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## **DOCTOR OF PHILOSOPHY**

### **An interference continuum for selective attention in vision : evidence from the attentional blink**

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**An Interference Continuum for Selective Attention in Vision:  
Evidence from the Attentional Blink**

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### Abstract

Theories of selective attention in vision proposed by Duncan (1996), Van Essen and De Yoe (1995), and Johnston & Heinz (1978) are brought together to formulate a model of processing. The new model proposes that selection processes in vision occur along a processing continuum and interference occurs when the processes demand the same resources. The model is tested using a rapid visual serial presentation paradigm examining the errors made during the attentional blink processing deficit. The model is supported by the results of the experiments.



An Interference Continuum for Selective Attention in Vision: Evidence from the  
Attentional Blink

*Modularity in Visual Processing*

Visual perception begins at the retina. Within it, the process of transduction takes place: light energy is transformed into electro-neural energy, which in turn is transformed into an internal representation of the visual world. Although this representation is one of structural coherence, neurophysiological evidence suggests that visual processing begins with the processing of basic visual features -- edges, colours, and endstops, for example -- and that it is from these that a coherent representation of the outside world emerges (Livingstone & Hubel, 1988).

Starting with the basic neuroanatomical structure of the visual system, this thesis will examine the neurophysiology of attention, behavioural characteristics of selectivity, and introduce a model for selection that accounts for the behavioural and neurophysiological evidence presented. Following the introduction, evidence will be presented supporting the model, followed by a discussion regarding the ability of other models to account for the presented findings.

\* \* \*

The work referred to in this thesis has been obtained from a variety of sources, many of which have involved research on non-human primates. Because of commonalties between these primates and humans, it is assumed that

the underlying structure found in primates also applies to humans (Ungerleider & Haxby, 1994).

Neurophysiological research has found that the neural processing units that make up the visual system vary widely in the stimuli to which they will optimally respond (e.g. Desimone & Ungerleider, 1989; Felleman & Van Essen, 1991; Livingstone & Hubel, 1988). The brain processes different features of the visual world separately in specialised systems; it then assembles these features (based on their spatio/temporal proximity) into coherent objects. Van Essen (see e.g. Felleman & Van Essen, 1991) estimates that there are as many as 34 specialised areas for processing visual information in the macaque monkey. Throughout this thesis, such specialised processing areas within the visual system (and within the brain as a whole) are called *modules*.

The modules within the visual system respond to progressively more complex stimuli as information moves from the primary visual processing areas to higher levels of processing (Desimone, 1992). For example, the module processing luminance edges contains cells in the primary visual cortex that respond only to luminance edges, but when information is received at the next stage of processing (area V2), there are cells which respond both to edges and to the orientation of the edge; and, later still (V4), there are cells which respond both to edges of a given orientation and to those with an end-stop, making a bar of a particular length the feature to which the cell optimally responds (Livingstone & Hubel, 1987). Although the cells themselves become less specialised, the increased complexity of the cells allows them to become more specific with regards to the combination of basic features that induce firing. In

this view, more complex cells, for example, process a bar of a specific length, while a luminance edge is processed by a primary visual cortex cell.

Early research demonstrated that the visual system is organised with two types of neural fibre: the *magnocellular* and *parvocellular* (Livingstone & Hubel, 1987). The beginning of both of these fibre types is at the retina. The magnocellular neural fibres are made up of large cell bodies and fibres that respond quickly to stimuli, primarily carrying information regarding luminance and motion. The parvocellular system, by contrast, comprises small, slower responding cells and fibres, carrying colour information. The two cell types extend through all the visual modules.

There are also two major divisions in the processing pathway for visual information: the *occipitotemporal* cortical pathway, which takes a ventral route to the inferior temporal lobe, and the *occipitoparietal* cortical pathway, which takes a dorsal route to the posterior parietal area of the brain (Schneider, 1967; Ungerleider & Haxby, 1994).

The occipitotemporal cortical pathway -- areas V1, V2, V4, and inferior temporal areas TEO and TE -- appears to involve modules which process information concerning *what* an object is; to this end, the pathway includes modules for determining colour and shape (Goodale & Milner, 1992; Maunsell & Ferrera, 1995).

The occipitoparietal pathway -- areas V1, V2, V3, middle temporal area (MT), medial superior temporal area (MST), and other areas within both the inferior parietal and the superior temporal sulcal cortex -- involves areas of the brain which process information concerning *where* an object is; specifically, its

spatial relationship to the observer (Mishkin, Ungerleider, & Macko, 1983). This is important in mediating visually guided behaviours such as reaching (Goodale & Milner, 1992, 1994; Maunsell & Ferrera, 1995).

The ventral or occipitotemporal pathway comprises inputs from both parvocellular and magnocellular layers of the lateral geniculate nucleus (LGN), while the dorsal or occipitoparietal pathway comprises inputs from the magnocellular layers of the LGN. Although there is communication between the pathways at each level of processing, the main connection that serves to tie an object with its spatial relationship to the observer is the connection through the rostral superior temporal sulcus (Boussaoud, Ungerleider, & Desimone, 1991; Ungerleider & Haxby, 1994).

#### *Form, Colour, Texture, Motion and Location Modules*

The form processing module is the culmination of several early, and presumably automatic, perceptual processes. The first of these is a process to detect edges.

Edge coding begins at the retina with the photoreceptors responding differentially to changes in luminance levels. This activity is enhanced by the receptive field characteristics of the retinal ganglion cells. The centre-surround organisation of the different sized fields enhances edges in the visual field. In the primary visual cortex (V1), cells in the *inter-blob* region respond to edges and changes in luminance levels. This information is thought to be carried by the magnocellular pathway of the visual system (Livingstone & Hubel, 1988).

End stop information is the next feature from which the form or shape of visual stimuli can be extracted. End stops are the features that indicate the end of an edge. Between 10% and 20% of the cells in the inter-blob regions of primary visual cortex respond to end stops. In area V2, over half of the cells in the pale stripes are sensitive to end stops. This is a dramatic increase in the proportion of cells responding to a single feature while the information moves through the visual system (Livingstone & Hubel, 1988).

Orientation of the edges and end stops is another important feature for form and shape discrimination. Within the primary visual area, some cells in layer 4b and all (or almost all) the cells in the inter-blob regions respond to orientations. At the next stage in the visual processing system, area V2, all (or almost all) of the cells comprising the pale stripes are orientation sensitive (Livingstone & Hubel, 1988).

Once the form and shape of an object have been established, the object may be identified and classified. Although other information is usually needed for this task, because of the critical role form or shape plays in object identification, the pathway will be described here. This task is carried out along the infero-temporal pathway of the visual system. This area is close to the language centres of the brain; it is reasonable to suppose that classification and identification take place in close proximity to auditory processing centres (Mishkin, Ungerleider, & Macko, 1983; Ungerleider & Haxby, 1994).

The colour module extends from the retina to area V4 in the human visual system. It is responsible for giving colour values to the forms that are processed. Colour coding starts at the retina with the three different cone types: long-

wavelength cones (responding best to red light), medium-wavelength cones (responding best to green light), and short-wavelength cones (responding best to blue light). At the LGN, the slower fibres of the parvocellular system carry colour information. Ninety percent of the parvo-cells in the LGN respond differentially to light of different wavelengths. Within the primary visual cortex, blobs are both colour and brightness sensitive. The colour input for the blobs comes from the parvocellular inputs, and the brightness information comes from the magnocellular inputs (Livingstone & Hubel, 1988).

In area V2, over half of the cells in the thin strips respond to colour information. Research suggests both that area V4 receives the colour information from area V2, and that it is the highest area involved exclusively in colour processing (Zeki, 1991).

Texture perception is important in figure/ground discrimination and in depth perception. It is thought to derive from rapid first and second order statistical calculations carried out on edges, end stops, and their orientations in a visual scene. As a result, texture perception relies on the same inputs as form perception. Texture perception is also important in isolating objects as distinct forms from their backgrounds (Julesz, 1981).

Motion perception is necessary to update the current location of an object and to evaluate any change in location in relation to the observer. In the primary visual cortex, some of the cells in layer 4b are both motion and motion direction sensitive. These motion sensitive cells receive their input from the magnocellular pathway. Cells in visual cortex area V5 (area MT in a macaque monkey) receive inputs from the motion sensitive cells in primary visual cortex.

These same cells also receive inputs from the thick stripes from area V2, which comprises cells that process binocular disparity between the eyes (Livingstone & Hubel, 1988; Zeki, 1991).

The location of objects comprises two components, the XY co-ordinates and the Z co-ordinate. The XY co-ordinates are maintained throughout the visual system by virtue of the fact that the organisation of the processing cells maintains a *retinotopic* map from the retina through to the highest levels of processing (Livingstone & Hubel, 1987). Spatial proximity of the processed information within the visual system reflects the spatial proximity in the observer-centred XY co-ordinates of the real world.

The Z co-ordinate or the depth plane of an object is processed in a number of ways. The thick stripes in the visual cortex area V2 respond to luminance bars that fall on both retinae and co-ordinate the responses from both retina to evaluate the binocular disparity of the object (Livingstone & Hubel, 1987). Other visual cues are used to evaluate the depth plane; these include texture gradients and object occlusion. Processing the XY and Z co-ordinates of an object gives the observer location information in the form of *egocentric* positioning (Stein, 1989).

### *Competitive Processing in Vision*

Processing modules within the visual system operate in a competitive manner (Desimone & Duncan, 1995; Duncan, 1996; Van Essen & DeYoe, 1995). This is expressed as one stimulus gaining activation at the expense of another stimulus, both when two stimuli are being processed within the same module

and when the stimuli come from different objects and are therefore being processed by different modules

As an example of how competitive processing between objects has been demonstrated. Duncan (1996) recorded the activity of cells in inferotemporal cortex (IT) which were found to be responsive to specific objects. Recordings from these cells were taken both when the object to which the cells optimally responded was a targeted object in a display and when the object was a distracter object within a display. It was found that, when the effective object was the target stimulus in the display, the cells maintained a state of heightened activation; however, when the effective object was the distracter stimulus in the display, there was a suppression of activity following an initial burst of activity. Thus, when the item to which the cell optimally responded was targeted, the cell enjoyed sustained activity, but, when the item to which the cell optimally responded was a non-targeted distracter, after an initial burst of activity, the cell's activity was suppressed. This observation suggests that the competitive processing which occurs between objects is "won" by the targeted item.

Another area in which competition has been observed in visual processing has been with patients who suffer from lesions leading to unilateral neglect. Unilateral neglect is characterised by the ignoring of the (usually) left half of visual space (Kinsbourne, 1987). The deficit is considered a deficit in attention because, in order to perceive anything on the left, the cues must be strong, and the patient must expend effort. In addition, unilateral neglect is aggravated by the presence of competitive stimuli; these occur in the unimpaired visual field and the phenomenon has been called *unilateral extinction* (Karnath, 1988). This



deficit suggests a "competitive imbalance" with the *ipsilesional* side displaying a processing advantage (Duncan, 1996).

