell & Sorensen (in submission). When subjects are presented with their own name as the probe, there is no attentional blink. Subjects can fully process their own names, even within the region of the AB, to the level of retrieval and output.

It is difficult to conceive of a mechanism that is considered an early-selection mechanism that could be used to describe the outcomes of the studies described above. Early-selection mechanisms are thought to carry out their selection based on the physical properties of the stimulus. The studies described here show that the information within the blink region has at least some of the semantic information carried with it or it would neither be reportable nor able to influence the items coming later in the stream, as well. Thus the evidence from these three experiments is taken to support a late-selection mechanism for the attentional blink.

Although the three experiments presented above can be used to support the idea that the AB is a problem associated with a late-selection mechanism, it does not clarify whether temporal predictability is effecting an early-selection mechanism or a late selection mechanism. Temporal predictability is a low-level cue that can be used to guide attention. Since temporal predictability is a low-level cue, it could be affecting an early-selection mechanism. If temporal predictability is affecting an early-selection mechanism then that would suggest the critical item (the probe) is arriving at the retrieval stage fully processed. If temporal predictability is working at a later stage in processing, then it means that the information is arriving in the same partially processed state as when the task is unpredictable, but temporal predictability allows the state of readiness to have other processes available to extract the information required to make the identification possible. With the information available from these experiments, it is unclear where the advantage of temporal predictability in this task is having an effect.

Practice and the Attentional Blink

The second set of experiments (Experiment 5) looked at the effects of practice on the AB. In almost every case where more than one session was conducted, subjects showed significant improvement in the second session. Experiment 5 examined the effects of changing the probe identity as a means of revealing the mechanism underlying the practice effect. The critical findings are that there is a general improvement in performance due to practice and that different letters yield different processing deficits ('T's show less of a blink than 'X's) These results provide evidence that practice attenuates the attentional blink but because of the differences in the processing required for the stimuli chosen, whether or not the sharpening of the probe template is responsible for some of the improved performance observed is inconclusive. By sharpening the probe template I mean that within the information processing system, the template used to either accept or reject a stimulus becomes more effective.

The first part of this discussion will deal with the overall improvement observed between the first two sessions. The second part will deal specifically with the findings that the stimuli chosen were processed with different amounts of effort.

In Experiment 5, there was a general improvement in subject's performance in the AB in session two when compared to their session one performance. This improvement may be viewed as a general practice effect. When practice is carried out to a third session (involving a total of 240 trials), in two of the experiments (Experiments 5b (XXT) and 5c (TTT)) the AB disappeared entirely. Weichselgartner & Sperling (1987) reported on the presence of a deficit (that is assumed to be the AB) even after subjects had engaged in over ten thousand trials. Such differences in results could be due to differences in the experimental tasks used. In the Weichselgartner & Sperling (1987) task, subjects had to report on the first four items that followed a target delimiter. This is a task that required identification, rather than recognition, as in the tasks reported above. If it can be assumed that the partially processed items that subjects were trying to report were in a state similar to that of perceptual degradation, then this may serve to explain their failure to attenuate the AB. The identification of a perceptually degraded stimulus is much more difficult than recognition of a perceptually degraded stimulus (Farah, Monheit, & Wallace, 1991).

Another difference between Experiment 5 and the task performed by the subjects of Weichselgartner & Sperling (1987) is the report requirement. With four items to report in the Weichselgartner & Sperling (1987) study, there may have been a memory load problem not present in Experiment 5. Although four items are not many to remember for a very short period of time, the additional report requirements may have made the difference in that the deficit would not disappear with practice.

The original intent of running two sessions was to use the improvement found in the second session to gauge the affects of the temporal manipulations. Even though there was not a significant interaction between predictability and sessions, nevertheless, there were differences worthy of discussion. When the target and/or probe were put in predictable temporal positions, there was a significant session effect. When the target and probe were both unpredictable, the session effect was only marginally significant. This difference strongly suggests that temporal predictability is a factor in practice. Furthermore, when the critical items are in predictable positions, the effects of practice are greater. The additional information provided by temporal predictability may have allowed subjects to sharpen one or more of the component processes involved in the information processing system. Experiment 5 fixed the temporal position of the probe in order to observe session effects on one of the possible mechanisms that could be improved.