Unilateral neglect and unilateral extinction have been associated with damage to the parietal lobe, usually occurring on the right hemisphere. It is problematic for the idea that unilateral neglect and unilateral extinction arise from competition to brain systems if neglect and extinction were limited to lesions occurring in particular regions of the brain; competition is a general phenomenon occurring in all areas of the brain and deficits associated with competition should be observable anywhere competition occurs. Although spatial neglect and extinction are commonly found following lesions to the right parietal region of the brain, they have also been observed arising from lesions in other brain areas. In more than half of the patients reported by Husain, Shapiro, Martin, and Kennard (1997), the observed unilateral neglect resulted from lesions in the frontal lobe; additionally, one of the patients suffered from a haemorrhage of the basal ganglia. Unilateral extinction has been observed in patients with occipitotemporal, lateral pulvinar, thalamic nucleus, and superior colliculus lesions (Duncan, 1996). Neither unilateral neglect nor extinction is limited to lesions occurring in a single area of the brain.

This evidence suggests that the bias observed in both unilateral neglect and extinction could be the result of processing competition (other evidence suggests a more general spatio-temporal disorder that effects the time course of attentional mechanisms within the brain – c.f. di Pellegrino, Basso and Frassinetti, 1998). The theory is that the non-lesional side of the brain, with all its processing power intact, enjoys a competitive advantage over the side with the lesion. If

this theory is true, when damage occurs to an area of the brain which processes spatial information, there will be a spatial bias toward the undamaged side of space; further, this spatial bias will result in the non-lesioned side enjoying a competitive processing advantage -- this is because it is intact and enjoys a higher overall activation level.

The evidence from brain-damaged patients, coupled with that of target processing competition, suggests that the visual system is competitive both within and between modules. This competitive structure implies that, although initially features might be encoded in parallel across the visual field, as items are processed through the visual system, the competition observed during the processing stages will result in particular items being processed and others being eliminated from further consideration. Thus, at any stage in which competition is invoked, some of the information considered by the system as redundant or unnecessary will be excluded. This competitive design is an important theoretical construct for the development of this thesis.

As competition occurs throughout the brain between different processing systems, there must be a mechanism in place which biases the competition towards specific items. This is for two reasons.

First, features must be tied to other features; this is in order to perceive objects (how features are tied together is known as the *binding* problem). Since different modules process the various features of an object, a mechanism must exist to bias all the modules to process and then bind together all its features.

Second, either via extrinsic means (e.g. a physical threat) or intrinsic means (e.g. a goal such as foraging for food), there must be a biasing mechanism for processing particular items with explicit meaning to an organism.

Two types of mechanism have been suggested for visual processing: those that involve automatic selection and those that involve goal directed selection (Desimone & Duncan, 1995; Duncan & Humphreys, 1989).

#### *Automatic selection.*

The automatic process for selecting a different item from a homogeneous background operates as follows.

The activation of those cells within the visual system that are optimally tuned for a particular stimulus is diminished when more than one of the tuned stimuli are present in the receptive field. This mechanism allows for the selection of objects that differ from the background items. A classic example is selecting a "Q" from among an array of "Os". As a result of the automatic selection mechanism that suppresses activation to a homogeneous array, the targeted item -- the "Q" -- *pops out* (Desimone & Duncan, 1995).

There are also mechanisms available for suppressing responses to stimuli that have recently been processed. Fahy, Riches, and Brown (1993), in tests on primates, found that the responses of a proportion of cells in IT were suppressed as the primates grew familiar with the stimuli to which the cells were selective. This suppression assists the selection of novel stimuli. This is not because the cells respond to novel items; it is because, once an item becomes familiar, the activity is suppressed: this reduction of activity for familiar stimuli increases the

efficiency of the system in that it requires less activation to process a novel stimulus.

A reduced activation for familiar items results in novel items, or items not recently seen, having a larger activation signal (Desimone & Duncan, 1995). In a competitive processing system, greater activation leads to selection of, or the biasing of processing toward, the novel object. As a result, the visual system is structured to automatically process novel items.

#### *Goal directed selection.*

Maunsell and Ferrera (1995) reported on cells found in area V4 which appear to be involved in selection from a goal state based on features. Monkeys were trained to respond to a *target* stimulus (an *orientation grating*) which matched a *cue*. There were many cells found in V4 which responded with heightened activation preferentially to specific orientations: if a cell responded to right oblique grating patterns, activation was observed whenever a right oblique grating was shown; when a left oblique grating pattern was shown, however, no activation was observed.

Maunsell and Ferrera (1995) observed another more interesting set of cells. These cells responded according to the cue, or goal orientation. In these cells, the activation was specific to an orientation, but only if the orientation was the cue. The activation remained high for all orientations while the monkey was looking for the target. If, for example, one of these cells were responsive to right oblique grating patterns, it would become activated *only* when the cue was a right oblique pattern; then the activity was sustained until a response was made.

Thus, even though the preferred orientation of the cell was right oblique, the cell did *not* respond to right oblique grating patterns *unless* the specified cue had a right target orientation; if, for example, the specified cue had a target orientation of left, the cell did not respond.

This mechanism allows for selection to take place by looking for a match between cells which respond automatically to specific orientations (a right oblique cell) and cells which are activated when looking form a particular orientation. When the two cells were firing together, the match would signal the presence of a target that was defined by a goal state.

Cells in MT, which respond to motion stimuli, were observed to react in an identical fashion. A cell, which was selective for motion in a certain direction, fired only when the monkey was searching for a target consisting of motion in that direction. The cell did not fire when any stimulus was presented moving in its preferred direction, it fired only when the targeted item was motion in a certain direction (Maunsell & Ferrera, 1995).

In other work, Chelazzi, Miller, Desimone, and Duncan (1993) observed cells in IT in which activation to a preferred stimulus was quickly suppressed if the stimulus preferred by that cell was not the target stimulus. This illustrates that the selection mechanism works in these cells by suppressing non-target activation. They also observed that the suppression effect is more powerful when the distracters occur adjacent to the receptive field of the target item, increasing the chances of selecting a target item from the noise induced by a busy background.

Features are not the only goal directed selection mechanism; locations can also be selected. When two items are presented to a monkey, and the target item is determined strictly by its location, cells in both IT and V4 appear to have receptive fields which shrink to cover the area where the target is to be found (Moran & Desimone, 1985). This occurred even when the items were placed within the normal receptive field of the monkey. What Moran and Desimone observed was that there was attenuation for the distracter item (or location) while there was normal activation for the item in the target location. They also observed that there was no attenuation observed in IT cells for the distracter stimulus when the two items were not in the same receptive field. This follows the prediction of the competitive bias selection model. Since the two items were not competing for the cell's response, there was no need for the activation from one of the items to be suppressed (Desimone & Duncan, 1995).

### *Concurrent Processing*

Concurrent processing refers to processing that occurs simultaneously along distinct streams, but for which there are numerous points where interactions can occur (Van Essen & DeYoe, 1995). Van Essen and DeYoe argue that the visual processing system in primates does not consist of independent, non-interacting parallel processing pathways, or even distinct parallel pathways which enjoy some interaction; rather it comprises a series of converging and diverging streams of processing (see Figure 1). The streams of processing converge on processing modules, with the output from any one module being used as input for several other processing modules. As an example, a module

processing the velocity of an object would make a large contribution to the module processing motion, but additionally, would contribute importantly to form and depth perception (DeYoe & Van Essen, 1988; Stoner & Albright, 1993). Other basic precepts (such as binocular disparity) would have critical inputs to higher order processes as well (motion and form).

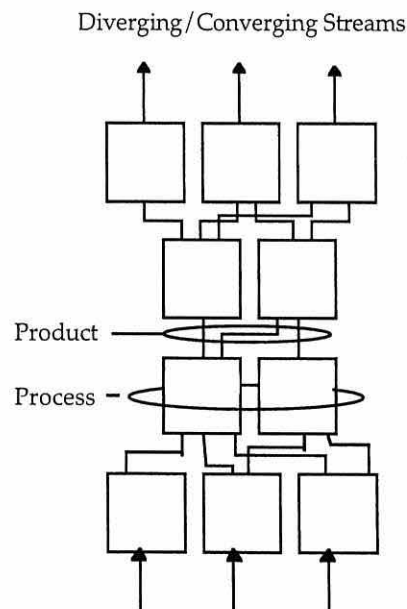


Figure 1: Concurrent processing, which shows convergence and divergence of processing streams, such that some modules are not dominated by a single input. This is based on an analysis of ascending flow signals, but is compatible with descending flow signals at some or all levels (adapted from Van Essen and DeYoe, 1995, p. 384).

□

In addition to the direct contributions of basic precepts to higher order visual processing, there are indirect contributions. Both textural discontinuities and colour changes can specify an edge or border even in the absence of any changes in luminance (Papathomas, Gorea, & Julesz, 1991). Although these examples may not be the principle source of information for the higher order processes, their contributions are effective. Non-binocular depth cues have long

been exploited by visual artists to convey depth. Having converging sources of information adds to the robustness of the visual processing system. If one cue is unavailable, others can be used in its stead.

Although concurrent processing is not the most parsimonious explanation available for the visual processing system, the additional complexity of a concurrent system is desirable for two reasons: (a) there can be efficient specialisation of function for each module; and (b) there is great flexibility in this type of design (Van Essen & DeYoe, 1995). The principle drawback for this type of design is the need for a complex system of communication between the modules. The communication necessary for this system to work is satisfied by a complex system of connections between processing modules. Within the visual system, this requirement is satisfied with each distinct visual area having (on average) 10 distinct inputs and 10 distinct outputs (Felleman & Van Essen, 1991). There are 305 corticocortical connections which have been identified, which is about one-third of all the connections possible between the 32 identified visual processing areas (Van Essen & DeYoe, 1995). Since it is clear that a complex system of communication is necessary, it is reasonable to expect that the functional advantage for this type of brain structure is desirable.

Another requirement of a concurrent processing system is an increase in processing available as items move through the entire system. If the output from one system becomes the input for multiple processing units, the available routes through the visual system would have to multiply as processing becomes more complex. Although the functional architecture of the visual system is hierarchical in nature, with the basic precepts processed during the early stages



of visual processing converging to representations of unitary objects in the visual world during the final stages of processing (Desimone & Duncan, 1995), the number of neurones involved in processing expands as the information progresses through the system. There are approximately one million neuronal projections from each LGN to area V1 (Van Essen & DeYoe, 1995). In area V1, there are about 250 million neurones (O'Kusky & Colonnier, 1982). Extrastriate areas contain an additional 400 million cells (Rockel, Hiorns, & Powell, 1980). This cortical magnification results from about 1.3 billion neurones in the visual cortex (both hemispheres) processing information from 2 million LGN inputs. This represents an expansion of 600 cortical neurones to 1 LGN input. In order for this to occur, at each stage of processing, neurones must have multiple outputs to higher levels.

In a concurrent processing model, the flow of information between an input and output stage has various intermediate stages of processing which may use the same, or different, inputs from lower stages. This does not imply a linear ascending processing model: descending signals could be incorporated at any or all of the levels within the system.

### *Attentional Selection*

Within the context of this thesis, selection means that a product has been targeted as being singularly important either for the next stage of processing or for report. These may seem to be two different processes, but they can be seen as the same thing. If the system is required to detect the presence of a white target, and if the product of a processing module indicates a positive change in

luminance, that product can be selected to meet the report requirement. This in no way precludes further processing of other features of the item, but the necessary product of processing has been targeted and this information can be made available for report. If the goal of processing is to identify a white target, the product of the processing module indicating a positive change in luminance is only a part of the complete picture, and in and of itself, is not sufficient for report. It must be targeted and selected, not for report, but in order to delimit the item that is to be identified. This does not imply a two-stage model of processing, but it does imply that at least two processes are necessary to complete the particular task. Selection is the targeting of a processing product as important to the goal of the organism.

Before selection within a concurrent processing system framework can be considered, a better understanding of what selection is will be provided through a brief overview of the major theories of attention. Following this, some of the basic findings important to the basic paradigm used for the experiments in this thesis will be visited. At that point, a proposal for selection will be discussed.

In behavioural literature, the process of selection and the process of attending to stimuli are thought of as the same function. Attention has been defined in many ways (Allport, 1993) with little agreement between experts as to what the observed phenomenon really is. The most traditional viewpoint, as proposed by Broadbent (1958), implies selective admission of information to some limited capacity processing unit. Attention is the selective process or the mechanism by which information is selected for further consideration by a processing unit of limited capacity. The logical extension of this is that the

purpose of attention is to protect the limited capacity processor from overload by limiting the amount of information that has access to the processor.

This traditional viewpoint has played a central role in research in the area for many years. Broadbent's (1958) original theory was couched in terms of the psychological research current at the time. He articulated his theory within the framework of information processing, learning theory and Gestalt psychology. He proposed the idea of capacity limitations to explain the observance of interference when "one chain of events physically excludes another" (Broadbent, 1958, p. 6). The latest technology of the day -- telephone systems -- was used as a metaphor of how the human brain processes information. The capacity of the nervous system leading to the information processing centres of the brain was thought to consist of a single communication line. Naturally, there would be limitations as to the amount of information this line could carry, and as a result, there were capacity limitations. Because of this limited capacity, selection had to occur before the information entered the channel.

The selection mechanism envisaged by Broadbent (1958) was placed at the input end of the communication channel. The selection was for information from all the sensory modalities "having some feature in common" (Broadbent, 1958, p. 297). In other words, Broadbent made allowances for an object having many attributes from different sensory modalities (texture, sound, colour, etc.). The mechanism did not operate randomly, but appeared to be biased either by top down goals or by certain physical properties of the stimulus (e.g. intensity). In addition to the selection mechanism described here, Broadbent made allowances for the feedback of information and observed that the shift of

attention from one event to another would take time. Figure 2 illustrates this process.

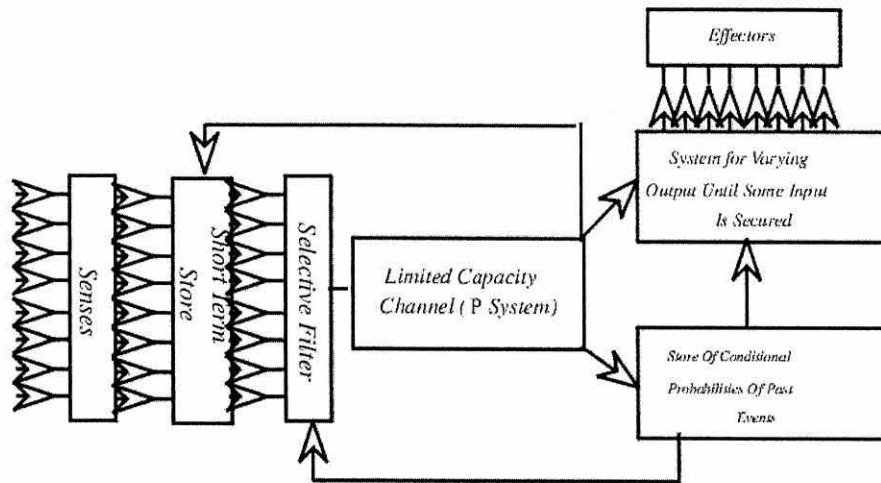


Figure 2: A schematic showing information processing from Broadbent (1958, p. 299). Sensory information enters on the left and proceeds serially to the right.

Developments in attentional research led to changes in the filter theory of attention. Treisman (1960) found that when participants were shadowing a prose passage in one ear, if the passage was switched to the other ear, the shadowing briefly followed the passage to the unattended ear. According to Broadbent's theory, this should not happen. Because of the capacity limitations inherent in the system, the filter needed to be complete. Treisman therefore proposed a modification to the theory in order to explain this anomaly; this modification involved thresholds and attentional weightings.

Treisman's (1964) theory involved the following. Dictionary units in the nervous system have corresponding semantic meanings, and these dictionary units have different perceptual thresholds depending on both the dictionary units salience and probability. If a dictionary unit (word) has a high probability

(or salience), the threshold for that unit is lower than other units. Because the firing threshold is lower, less perceptual information is needed to activate that unit.

Although Treisman (1964) explicitly supported the idea of an attentional filter occurring early in the processing system, by allowing different words to have different perceptual thresholds, she introduced the idea of multiple locations for attention to select information for further processing.

Treisman (1969) further enlarged the area of study by suggesting that selective attention is not a single, unitary process; instead, she said, it is a series of processes. She outlined four different functional aspects of attention: (a) to restrict the number of inputs to be analysed; (b) to restrict the number of feature dimensions to be considered (e.g. colour and shape); (c) to restrict analysis to particular sets of features (e.g. red and round), or feature conjunctions; and (d) to select which of all possible results of the perceptual processes controls access to responses and memory.

Along with her earlier modifications to Broadbent's (1958) theory, Treisman's (1969) articulation of the several mechanisms involved in selection suggested that attention is more complex than had been originally envisaged. Once again, she appeared to be suggesting that attention operated at more than a single locus within the processing system (Johnston & Heinz, 1978).

At the same time as Treisman (1969) was articulating her theory that attentional selection is multifaceted, Moray (1969) presented evidence to support Broadbent's (1958) original filter theory. He suggested that the findings which were problematic for the original Broadbent filter theory could be explained if

the speed at which the filter could switch between inputs was fast enough. Because evidence (see below) was mounting for a different theoretical approach to attention, the problem could be settled only when there was clear evidence for either attenuation of inputs -- as a filter would suggest -- or enhancement of selected processes. During the 1970s, it was felt that there was no way, in principle, to answer two questions: (a) were non-selected incoming messages inhibited in some way? or (b) did the selected information enjoy some enhancement in processing? Whenever there was valid evidence supporting one view, there was equally valid evidence supporting the other.

The idea for informational enhancement arose from work which showed that the filter proposed by Broadbent (1958) was incomplete (Treisman, 1960). As Cherry's (1953) work demonstrated, in a noisy environment (a party) a salient stimulus, such as one's own name, can attract one's attention away from a conversation to which one is attending. This is called the *cocktail party phenomenon* (see also Moray, 1959). Although Treisman (1964) proposed modifications to Broadbent's filter theory to account for this, another possible explanation was emerging. If all the information to which the sensory organs are exposed is processed to at least a semantic level of understanding before selection takes place, all the observed anomalies in selection can be accounted for. With this theoretical approach, there is no need to have items filtered out; rather, selected items, or features, enjoy enhanced processing to reach the final stages of processing.

Deutsch and Deutsch (1963) were the first major proponents of an enhancement theory. They suggested that all information is processed, and that

attentional filtering takes place after semantic information has been extracted. Selection is dependent on a comparator unit that favours the object enjoying the most activation. The object that receives the most activation is the object that reaches consciousness. Deutsch and Deutsch presented neurophysiological evidence that indicated that there is no attenuation of evoked potentials to be found at an early processing level in the brain. When attention is being directed at an object, there is an enhancement of the signal associated with that object, but no concurrent diminution of the evoked potentials associated with distracter objects, as suggested by a filter theory.

Deutsch and Deutsch's (1963) late selection theory was the most serious challenge to Broadbent's (1958) filter theory for the next 20 years. The two alternatives (Broadbent's early selection, filter theory and Deutsch and Deutsch's late selection theory) became the focus of the search for a selection mechanism that resides in a particular place in the brain.

Kahneman's (1973) late selection theory of attention introduced a different idea for the limitations of processing. In his theory, selection is dependent on the effort (or arousal) of the individual. The limiting factor in this model is processing capacity. As arousal increases, processing capacity increases. As the demands for processing capacity increase, the capacity increases through the application of effort (or attention) -- though this is within limits. The model asserts that processing capabilities are far more complex and flexible than either early or late selection bottleneck theories allow. Having stated his support for a more flexible model of attention, Kahneman's capacity model falls in line with late selection theories rather than with early selection theories.

Significant support for late selection was found in the work of Duncan (1980). He found that selection could be made both quickly and efficiently on categorisation information (digit among letters); this was important because categorisation was supposed to take place after an early selection bottleneck. He also found that the correct rejection of a non-target item presented simultaneously with a target item during a divided attention task led to a greater chance of a hit for the target item. If there was no way to reject a non-target item based on purely physical features, the rejection had to take place prior to an attentional bottleneck. Both the categorisation and the divided attention evidence strengthened the late selection theorists.

In addition, Duncan (1980) found that selection could be manipulated such that it would take place after all the items (targets and non-targets) were processed to a level of conscious awareness (or very close to it). This was accomplished by manipulating the complexity of the selection cues. This proposition becomes an important element in the development of this thesis.

Pashler's (1984, 1991) work on the psychological refractory period (PRP) has for many years been interpreted as lending support to a late selection bottleneck. The PRP is found when speeded responses are required to both of two presented stimuli. The PRP finding is that the speeded response to the second of the two stimuli is delayed the closer the second stimulus follows the first in temporal sequence. A correlation between the two speeded responses is also observed. Over the years, this delay in processing or the PRP has been attributed to a variety of sources.



Two principle explanations have been proposed for the PRP: a bottleneck in processing (Pashler, 1991) and a graded sharing of capacity between tasks (Kahneman, 1973). The locus of the bottleneck has been the matter of some debate: Broadbent (1958) proposed a perceptual bottleneck, while Welford (1952, 1980) favoured a response selection locus, and Keele (1973) suggested that the bottleneck occurred at the stage of response execution.

The sharing of central processing resources (Kahneman, 1973) was proposed because the response to the first item sometimes slowed along with the response to the second item. The logic was that both items are fully processed, but the demands on the central processing mechanism exceed capacity and interference occurs.

Recent evidence (Pashler, 1991; Pashler & Johnston, 1989) has demonstrated that the PRP effect is due to a bottleneck at the stage of response selection (Welford, 1958). It could be that PRP is a result of processes which co-ordinate action. Only one purposeful action can occur at a time, and, as a result, a mechanism is in place to prevent two simultaneous actions from being selected at the same time (Allport, 1993).

Although traditionally the most compelling and studied of the theories of attention, bottleneck theories which presume a need to protect a limited capacity processor are not the only theories which have been proposed. Johnston and Heinz (1978, 1979) suggested a flexible selection mechanism different from the one envisioned by Kahneman (1973). Johnston and Heinz proposed a selection mechanism that operates along a continuum from selection based on the earliest physical features processed to the full processing of all available information.

They proposed that the location where selection takes place depends upon the task demands -- the constraining factor being conservation of energy. In this way, the theory reflects some of the work of Kahneman. Energy, or effort, is a necessary part of the theory. As a result, selection is a trade-off between necessary processing and available attentional resources.

If selection can take place using a basic physical stimulus (e.g. select the red item) which is processed automatically (presumably no attention or energy is needed), it appears to take place early and with as little expenditure of attention as possible. In the model, this is the default setting: low energy (attention) and early selection. If the task demands require selection of semantic information (identification of the red item) identification takes place after the item meeting the selection criteria has been processed.