The purpose of Experiment 5 was to examine probe processing as a potential source of the attenuation of the AB. In the majority of the experiments examining the AB, the identity of the probe has remained constant (e.g. Raymond *et al.*, 1992; Shapiro & Raymond, 1994; Shapiro *et al.* 1994). A sharpened pattern template for the probe could have been one of the primary reasons for the session effect revealed in Experiment 5. However, the results from these manipulations is inconclusive. A sharpened pattern template (for the probe) would be that mechanism that either accepts an item as a match (similar enough to a probe to warrant further processing), or rejects the item as no match for the probe. Although Experiment 5d (TTX) showed that the identity of the probe letter has an effect on performance (the third session showed significantly lower probe performance than session two), Experiment 5b (XXT) showed the opposite effect as there was continued improvement, even in the third session after the identity of the probe had been changed. The only conclusion that can be drawn from these findings is that the different letters require different amounts of processing resources.

That different letters require different amounts of processing should not be surprising. Two different aspects of the letters themselves could easily account for these differences; letter frequency and letter confusability. It has been found that high frequency words are processed easier than low frequency words. High frequency words can be displayed for shorter amounts of time in visual identification tasks to reach the same level of identification as low frequency words. High frequency words can also be played softer than low frequency words in listening tasks but yield the same results (Keele, 1973). Such a pattern of less processing resources being needed for high frequency words than for low frequency words should be generalizable to individual letters, as well. The letter 'T' is a much higher frequency letter than the letter 'X'. Thus it should be expected to be processed easier and with less difficulty than the low frequency letter.

The other reason for the differences in the performance on the 'X' and the 'T' probes could be a result of the distinctiveness of the letters. When you look at the number of distinctive features that the letters have in comparison to the rest of the alphabet (Gibson, 1969), it becomes evident that an 'X' is confusable with more of the other letters than a 'T'. This confusability would add to a subjects unwillingness to commit to having seen an 'X' when it could very well have been a 'K' or a 'Y' or even a 'Z'. When the letter 'T' is considered, the letters that share the most distinctive features are the letters 'L', 'H', 'E' and 'F'. None of these letters have the same obvious confusability as have letters similar to the 'X'.

The effect of practice on the AB is an improvement from one session to another. Since the evidence is inconclusive with regard to the hypothesis that the sharpening of the template for probe item recognition is responsible for this improvement, any conclusions as to why improvements are observed are speculative. What is observed is a general improvement in probe task performance, and the only firm conclusion that can be drawn is that the subjects are simply getting better at one or more of the component processes that underlie the task.

General Observations

Evidence from the experiments included in this thesis suggests that the AB is responsive to both temporal predictability and practice. Earlier in this discussion, evidence was presented to show that the source of the deficit underlying the AB is a late-selection rather than an early-selection mechanism. This conclusion was drawn from the results of the three experiments; dual probe (Shapiro, 1993); categorization of digits and letters (Hamm & Taylor, 1994); and the personal name experiments (Shapiro *et al.*, in submission), that showed the usually non-reported items are processed, at least to a level of semantic activation. Since at least some of this deficit is occurring very close to the retrieval stage, it could be that subjects are possibly unable (or unwilling) to report the items of interest because they are not confident in their judgments. The AB could be (at least in part) the result of a conservative response criterion.

A conservative response criterion is the result of an inequality in the costs involved in choosing a particular response. In the multiple-target RSVP task, the responses have been reduced to a simple 'yes' if the subject sees a critical item, or a 'no' if they fail to see a critical item. An item that is only partially processed is difficult to retrieve, and on a number of trials subjects may hesitate to commit to an affirmative response, based on the amount of information available from a partially processed item, due to the costs involved. To say that you 'saw' something commits you to a position of having seen it and are certain enough of the occurrence of an event to be willing to report it. To say that you did not see something does not force you to commit to the absence of an event, only that you are unwilling to say that the event has occurred. This is a reasonable expectation because on 50% of the trials the (probe) event does not occur. The cost of an affirmative response is the willingness to commit, whereas there is little (if any) cost associated with a negative response The primary objective measure of a conservative response criterion is low false alarm rates. In the experiments carried out as a part of this thesis, the false alarm rates were generally in the 10% to 15% range. This would indicate a conservative response criterion with a bias toward responding 'no' when they were unsure.

Although a conservative response criterion may be the reason for some of the observed deficit, it does not explain why the information is only partially processed. The processing occurring requires encoding the features of objects, presented in a rapid sequence, and then the conjunction of the features to form representations of whole objects to be reported when the trial is finished. According to Treisman's (Treisman & Gormican, 1988) feature integration theory, the purpose of attention is to carry out the conjunction or binding process of putting the individual features together to form whole object representations. When the resources of the system are overloaded, as would occur in an RSVP situation, some of the conjunctions may not be carried out accurately. It also follows that in the case of extreme load, the conjunctions may be interrupted by new information demanding processing. This would result in some partially processed items, items whose features may all be present, but not conjoined; in other cases items in which some of the features may be conjoined properly but other features are not conjoined to anything.