Two factors emerge from this model.

The first factor revolves around the capacity available and the amount of resources needed to resolve a processing problem. If the task is complex, such as identifying an item, the amount of resources needed to complete the task is great, far greater than the resources necessary for the detection of a simple feature. If the amount of resources needed approaches the total amount available to the system, the amount of resources remaining to carry out any additional processing will be low. As processing demands increase in complexity, which increases the amount of resources needed, the number of different objects or items that can be simultaneously processed decreases. This can be carried to the extreme where only a single object can be processed at one time.

The second factor arises because of resource conservation. Since the system is built on the basis of resource conservation, processing redundant information, such as identities, for non-target items should not occur. Johnston and Heinz (1979) found that depth of processing was positively correlated with resource use. The greater the depth of processing, the more attentional, or processing resources required. According to their model, the system is a conservative one (resource wise). Since resource conservation is one of the hallmarks of the system, processing for non-target or redundant items should take place only until enough information has been gathered to reject them as possible target items. Because the system is based on resource conservation and further processing of redundant items is a waste of resources, selection is exclusionary; this is because, once an item has been selected for processing, no other items receive further processing: there is no redundant processing. Thus, if an item does not fit a goal state, it will be rejected, with no further processing, as early as possible.

The locus at which attention operates along the continuum, from simple physical features to complex semantic relationships, is under volitional control. The cocktail party phenomenon (Cherry, 1957) illustrates this point (Johnston & Heinz, 1978). If one is engrossed in an engaging conversation, it is unlikely that one will hear anything going on around one. In this situation, in order to select a single conversation to follow, resources must be expended to filter out the extraneous and potentially interfering noise. However, if one is involved in a boring conversation simply through social protocol, one may be able to monitor several conversations going on around one for interest's sake. As a result, the

mention of one's own name, or something else with which one is familiar, will attract more resources, and one will become aware of it. This could be used as evidence that the locus of attention is under volitional control.

Modular theories are another class of attentional theories. Expressed by Allport (1989, 1993) and Duncan (1996), modular theories do not see attention as a unitary process that guides or directs processing in some centralised executive manner. Rather, attention operates in a manner specific to the task at hand. From this perspective, attention is necessary for coherent control of action (a specific task), or it is necessary to coordinate or segregate between two separate tasks. Duncan specified a model for attention wherein systems of processing operate in a competitive nature, with selection occurring within a system at the expense of other objects available for processing; this fits well with neurological findings. In addition, he proposed a mechanism for the integration of features across the various systems of processing.

In Duncan's (1996) competitive, integration theory, although the featural processing takes place within a module, it is only when the modules, or systems of processing, are integrated to settle on a single object that selection occurs. Integration across modules occurs because activation is shared between the features of a particular object. As one of the features of an object gains ascendancy within one module, activation for that object is carried to those modules that are processing features of the same object. When the activation levels for a particular feature are raised above those of competing features within the same module, the feature with the greatest activation gains the competitive advantage over other features being processed by that module.

This activation spreads from processing module to processing module for the features that belong to a particular object. As this activation spreads, the modules are integrated to all process the features of a single object.

A feature may initially gain a competitive advantage within a module because of an external cue which demands processing (e.g. a ball which is tossed at a person) or because the activation level of a feature has been raised in response to a goal state -- an internally generated process (e.g. to find a red item). In any event, once a feature gains ascendancy within a module, and that ascendancy spreads to other modules with integration around one object, the result, rather than the cause, is selection or attention to that object.

Two of these theories of attention, namely Johnston and Heinz's (1978) flexible mechanism and Duncan's (1996) competitive integration theory, will play a central role in the development of this thesis. Following a discussion of the development of the rapid serial visual presentation (RSVP) methodology used for the experiments in this thesis, these two theories, along with Van Essen and De Yoe's (1995) concurrent processing model of neurological processes, will be integrated, with specific predictions arising.

### *Rapid Serial Visual Presentation*

RSVP methodology involves the presentation of stimuli in rapid succession (6 to 30 items per second) at the same spatial location. Typically, the items consist either of words or of single characters, although other items have been presented (e.g. Intraub, 1985, with pictures, and Shapiro, 1993, with shapes). The interstimulus interval (ISI) can be varied with the stimulus duration along a

continuum from simultaneous offset and onset to variable ISIs to yield different stimulus onset asynchronies (SOAs). The typical task for an RSVP experiment involves either detecting or identifying the presence of one or more targets from among a stream of distracter items (e.g. Broadbent & Broadbent, 1987; Lawrence, 1971). The targets are delimited in some way from the rest of the stream items in order that the task (identification or detection) can take place. The target can be defined so that a filter or template is used to provide an exact match (e.g. a white "X"), or a processing dimension can be employed to define the set to which a target belongs (e.g. a digit among letters).

The advantage of using an RSVP paradigm is that temporal parameters may be varied within an experiment while the spatial aspects of a task are held constant. This type of research allows control over when a stimulus item is presented and the measurement of its effects on other items that are presented either before or after the target item. Whereas spatial attentional tasks require the responding to items presented in the spatial domain, RSVP tasks require responses to temporal arrays (e.g. Raymond, Shapiro, & Arnell, 1992). Because items are presented in the same spatial location, the need for eye movements and attentional shifts is eliminated (Young, 1984). Use of this methodology has resulted in a rich variety of findings; they are rich because they have either clarified theories based on work in the spatial domain or they have raised questions which require a re-thinking of spatially based theories.

Early RSVP tasks involved the identification of a target word in a stream of words (Lawrence, 1971). Lawrence found that it was more difficult for participants to identify an item embedded in an RSVP stream than to identify an

item presented singly for the same amount of time. He also found that when participants mis-identified an item, the most probable error they made was to name the item that immediately followed. The intrusion of the item immediately following the target item (T +1 intrusion) in place of the target item has been reported as the most common error made in RSVP tasks (e.g. Botella & Erickson, 1992; Lawrence, 1971; McLean, Broadbent, & Broadbent, 1982). Although the T +1 intrusion error is the most common error made, there are other error patterns observed in RSVP research. The item reported as the target item may precede the target item in the RSVP stream (pre-target intrusion), or there may be a symmetrical pattern of intrusion errors both preceding and following the target item.

The predominance of post target intrusion errors has been used to substantiate detect-then-identify models of processing (Broadbent & Broadbent, 1986; Gathercole & Broadbent, 1984; Lawrence, 1971; McLean, Broadbent, & Broadbent, 1982). The first stage of processing involves the detection of the target item from among the other stream items. Following the detection of the key feature used to delimit the target item the item is then selected for identification. If processing resources are strained, the selection process might choose the item immediately following the target item for identification. The incorrect report is a T +1 intrusion error.

Less common intrusion errors than the post target intrusions are the pre-target intrusion errors, which are usually combined with post-target intrusion errors to produce a symmetrical pattern of pre- and post-target errors. This pattern of errors has been observed in RSVP tasks involving pictures (Intraub,

1985), filtering (Botella & Erickson, 1992), and selective sets (McLean et al., 1982). Two-stage models of the detect-then-identify kind cannot account for symmetrical intrusion patterns. A different explanation is rooted in the work of Keele and Neill (1978), who 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. demonstrated that differential processing speed could not account for different intrusion patterns when they reversed the role of the key feature and the report feature; they found that post-target intrusions predominated in both cases. According to Keele and Neill, there should have been post-target intrusions in one case, and pre-target intrusions in the other. Duncan (1980) suggests that the key feature may always precede the report feature into visual short-term memory (VSTM), where selection takes place. This explanation implies the task demands are more important than the features themselves in determining the order of processing.

Another finding reported by virtually all the single target RSVP tasks is the time taken for processing. Since there are rarely intrusion errors reported outside the target  $\pm 100$  ms range, the conjunction of the key and report features must be largely completed within that time frame. If this were true, then the processing mechanisms would be free to process items that followed at least 100 ms after a target item. The results of many dual target tasks have indicated that this is not the case. Processing deficits are observed well beyond the 100 ms range, and in some cases have been seen to last for up to a full second.

Multiple target RSVP research examines the effect of processing one target on the processing of subsequent targets. Broadbent and Broadbent (1987)



found that there is a processing deficit that follows the successful processing of a target presented in an RSVP stream. They found that when the two targeted items occur either temporally adjacent or within close temporal proximity, participants can correctly identify one of the targets but not both. As the temporal distance between the two items was increased, the probability of correctly identifying both targets increased. When the temporal interval was less than 400 ms, the proportion of trials when correct identification of both items occurred was often as low as 0.1. As the temporal separation reached as long as 720 ms, correct identification of both items reached to about 0.7. Participants in these experiments reported that on many trials they were unaware of the presence of the second targeted item in the stream. This result was attributed to the detect-then-identify mode of processing. The slow identification of the first item interfered with the processing of the second item.

Weichselgartner and Sperling (1987) observed the same processing deficit in the multiple target tasks they conducted. Their participants identified the four items that immediately followed a target item. They found that participants could identify the item that immediately followed the target item, but the next item reported after the target tended to follow between 300 and 400 ms after. Participants missed the three or four intervening items. Weichselgartner and Sperling attributed their findings to a dual-stage model of processing. The first stage was a fast process triggered by the detection of the first target item; this resulted in near perfect identification of the target itself, and usually the item immediately following; this was followed by a slower, more effortful processing stage which was sustainable over a longer period of time, but took several

hundred milliseconds before it was fully activated. The deficit that was observed was caused by the rapid decline of the first mechanism; this occurred before the second mechanism became fully functional.

After their initial investigations into this processing deficit, Raymond, Shapiro, and Arnell (1992) named the deficit the attentional blink (AB). They initiated an in-depth examination into the AB in order to understand both the nature and function of the deficit (see e.g. Raymond, et al., 1992; Raymond, Shapiro, & Arnell, 1995; Shapiro, Raymond & Arnell, 1994; Shapiro & Raymond, 1994). The standard paradigm used for many of these experiments involved detecting or identifying the first target item (T1) and then detecting the presence of the second target item (T2). Using this procedure they were able to establish four characteristics of the AB: (a) they ruled out memory effects; (b) they established that it was an attentional effect rather than a perceptual masking effect; (c) they showed that Weichselgartner and Sperling's (1987) two-stage explanation could not explain the deficit (Raymond, et al., 1992); and (d) they determined that the T1 difficulty did not affect T2 performance (Shapiro et al., 1994). All of these findings are accepted as valid except for the last. Research by Seifert and Di Lollo (1997) showed that T1 difficulty (manipulated through low level masking) affects T2 performance, although, once again, recent work does not support this (McLaughlin, Shore, & Klein, 2001). McLaughlin et al. concluded through a series of studies that although masking may have an effect on T2 performance, T1 difficulty, as defined by perceptual quality, did not effect T2 performance.

The original theoretical basis for the AB proposed by Raymond et al. (1992) has not withstood systematic scrutiny. The original explanation involved an inhibitory mechanism which was invoked in order to prevent too many of the RSVP stream items from entering VSTM and interfering with T1 identification. This inhibitory mechanism was triggered by the arrival of the item immediately following the T1 item (T1 +1). Because the T1 +1 item posed a potential threat to the processing integrity of the T1 item, the inhibitory mechanism was initiated to keep all other items from interfering. Work by Shapiro et al. (1994) demonstrated that the detection of a white T1 item resulted in an AB. Because there was no identification necessary (participants reported only the presence of a white item), and yet the AB was still present, Shapiro et al. (1994) proposed a new explanation involving interference rather than inhibition; this was based on Duncan and Humphreys' (1989) distracter similarity theory.

According to distracter similarity theory (Duncan & Humphreys, 1989), processing interference is based on the similarity that items have to each other. If items are similar to each other (i.e., if they both match a template for selection), they will cause interference in processing. The more two items match the selection template, the more difficult they are to discriminate. Similarity, which can result in interference, can occur between the target and its distracters or between targets. If the distracters are very similar to each other, but bear little resemblance to the target, there is little interference observed, and the target item can be processed more efficiently. However, if there is a heterogeneous distracter set, the target will be more difficult to process: the selection template may not be able to reject all of the distracter items at once.

According to Shapiro et al. (1994), both the target items are selected for processing in VSTM; this is due either to their perceived similarity or to the fact that they both match internal templates for selection. Because of the close temporal proximity to the two critical items, the T1 +1 item and the T2 +1 item are also selected. The AB is then a result of interference caused when there are more items in VSTM than are necessary. On a proportion of the trials, the item selected for response from VSTM does not match the template for the T2 item and the participant does report not detecting a T2 item even though a T2 item was present.

An alternative explanation for the AB has emerged from the work of Chun and Potter (1996); this is based on Broadbent and Broadbent's (1987) two-stage model of processing. In the modified two-stage model, there is a rapid first stage that detects the presence of the target's key feature and a slower capacity limited second stage for consolidation. If an item is detected by the first stage while the second stage of processing is engaged, the rapid decay of information within the first stage will make the information unavailable for the second stage on some proportion of the trials. This rapid decay of information in the first stage of processing is expressed as the AB. Although the two-stage model has elegance, after the initial first stage of parallel processing, it is a serial based model of processing. Isaak, Shapiro, and Martin (1999) have results that suggest a parallel model of processing and provide support for an interference-based model of the AB.

Isaak et al. (1999) found that when participants attempt to identify the T2 item, the errors that occur within the AB could be evenly distributed between all

of the items presented within a minimal RSVP stream. A minimal RSVP stream consists of the essential items that are necessary to cause an AB (Duncan, Ward, & Shapiro, 1994; Ward, Duncan, & Shapiro 1996). The necessary items include the first and second targets, along with the items that immediately follow them. Thus a minimal stream is made up of four items, T1, T1 +1, T2, and T2 +1. The findings of Isaak et al. include T2 report errors of items that precede the T2 item. According to the two-stage model of processing, the identities of items are consolidated after the detection of a key feature. The two-stage model predicts that T2 intrusion errors occur following the detection of the T2 key feature. It is difficult to imagine how a two-stage model of processing could account for a T2 intrusion that would occur after the T1 item and immediately before the T2 item. A more plausible explanation, as mooted by Isaak et al., is that both the T1 and T2 items are processed to some degree, and the items interfere with one another at a later stage of processing (VSTM) -- when the T2 key feature is to be conjoined with one of the items.

There has been evidence accumulated to support processing during the AB. Maki, Frigen, and Paulson (1997) used semantically related word pairs to demonstrate that a T1 item would semantically prime a T2 item, even when it occurred in the depths of the AB. In addition, they showed that a semantically related distractor occurring prior to a T2 item also primed T2 processing within the AB (see also Shapiro, Driver, Ward, & Sorensen, 1997).

Shapiro and Luck (1999; and see Luck, Vogel & Shapiro, 1996) used event related potential (ERP) data to show that there was semantic processing during the AB. Through the presence of the N400 wave for targets present during the

AB they demonstrated that words were processed to a level of semantic understanding, even though the items were subsequently unavailable for reporting.

As further evidence of processing during the AB, personal names are reported as T2 items during the AB (Shapiro, Caldwell, & Sorensen, 1997). Participants in these experiments were instructed to look for personal names as a T2 task. When the participants encountered their own personal name, there was no AB deficit observed.

Recently, Allport and Hsieh (2001) have looked into the effects of task switching on target performance as an explanation for the deficit observed during the AB. They used a variant of the RSVP dual target task used in most AB research. Although a participant always had two tasks to perform, the two targets did not always occur. A cue which occurred during the presentation of the RSVP stream signalled the time when the participant needed to switch from monitoring the stream for the first target to monitoring the stream for the second target. A drop in accuracy followed by a gradual recovery was observed in the RSVP positions immediately following the cue. It has been suggested that the AB deficit is, at least in part, accounted for by a criterion shift between the two targets.

Jolicoeur (Jolicoeur, 1998; Jolicoeur, Dell'Acqua, & Crebolder, 2001) has argued that the AB deficit is the result of a central processing bottleneck akin to the deficit found in psychological refractory period (PRP) studies (c.f. Pashler, 1984). Through a series of experiments, he found that, among other things, there was a correlation between T1 and T2 performance at short SOAs (under

speeded conditions). This correlation is used as evidence that the at least some of the deficit observed during the AB is similar to the deficit observed during the PRP. The PRP deficit is a central processing bottleneck, and Jolicoeur argues that some portion of the AB deficit observed is attributable to this central bottleneck.

Within AB research, there have been clear demonstrations of what appears to be late selection supported by parallel processing. Although the demonstrations are clear and convincing, they often tend to account for a portion of the observed deficit (e.g. the effect size of the priming found in Shapiro et al, 1997 is statistically reliable, but very small). The evidence suggests that parallel processing and late selection theory can be used to account for some of what is happening within the AB; however, this theory cannot account for the entire observed deficit. The main attraction of the arguments for having either an early or a late selection model have revolved around parsimony. Although a single explanation for selection might be desirable, it is not in accordance with behavioural findings supporting both extremes, and neither is it supported by physiological evidence. As stated earlier, over the last 30 years there has been a consensus emerging that selection occurs along a continuum rather than at either end of the spectrum of possibilities (Allport, 1993; Desimone & Duncan, 1995; Johnston & Heinz, 1978; Treisman, 1964).

Choosing various parts of three different visual processing hypotheses, a coherent viewpoint of the visual selection process will be presented. This new, emergent hypothesis will then be tested. The three component parts of the hypothesis will first include (a) components from the modular structure proposed by Van Essen and DeYoe (1995) (concurrent processing system), which

will serve as a basic structural framework for my visual processing system; (b) the functionality envisioned in Duncan's (1996) competitive integration hypothesis will then be incorporated into the structure; and finally, (c) the flexible selection mechanism proposed by Johnston and Heinz (1979) will be used to complete the picture. Each of the components, and how they fit together, will be discussed below.

Van Essen and De Yoe's (1995) concurrent processing system is a structural framework that is based largely on physiological work. The model is made up of multiple processing modules connected by streams of processing which converge and diverge throughout the visual system (see Figure 3C). This is a modification of either a straight parallel (independent) stream processing model (Figure 3A) or even an interacting parallel processing model (Figure 3B), both of which support a late selection theory of attention.



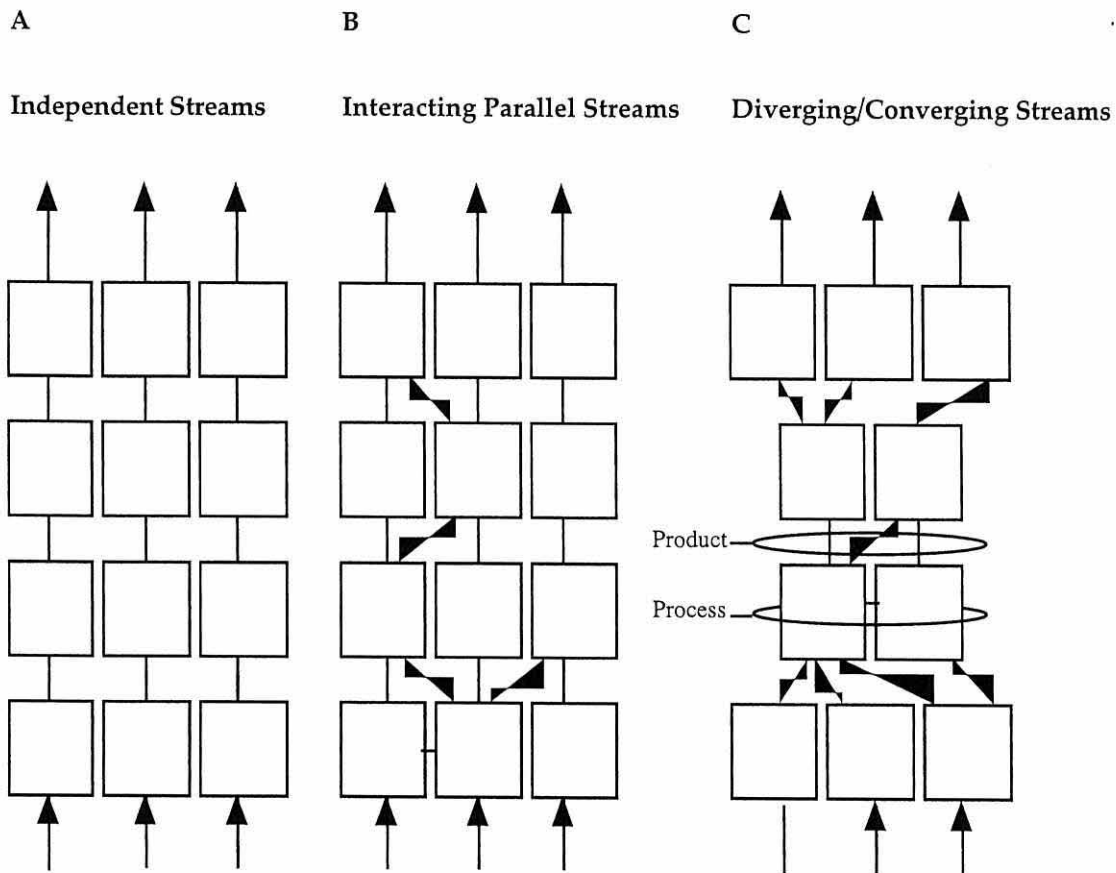


Figure 3: Three conceptually distinct types of concurrent processing, each which involves a set of processing modules (boxes) interconnected by lines which represent their inputs (products). (A) The simplest arrangement is one in which each processing stream is completely independent of the others. (B) An alternative pattern involves streams that have significant cross talk with one another but nonetheless are dominated by “main-line” pathways and thus remain parallel to one another. (C) A third pattern shows a greater degree of convergence and divergence, such that some modules are not dominated by a single input. Note that these distinctions are based on an analysis of the ascending flow signals, but each scheme is compatible with descending signals at some or all levels. (Van Essen & Deyoe, 1995, p. 384).

In the concurrent processing model (Figure 3C), the flow of information between an input and output stage has various intermediate stages of processing which may use the same, or different, inputs from lower stages. This does not

imply a linear ascending processing model; descending processing signals could be incorporated at any or all of the levels within the system.

As the various processing streams converge on one of the processing modules, there is a possibility that interference will be observed. Because of the number of features that normally make up an object, there is great flexibility in the system. Under normal conditions, information can be accumulated over time, and the components that make up a complete representation can be gathered. Top-down memories can also be used to "fill in" features which may suffer from interference during processing. Van Essen and DeYoe (1995) also propose that the processing modules have overlap in their products. This redundancy in processing, along with the other reasons mentioned above, means that, under normal conditions, the system is robust.