There are two models that have been proposed to explain why items are unreported within the AB region. The first was an early-selection inhibition or gating model (Raymond *et al.*, 1992). This model has the critical items acting as triggers to close the "gate" that allows items into VSTM for further processing. When the target is encountered, the gating mechanism is triggered, but before the gate can fully close, the item following closely behind (the target +1 item) also gets into VSTM. It takes a certain amount of time for the items in VSTM to be fully processed (with the gate still shut). This time is observed as the AB, and the reason the items are missed is because the gate is closed that would allow them to be processed further.

The evidence cited above (Shapiro, 1993; Hamm & Taylor, 1994; and Shapiro, Caldwell & Sorensen, in submission) makes this explanation untenable. In all three cases the evidence suggests that items presented in the blink region are either fully reportable, or have an effect on items occurring later. This leads us to the second model proposed in Shapiro *et al.* (1994). This model postulates that all of the critical items (target and probe) enter visual short term memory (VSTM), along with the item immediately following them (target +1, and probe

+1). Because the target is the first item in, and it receives a higher weighting (or reason to be processed), the target is usually fully processed with whatever resources are demanded. As a result there are usually very few target errors. Because of the speed of presentation and the numbers of items in VSTM, not all of the items there are fully processed. This means that the probe item must be identified from among a group of partially processed items. The interference caused by the presence of the other partially formed items thus yields a high number of probe errors.

Most of the evidence gathered from the experiments in this thesis could be used to support either of the two models that have been put forward as explanations of the AB. The critical piece of evidence that promotes one model over the other supports the interference model and comes from the practice data.

The differences found in the processing of the 'X's and 'T's from the practice data offers support for the interference model. The letter 'X' is more confusable with other letters and as a result, lower performance would be expected when it is the probe. The number of letters that have confusable features with an 'X' are more than those confusable with a 'T', but are still very low. The interference model suggests that the features present in VSTM are not distinct enough to facilitate the detection of the probe letter ('X') from the other letters present (target, target +1, and probe +1). Since the target is always a white 'S', whose features are very distinguishable from the features of an 'X', that only leaves two other items as potential sources of confusion (target +1, and probe +1). If the data from the third practice session is examined, the probability of detection when 'X' is the probe is 0.41 for the dual task and 0.74 for the control task. If the experimental results are subtracted from the control results, that leaves a probability of an error in the two probe task as 0.33 over and above the baseline control condition. As indicated above, I estimate that there are three letters that are potentially very confusable with an 'X' (K, Y and Z) when the distinctive features are examined. The probability that one of these three letters could occur in one of the two critical stream positions (target +1, and probe +1) on a given trial is 0.25. Subtracting the probability of one of these three letters occurring from the probability of an error when 'X' is the probe leaves 8% of the errors unaccounted for. This is very close to the rate of errors when the experimental condition is subtracted from the control condition when 'T' is the probe in the third session (4%) and there are no significant differences (no blink). Thus the potential confusability of the letters with one another can be used as a explanation to support the idea that the letters interfere with each other when they are to be recalled.

Another explanation for the AB is one involving an inhibitory mechanism, but not as an early selection, gating mechanism as envisioned in the first AB model (Raymond *et al.*, 1992). When the first critical item is processed (the target) and is followed immediately by another item that is a source of potential confusion (the target +1 item), an inhibitory mechanism is initiated that hinders (but does not stop) the processing of subsequent items until the target is fully processed. This would also result in the probe item being only partially formed. Unless the amount of information present in the form of the probe could allow for a positive identification, performance deficits would be seen. The potential for confusion is just as high in this model as in Shapiro's (Shapiro *et al.* 1994) interference model so the same results would be predicted. The difference between this inhibitory model and the Shapiro interference model is the role of the non-critical stream items. In the interference model, their role is negligible, as the only items in VSTM are the target, target +1, probe, and probe +1. The target intrusion errors that have been reported (Drake, 1992; Raymond *et al.*, 1992; Shapiro *et al.*, 1994) all indicate that majority of the target errors are the target +1 item. The interference model would predict that the probe errors (on a probe identification task) would either be the probe +1 item or the target +1 item, because they are the only other items in VSTM. The inhibition model, as outlined above, would predict that intrusion errors could come from any of the stream items, as the probe could be potentially confusable with any of the items. Such questions must be left for further experimentation.