Duncan's (1996) competitive integration model of visual processing adds specificity to the concurrent processing model. Within each of the processing modules, stimuli compete with one another for processing resources. The competitive processing results in a feature gaining ascendancy over other features. This ascendancy is at the expense of any other features which might potentially be processed by that module (the use of features within this context represents whatever the product of the module might be, whether a single feature or a combination of features, the principle is the same). The output from any one module will be one feature belonging to an object. Once the competition within a module is settled by the ascendancy of a feature of one object, activation for that object is spread to other modules via the rich network

of communication channels in order to ensure the competitive advantage for all of the features associated with that object.

As each of the modules completes its task within the processing system, more information is added to complete the internal representation of the object. The default of the system is to emerge with complete representations of objects. Research has shown that visual processing appears to be object centred (e.g. Duncan, 1980; Kahneman, Treisman, & Gibbs, 1992). Although full object representation is the default of the system, selection can interrupt the processing system at almost any stage of processing. This is where the ideas of Johnston and Heinz (1979) become relevant to the hypothesis.

Johnston and Heinz (1979) proposed a flexible selection mechanism in which the task demands, or goal states, are the overriding consideration. Selection was earlier defined as being "a product of processing which has been flagged as being singularly important for the next stage of processing". The selection process is driven by either internally generated goal states or externally mediated demands. In either case, selection is simply the flagging of a processed product as being important for the next stage of processing.

Johnston and Heinz (1979) found that, as processing progresses through the visual system from early featural processing to complex full representations, the demands for processing resources increase. As they proposed that the system is based on resource conservation, there is no allowance for the continued processing of non-selected items once selection has taken place. This makes selection an exclusionary process. Although more complex processing is more resource intensive, it does not necessarily follow that the system is based

on resource conservation. If the system is not based on resource conservation, then selection is non-exclusionary. If there are resources available, they will be used in processing whatever items are available for processing.

Within this model, more resources are needed as processing proceeds through the visual system, because the processing for an object propagates to different processing modules. As the processing propagates, it also becomes more complex, with the complexity itself demanding more inputs, and, as a result, more resources. In addition, resources are required to maintain the integrity of an object across the various processing modules.

The basic model then is as follows. There are many processing modules within the visual system with, a processing module being defined as a system of processing which has inputs of one kind, which after processing, emerge as a product which becomes the input for another processing module. Given this definition, there is a hierarchy of modules from basic feature detecting units to the entire visual system. For the purposes of this discussion, modules are basic units that receive inputs, carry out a process, and pass information on to another module for further processing. These processing modules potentially have several inputs and several outputs. The processing within each module is competitive, in that the product will be for one object only. This means that the competitive nature of the visual system itself will result in single objects being the output. This competitive processing feature means that, whenever there are multiple inputs into a module, there is a potential for interference. If the inputs come from more than one object, the feature belonging to the object which enjoys the competitive advantage as a result of integration will enjoy a

competitive advantage as an input to a module. Eventually a single object will gain ascendancy across all of the processing modules.

The convergence of processing onto a single object means that, as processing proceeds through the system, large amounts of resources are concentrated on single objects. Early in the processing stream, processing resources are widely allocated across a variety of features rather than on single objects. Selection based on a physical feature that can be processed with very little or no interference from other processing modules will enjoy a higher level of activation. This higher activation serves as a focus for the integration of other features that belong to the same the object. When there is interference where processes converge, single objects may not be unambiguously selected as target items. As a result, the visual system must attempt to allocate resources in such a way as to process as many items as possible, looking for breadth of coverage so as to probabilistically include the targeted item, rather than to process a single selected item in depth.

Selection takes place within this system on the outputs or products of module processing. At any point within the system, a product (which will belong to an object) can be selected as being singularly important for further processing. Once selection takes place, the object associated with the selected feature will enjoy a competitive advantage across all the modules as the processing is integrated around that object. Although integration and single object processing is the default for the system, due to its competitive nature, selection can interrupt that processing. As an example of this, consider the rejection of non-target distracters. In an RSVP stream, these occur at high rates

and can be discarded as potential targets with a minimum of interference. Although, at some level, they must be selected so as to judge their fitness as targets, in most cases, they are rejected before becoming fully represented. That does not mean that none of the items reach conscious awareness, but it does mean that object primacy does not cause a great amount of interference for the efficient selection of the targeted item.

In addition, within this model selection is not exclusive. As an example, according to this prediction if the task is to detect a luminance change (detect the white object), once the luminance change has been selected, processing of other features not belonging to the white object (the selected target) does not immediately cease. If there is another item that has a chromatic value (a red item), the colour is processed, even though it has nothing to do with the targeted item. This is possible because the module associated with luminance changes interferes only slightly with the module for processing colour. Finally, the selected value is available as an input to the next level of processing immediately following the selection. If the selection criterion is whiteness and the response is reporting the presence of whiteness, once selection is successful the response "whiteness" is available for execution irrespective of whether other attributes of the object are ever represented. Although full object representation is the default, the representation of the selection criterion can be made in the absence of full object processing.

The final aspect of the model is how it works in relation to resources. As objects progress through the processing system, the more complex processing requires more resources than the basic featural processing (Johnston & Heinz,

1978, 1979). Although pre-attentive processing is thought to be resource independent, within this model pre-attentive refers to basic featural processing for which the available resources almost always exceed the processing demands. In addition, when processing demands are great due to external factors (degraded stimulus, noisy environment, limited time, etc.) more resources are needed to meet the demands. As specified above, as processing becomes focused on a single object, processing resources become tied to maintaining the integrity of that object, and processing it to whatever depth might be allowed before another selection cue is recognised which will interrupt further processing.

Three predictions for the AB deficit observed during RSVP trials can be made from the model presented.

First, if the processing module necessary for detecting the presence of the key feature necessary for selection of the second targeted (T2) item is engaged in processing the same feature belonging to the first target (T1), the selection cue will be missed. This first prediction states that if the two targeted items share a basic feature which is the key selection feature for the T2 item, the processing of the same feature for the T1 item will interfere with the processing of the key feature for the T2 item. The classical "detect T1 letter, detect 'X'" experiments were the result of this type of interference. The T1 letter has an identity that is being processed in the "identity" processing module when the T2 item is presented for processing. This results in the identity of the T2 item being missed, and an AB occurs. However, if the T1 item and the T2 item do not require the

same processing module in order to complete the task, an attenuated AB (or possibly no AB) will be observed.

The second prediction is that if the selection cue for the T2 item is processed, but the task demands are such that the same modules are required for both the T1 and T2 targets, the primacy of the T1 item will interfere with the second target, preventing it from receiving the resources required for full processing. This means that there will be times when the participant will be fully aware of the occurrence of the T2 key feature, but because of the processing taking place on the T1 item, the T2 key feature will be attributed to the wrong item.

The final prediction (not specifically for this model) is that, if the selection key feature is processed, and the necessary information for the first target has already been processed, the second target can be processed, although with some interference; this is because it must overcome the ascendancy enjoyed by the first target which is already being processed. This is closely related to the second prediction, but the reason for the interference is fundamentally different.

This model of visual processing can be tested using the RSVP procedure in specific ways. If multiple inputs to a processing module is one of the causes of interference, and if there is non-competitive access to a processing module for the selection cue or target defining feature, reduced or no interference should be observed. This is analogous to a pop-out effect in spatial processing. The feature which pops-out of the display does not suffer from interference from other items which do not contain the same feature (Treisman & Gormican, 1988) because the processing module necessary to detect the presence of the pop-out feature does



not suffer from interference from other features. The prediction, under this model, is that, if the feature for the selection of the T2 item is unique and different from any of the features of the T1 item, there should be an awareness that a T2 item has occurred.

This has been implicitly acknowledged in the AB research area as ineffective masking. If the selection feature for the T2 item is not effectively masked, there is no AB (Giesbrecht & Di Lollo, 1998). Joseph, Chun, and Nakayama (1997) explicitly tested whether a pop-out T2 item could be detected within the AB. They found that participants could not detect a pop-out stimulus when it occurred as the second target in a dual target task within 500 ms of the first target. The first critical item was selected at fixation from among items being presented at rates of between five and eight items per second -- a difficult task requiring very focused attention. The T2 task involved detecting an "oddball" orientation from a Gabor array surrounding the fixation spot at 5.3° of visual angle. An explanation for this finding is proposed by Zenger, Braun and Koch (2000).

Zenger, Braun and Koch (2000) also found that in the absence of attention, Gabor arrays that normally pop-out from the surround, were not processed. There was a primary target task occurring at fixation, with Gabor arrays 4° from fixation. They concluded that the reason the oddball orientations did not pop-out from the display was because V4 receptive fields become smaller when attention is directed to the fovea (Morgan, Ward & Castet, 1998; Yeshurun & Carrasco, 1998).

If a unique feature can be processed, when a T2 item occurs within the depths of the AB, if the key feature is a unique feature and even if the item itself is missed, the item which will be most likely to be processed as the T2 item will be the item immediately following the T2 item. The reason for this is that, although the key target defining feature for the T2 item has been processed in a processing module which does not suffer from interference from T1 processing, the other features associated with the T2 item (and necessary for report) may have to be processed by modules for which the competitive advantage has been won by the T1 item. This competitive advantage must be overcome by a new item. Even if the item immediately following the T2 item is temporally within the AB caused by the first target (within about 400 ms), the features necessary for report will be able to gain ascendancy over the T1 features. This means that items that fall within the AB will be processed and reported, even though they may be errors.

In contrast, there is a different prediction for the processing of items when the T2 key feature which is not unique. If there is a processing module critical for both the T1 item (either report or detection) and the T2 key feature, there will not be an item which will reliably replace the T2 item when it is missed. In other words, if the T2 key feature is not processed unambiguously, the T2 item will be chosen from among all of the items processed. The T1 item will be a likely candidate because of the greater likelihood that the identity of the T1 item will have been processed as a result of the selection of the T1 item, but that identity may not have been adequately bound to the T1 defining feature.

*Experimental Rationale*

In Experiment 1, reduced interference is demonstrated with the T2 delimited feature being an additive feature. Treisman and Gormican (1988) concluded that additive features activate unique processes, and it is the product of these unique processes which is selected with little observed interference from other processes. Using a unique T2 feature, I predict that the interference observed in an AB task will be qualitatively different from the interference observed if the T2 item is delimited with a subtractive feature (as in Experiment 2).

The interference observed in Experiment 1 should be similar to the interference which is observed in a single target RSVP task. Interference in single target RSVP tasks is largely confined to the item immediately following the targeted item (Botella & Erickson, 1992; Broadbent & Broadbent 1986). Since the predicted dual task interference is no different from the predicted single task interference, the processing deficit observed can not be due to direct processing interference between the two principle items; it must be due to single target interference which has been augmented by the general lack of resources (as opposed to interference within a specific processing module) due to the processing requirements of the other target task.

If the interference were to arise as a result of converging processes (Van Essen & De Yoe, 1995) for two different items requiring the same resources, based on the model described above, the prediction is that the observed interference should be observed as reporting the item which demands the same resources. In the case of the dual target task, rather than reporting the item

immediately following the T2 item (as in the single target case), the item demanding the same resources necessary for processing the T2 item (the T1 item) is the more likely candidate for report. This is a difficult demonstration to make because of the probabilistic nature of the AB. If the AB was an absolute phenomenon, and on every trial in which two targets were presented the second target went unobserved, one would expect to see T1 interference on a high proportion of trials. The AB is not an absolute deficit, and on some proportion of the trials when two targets are presented, both targets are successfully processed. This means that, even though the interference is maximised, some of the T2 misses will result in T2 +1 intrusions -- just as in the single target trials -- and some of the T2 misses will result in T1 intrusions. What is expected is a difference in the rate of T1 intrusions between the two cases, with the subtractive T2 key feature resulting in the higher T1 intrusion rate.

Experiments 3, 4, and 5 are designed to demonstrate differences in interference when the T1 and T2 items are defined in order to invoke concurrent processing. In Experiment 3, the T1 and T2 defining features will be selected as features that would result in convergent processing (task demands converging on a single processing module). The prediction is that T2 performance in Experiment 3 will result in a significant amount of observed interference from the T1 item. This is contrasted with Experiment 4, in which the defining features for the T1 and T2 items will not require the same resources and should be able to be processed without a great amount of interference from the T1 item. This lack of direct T1 interference will be observed as a lack of T1 intrusion errors when the T2 item is reported. Experiment 5 is designed to demonstrate an asymmetry

in processing, with minimal interference contrasted with maximal interference when the targeted items are reversed.

## General Methods

### *Apparatus*

The stimuli were generated by an Apple Macintosh computer<sup>1</sup> using custom software and displayed on an Apple colour monitor. The monitor resolution was 832 X 624, with a pixel size of .28 mm. There were 28 pixels per cm. The screen refresh rate was 75 Hz; this resulted in a refresh every 13.33 milli-seconds. Participants viewed the display binocularly from a distance of 35 cm and stabilised their head position with the aid of a chin rest.

### *Participants*

In Experiments 1 and 2, participants were undergraduate volunteers from the University of Calgary Psychology Department participant panel. In Experiments 3, 4 and 5, participants were undergraduate volunteers from the University of Wales, Bangor School of Psychology participant panel who took part for course credit. All participants had normal or corrected to normal vision. Informed consent was obtained from all participants.

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<sup>1</sup> An Apple Macintosh II was used in Experiments 1 and 2, while an Apple Macintosh Power PC 9600 was used for Experiments 3, 4 and 5.

*Design*

In all five experiments, the same three-factor mixed design was used, with T1 task (detect, ignore) as a between-participants factor, T1 (present, absent) as a within-participants variable, and T1-T2 SOA (160, 240, 320, 400, 480, 560, 640, or 720 ms) as a repeated-measures variable.

*Procedure*

Each participant took part in a series of RSVP trials. Each trial consisted of four successive block-style alphabetic characters designated the T1, T1+1, T2, and T2+1 items. The characters were displayed singly at the centre of a uniform field. All standard sized characters were 0.4° in height and approximately 0.25° in width. All stimulus and ISI duration's were determined by the refresh rate of the computer screen.

On a random half of the trials, an item randomly selected from the T1 set appeared with the T1 defining key feature (depending on the experiment, colour, size, or luminance). On the remaining trials, an item from the same T1 set appeared but with no T1 defining feature. In other words, the participant was exposed to a T1 item on half of the trials within a session (the two trial types were not blocked). The subsequent T1+1, T2 and T2+1 items were randomly drawn from their respective letter sets. The key feature marking the T2 items was varied across the experiments. The item sets were mutually exclusive to ensure that none of the items would reoccur in the RSVP stream and to ensure

that T2 identification errors could be unambiguously attributed to intrusions by T1s, T1+1s, T2+1s, and importations.

Participants initiated trials when ready by depressing either the space bar or the computer mouse button. A small white fixation dot was in the centre of the background field until each trial started. Each trial began with the fixation dot remaining present for 160 ms. A variable ISI followed the offset of the fixation dot, ranging from 560 ms to 1200 ms in multiples of 80 ms. During this and all other ISIs, the uniform background field was viewed. The ISI was followed by the T1 item on T1 present trials, or a distracter item on T1 absent trials. The T1+1 item followed the T1 item with a 80 ms SOA. When the items occurred, the item was displayed for 40 ms followed by a 40 ms ISI, in order to maintain a consistent SOA of 80 ms. The T2 item then occurred following a variable ISI, giving a T1-T2 SOA of 160 to 720 ms in multiples of 80 ms. Finally, the T2+1 item occurred following the T2 item with a 80 ms SOA.

Participants received an average of 10 practice trials prior to data collection. In each experiment the participants were asked to determine whether the T1 was present or absent and to identify the T2 letter. Participants entered their own responses directly into the computer using specified keys.

### *Reporting Results*

For each experiment in the thesis, two sets of results are reported.

The first pertains to the correct detection of the T1 item. This will be reported as a proportion correct followed by the false alarm rate. This allows a calculation of an "a" prime measure. The use of a' provides a measure of

observer sensitivity taking into account both hits and false alarms. Because it is bounded by 0 and 1,  $a'$  is easily interpreted. An  $a'$  of 1 demonstrates perfect discrimination with responses correctly coded, and an  $a'$  of 0 shows perfect discrimination but with the responses being opposite of what is expected (100 % false alarms with no hits). An  $a'$  of 0.5 indicates random guessing.

The second set of results indicates which item was reported as the T2 item. Because of the design of the experiment, there are only five possibilities. The first is the correct T2 identity. The second is an intrusion from the item immediately following the T2 item (T2 +1). The third is an intrusion from the other targeted item in the RSVP stream (T1). The fourth is the item that fell between the T1 item and the T2 item (T1 +1). The fifth possibility involves an importation of an item that was not shown in the stream.

The way the T2 report is presented involves the trials in which both targets were shown (T1 present trials), and the trials in which the T1 item was absent and only the T2 item was shown. The only difference between the two trial types was the presence or absence of the T1 item. For the T1 present trials, the proportion of times each of the five possibilities was reported was calculated for the trials when the participant correctly detected the T1 item. This was done for each of the eight possible SOAs. These are the trials when the T1 item should have the greatest effect on reporting the T2 item, and the largest AB should be observed.

There are significant differences in the base rate of correct detections between experiments. Standardisation of the scores was considered as a method of eliminating the gross differences, but this is not possible. The basic findings of



these experiments examines the performance difference between the single and dual target task. If all of the scores are normalised in order to eliminate the differences in underlying performance between the experiments, then the differences between the single and dual target tasks (along with the differences in the single and dual target intrusion rates) is also eliminated.

The proportions for the T2 reported items were calculated for each of the items in the T1 absent trials as well. These rates of report provide a baseline of correct report and intrusion types for each possible response in the absence of the dual task stimuli. In addition, these response rates were calculated for each of the possible SOAs. The results of the dual target trials were then subtracted from the results of the single target trials across all eight SOAs and for each of the five possible responses.

The difference score that results from subtracting the dual target performance from single target performance indicates the difference between the dual and single target trials. Let us look at the T2 correct report in order to see what this scoring method tells us. If there is no effect of the T1 task on correct T2 report, the difference score would be zero. A deficit in T2 reporting during the dual target trials would be seen as a positive score because there would be more T2 items correctly reported in the single target trials than in the dual target trials. If more T2 items are correctly reported for the dual target trials than the single target trials, the score would be a negative one. This pattern is repeated for each of the five report types (T1 intrusion, importation) etc. If there are an equal number of that report type seen in both the single and dual target trials, the score is zero. If there are a greater number of a particular report

type seen in the single target task than in the dual target task, the resulting score is a positive number. Finally, if there are a greater number of the report type in the dual target trials when compared to the single target trials, the resulting score is negative.

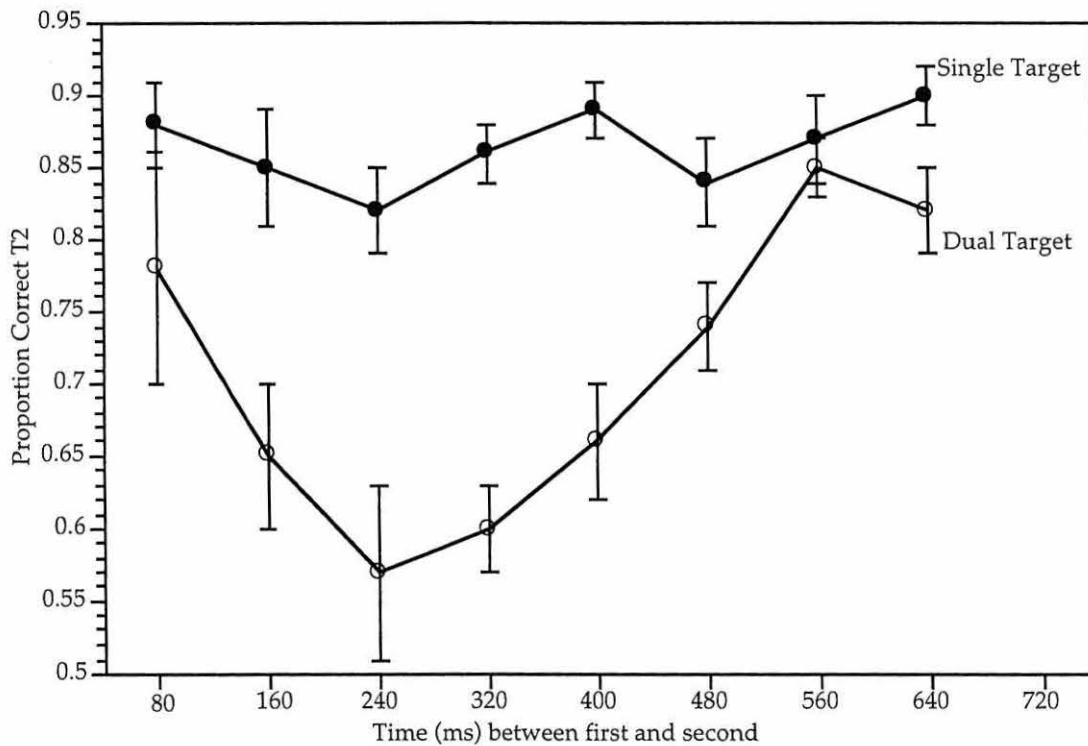


Figure 4: This figure is an illustration of an attentional blink. The single target performance is shown in the solid black circles, while the dual target performance is illustrated with the open circles. The exact same data is shown in the next figure with the subtractive method used throughout this thesis.