One of the larger issues that this thesis has addressed involves the differences between temporal and spatial attention. These differences can best be examined by discussing the limitations found in these two domains of attention. The limitations to spatial attention have been the most thoroughly studied. The first limitation to spatial attention to be discussed is one involving the simultaneous processing of a number of items. As the number of items increase, the ability to detect the presence of a target can be effected (Treisman & Gormican, 1988). Of course, this depends on the relationship of the target to the distractors and the distractors to each other (Duncan & Humphreys, 1989). If the target is very different from the distractors, then target detection is much easier than if it is similar to the distractors. The relation of the distractors to each other is also important in that if the distractors are very similar to each other, the target can be detected more easily than if the distractors are all different from each other. Another important finding is that processing a number of items simultaneously leads to illusory conjunctions (Treisman & Gormican, 1988).

Illusory conjunctions is usually seen in items that share close proximity. The final problem with processing an array of items is the concept of "objectness" (Duncan, 1979). If the items that make up an array are considered parts of the same object, they are easier to process than if they are perceived as different objects. Similar observations have also been reported in studies of texture segregation (Julesz, 1981). The items that are grouped together to make a figure stand out from a background in texture segregation are processed easier as a whole than the individual items.

The second major area where limitations pertaining to spatial attention have been found are the mechanisms involved in moving attention across the visual field. Attention can be moved around the visual field like a spotlight, but it takes a measurable amount of time to do so (Eriksen & Murphy, 1987; Tsal, 1983). Furthermore, researchers have concluded that attention can not be divided but can be 'zoomed out' to cover a broader area, but with less detail available for processing (Eriksen & St. James, 1986), or 'zoomed in' to process the fine detail of an image. Another mechanism that can impose some limitations on the processing system is the benefit of being pre-cued to a particular spatial location (Posner *et al.*, 1980). The limitations observed in pre-cueing arise when the cue provided is invalid, as there is a cost associated with moving attention to the place where the stimulus occurs.

The final spatial attentional limitation that I will discuss is inhibition of return (Posner & Cohen, 1984; Shapiro & Loughlin, 1993). This is a limitation found in spatial search such that when attention has recently searched an area for a target, there is a cost involved with having the target occur in that same spatial location again (within a short temporal window).

In the area of temporal attention, some limitations to processing have also been found. Negative priming is one of these limitations (Tipper, 1985). In order for an item to be a target, responses to competing, simultaneously present distractor items must be inhibited. When an object is presented as a distractor in one trial, and then as a target in the next trial, there is a cost to the subject revealed in longer reaction times to report the target. It is thought that this cost is associated with lingering inhibition from when the item was a distractor. Although some questions regarding this phenomenon have been raised (Park & Kanwisher, in press), only certain aspects of the findings are suspect.

Another of the limitations found in temporal attention is found in studying the phenomena of 'repetition blindness' as reported by Kanwisher and her colleagues (e.g., Kanwisher, 1987). This phenomena is best described as the reduced ability in reporting the second occurrence of a repeated object in a temporal stream, if it follows the first object by between 150 and 500 ms. An example would be found in the sentence "When he spilled the ink, there was ink all over". If this were to be presented in a RSVP paradigm, one word at a time, there is a high probability that a subject would fail to report the second occurrence of the word "ink".

The problem with illusory conjunctions occurring in a stream of rapidly presented items is another limitation to temporal attention (e.g., Botella, 1992). Illusory conjunctions occur when the features of two different objects are improperly conjoined. For example, when a green 'T' and a red 'S' are presented rapidly (and in that order), there is high probability that if there is an error made, it would be the reporting of a red 'T'. As with spatial illusory conjunctions, temporal proximity is an important factor in producing illusory conjunctions.

The final limitation to temporal attention is the one that is the subject of this thesis, that of the attentional blink. The attentional blink appears to indicate that it takes a certain amount of time dwell (about 500 ms) to process a target before the processing system can move on the next item (Duncan, Ward & Shapiro, 1994). Just as there are some mechanisms that facilitate processing in spatial attention (e.g., benefit of pre-cue, Duncan's concept of "objectness" (1979)), there are certain mechanisms that facilitate temporal processing within the AB. As the experiments in this thesis have illustrated, temporal predictability can improve performance on the probe task by allowing the subject to be 'ready' at the time the probe is presented.

Many of the limitations described above appear to have analogies in both the spatial and temporal domain of attention. Duncan's (1979) theory of objects appears to improve the processing efficiency in both domains. In addition to Duncan's (1979) "objectness", knowing when (or where) an object will appear also facilitates processing. Proximity can cause predictable errors in both domains (illusory conjunctions). And finally, there appears to be inhibitory mechanisms that are invoked by switching either the location or identity of targets and distractors. If could be possible that the same or very similar mechanisms underlie processing in both domains of attention.

Since the attentional blink is the focus of this thesis, it is important to discuss the relevance of the AB in visual processing and ask the following question: Does the attentional blink facilitate visual processing? The AB is an effect that is limited to situations where there is a specified target that must be detected or identified. This contention is supported by Reeves and Sperling (1986) were subjects had to identify a number of items presented sequentially, and by the work of Kanwisher (1990), where subjects had to read rapidly presented sentences. In both these cases the AB was not found after each reported item as would be observed if the AB were a deficit that followed any processing, rather it is specific to situations where a target is specified and subjects must respond to that specified item. If the AB were a measure of how fast sequentially presented items could be processed (whether the items were targets or not), neither of these tasks would be possible. Thus, the AB is a result of processing a specified target.

The advantage that might be gained from the AB is that when a target is specified (for whatever reason) the AB is a mechanism that assures that the target is processed as fully as possible with very little interference. The disadvantage comes when more than one target is specified, and the second target falls within the region of the AB. I think that the reason the this limitation has not been dealt with by evolutionary forces is that the probability of two targets occurring less than 500 ms apart is very low. In order for a mechanism to evolve, there must be some advantage by way of improved fitness for the species. Preventing interference for 500 ms following a single target is advantageous and as a result the AB has developed. The ability to process targets closer than 500 ms apart, because it is such a low probability event, is not enough of an advantage to humans for us to devote the evolutionary resources needed to overcome the perceived deficit.

There are still many unanswered questions regarding how attention operates through time, and the AB can be used as a tool to help in the understanding of the underlying processes. The final part of this discussion will focus on some of the related areas that I would like to examine in future work.

The first thing I would like to do is an identification task on the probe in order to measure the pattern of intrusion errors on the probe performance. This information would be useful to assess just what is being processed and to what level, or what is being held in VSTM. If the intrusion errors do not have a regular pattern, then it is possible that many of the stream items are in VSTM, and the forced selection of a probe identity would result in picking any item that is processed enough to be identified. Another possible explanation for an irregular pattern of intrusions would be that nothing entered VSTM so the choice is random. If the pattern of intrusion errors is predictable and regular (probe +1 or probe -1 items), then that suggests that only a very few items are in VSTM from which selection can occur.

Another area I would like to examine is the possible confusion caused by both the target +1 item as was examined by Raymond (Raymond *et al.*, in press) and the probe +1 item. If these are the items in VSTM that are causing the confusion and are responsible for the AB, then by manipulating their shapes, the AB should be attenuated.

A final area I would like to examine is the presentation rates of the RSVP stream, and what effect changing these might have on the AB. Will the AB only occur in the temporal window between 180 ms and 500 ms after a target, or is it related to the number of items that are being processed? I hope that by pursuing the questions listed above, a more thorough understanding of the temporal limitations of attention will be reached.

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Appendix 1

Title of Investigation:

The Effects of Selection Factors on the Suppression of Visual Processing in a Target/Probe RSVP Paradigm

Investigators: Jesse Martin and Dr. K. L. Shapiro

Description of Research Project:

The experiment you are about to participate in is a target identification experiment. You will be asked to observe a stream of letters on the screen and to report what you see and to identify whether a target is present or absent and whether a probe is present or absent. You will indicate your responses by telling them to the experimenter who will record them on the computer you are observing.

This is to certify that I, ______________________ hereby agree to participate as a volunteer in a scientific investigation (experiment) as an authorized part of the research undertakings within the department of psychology at the University of Calgary under the supervision of Dr. K. l. Shapiro.

The investigation and my part in the investigation have been fully explained to me by Jesse Martin and I understand his explanation. The procedures of this investigation and their risks and discomforts have been fully described and discussed in detail with me.

I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.

I understand that I am free not to answer specific items or questions in interviews or questionnaires.

I understand that any data or answers to questions will remain confidential with regard to my identity.

I UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TERMINATE MY PARTICIPATION AT ANY TIME WITHOUT PENALTY AND THAT I MAY REQUEST A SUMMARY OF THE RESULTS OF THIS STUDY.

______________ ______________ ______________________

Date Date of Birth Participant's signature

I, the undersigned, have fully explained the investigation to the above individual.

______________ ______________________

Date Investigator's signature