To better understand how this reporting is done, a typical AB is illustrated in Figure 4. In this figure, both the single target task and the dual target task are shown as separate lines. In

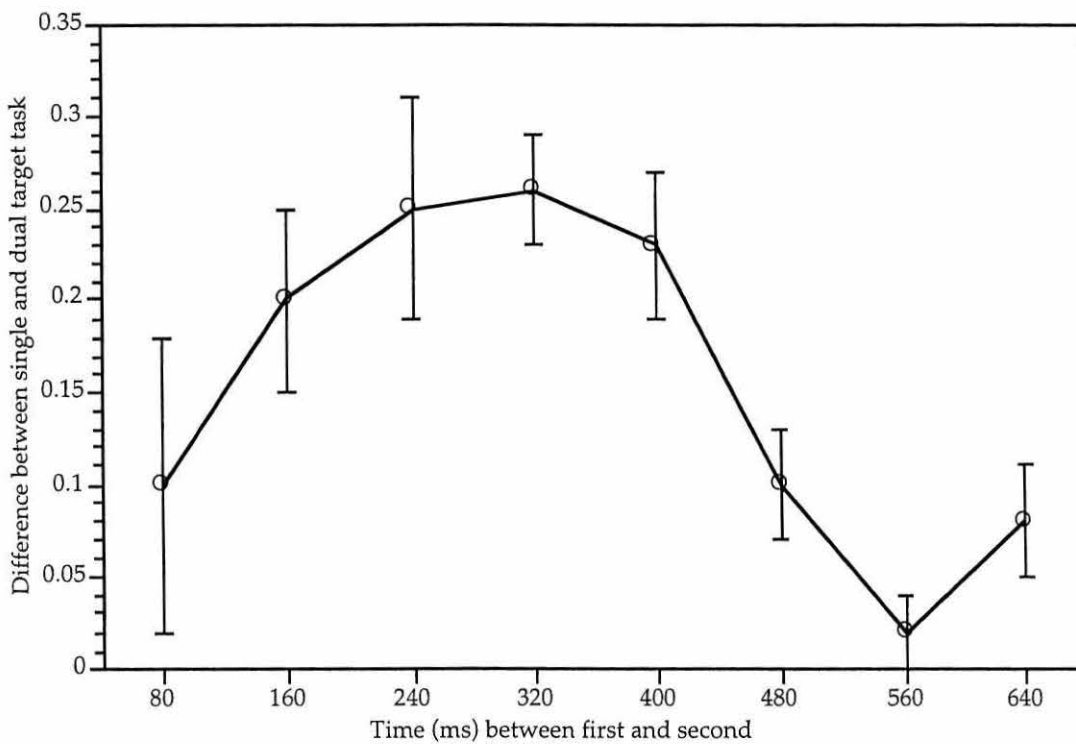


Figure 5: The difference scores for correct T2 identification as a function of SOA for the two target conditions. The dual target performance has been subtracted from the single target performance with the dual target deficit being shown as a rise between 160 and 400 ms.

Figure 5, the same results are displayed using the subtractive technique employed throughout the thesis. In this example, the advantage of using the subtractive method for displaying the difference between single and dual task performance is that only the T2 deficit is illustrated, and differences in baseline performance are ignored.

The other advantage is that the intrusion rates for several items can be illustrated on the same figure without the unnecessary clutter of two lines for each condition (dual target performance and single target performance). Figure 6 illustrates the clutter associated with displaying several measures using

traditional methods, while Figure 7 shows the same data using the subtractive method.

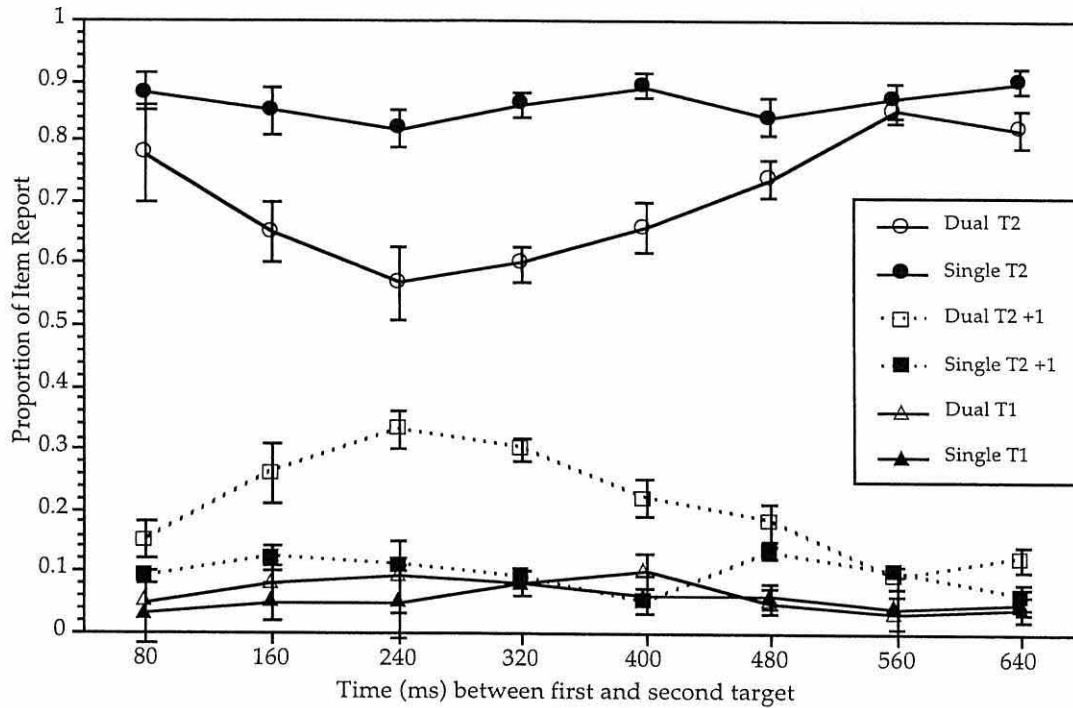


Figure 6: This figure uses the traditional method of display to show the correct T2 performance for both the single and dual target task, as well as the T2+1 intrusions for both tasks, and the T1 intrusions for both tasks. I have purposefully omitted the T1+1 intrusion errors as well as the importations, as the clutter makes the graph unreadable. The figure below illustrates the same data using the subtractive method.

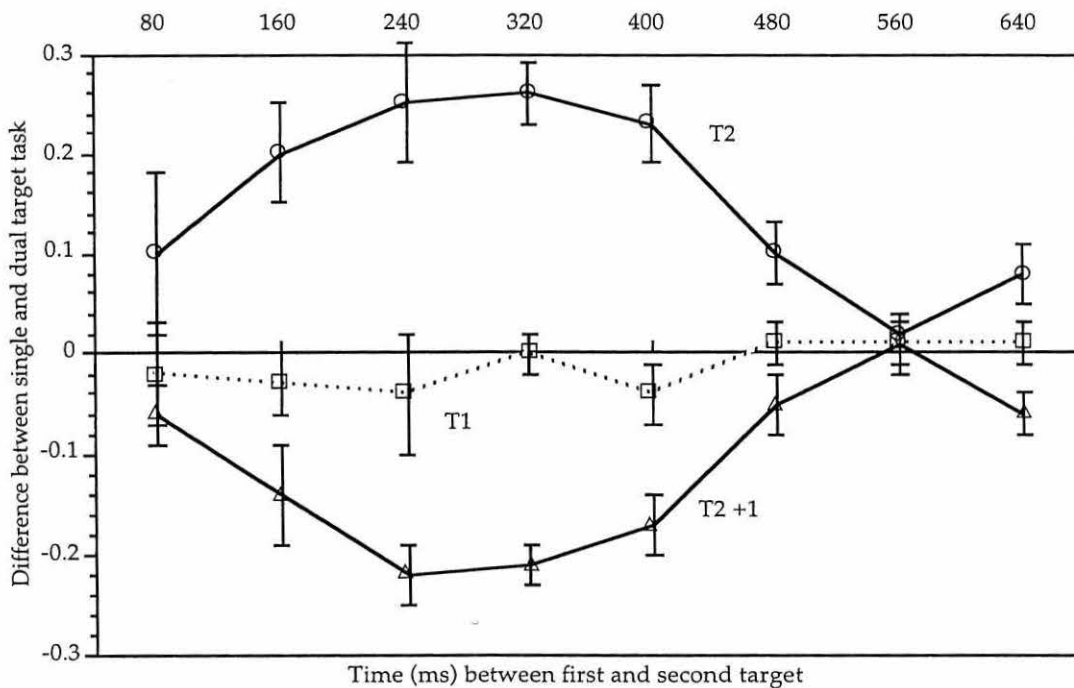


Figure 7: Using the subtractive scoring method, all three of the difference scores are illustrated. A positive score indicates that the single target task performance is higher than the dual target performance. In this case, there is a pronounced attentional blink peaking between 240 and 400 ms with a 25% difference in performance between the two tasks, with a deficit in the dual target task. At 560 ms, the performance is close to zero, indicating that there was virtually no difference between the dual and single target tasks performance. The other two lines represent the difference in intrusion rates for the two task types. The dashed line close to zero indicates the T1 intrusion rate, and being close to zero at all positions indicates no differences between the single and dual target tasks. The lower line represents the T2+1 intrusions, and the negative scoring indicates that there were many more intrusions in the dual target task than in the single target task. The single and dual target performance can be directly compared, even though the baseline performance for the three measures differed by as much as 80%.

Although the results of the individual experiments are presented as the thesis progresses, the principle analyses testing the model that has been

proposed are those which take place between the experiments which are designed to have minimal interference between the T1 and T2 processing, and the experiments designed to maximise the interference between the two targets. This grouping is accomplished by selecting the two targets so that they will require the same processing resources, or selecting the T1 and T2 key features that will rely on different processing resources. The maximal interference versus minimal interference comparisons will accumulate as the experiments are presented, with the final section closely examining the overall results for all of the experiments.

#### Experiment 1: Additive-Feature T2, Framed Item

In Experiment 1, the T2 item was defined by a unique perceptual feature shared by none of the other items in the RSVP stream: the T2 item was the only item surrounded by an enclosing frame<sup>2</sup>, which subtended  $0.98^\circ \times 0.98^\circ$  of visual

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<sup>2</sup> □To ensure that the frame functioned as a unique feature, I presented eight additional participants with typical, 300 ms visual search displays containing either two, five, eight or eleven letters. On half the trials, one letter was surrounded by an enclosing frame: The frame was the target. On the other half of the trials, the frame was absent. Participants responded via key presses whether the frame was present or not. When the frame was present, there was virtually no effect of the display size (mean search rate = 3.8 ms/item; intercept = 497 ms): The frame "popped out". When the frame was absent, the effect of display size was still small (mean search rate = 11.4 ms/item; intercept = 528 ms). These search rates conform roughly to the 2:1 ratio between target-absent and target-present search rates noted by Treisman and Gormican

angle. As we hypothesised earlier, the T2 key feature should be the only item activating the processing system or feature detectors associated with the frame, and should be the only item matching the template as the T2 item. Since the key feature processing is different for the T1 and T2 items, the prediction arising from this thesis is that the two items should not interfere with each other. This in no way implies that there will be no AB processing deficit, only that the T2 report will not result in a high number of T1 intrusions because the resources required for the two tasks do not rely on the same processing resources. It is anticipated that the frame will be improperly conjoined with the T2+1 item on some of the trials, causing the T2+1 item to be selected and processed in place of the T2 item. When participants must identify the T2 item, they should almost always name either the T2 item or the T2+1 item.

### *Participants*

Fifteen University of Calgary undergraduates (nine women and six men) ranging in age from 19 to 34 years (mean = 22.8 years, *S.D.* = 3.30 years) participated in Experiment 1. Ten participants took part in the T1 detection condition; five participated in the ignore T1 condition. Participants in the T1 detection condition were instructed to determine whether a white letter (T1) was present and then to identify the framed letter (T2). They were not required to

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(1988). The combination of target-present pop-out and the 2:1 ratio indicates that the frame produces activity in a unique set of feature detectors (Treisman and Gormican, 1988).

identify the T1 item. Participants in the ignore T1 condition were instructed to ignore the white items and to identify the framed letter.

### *Apparatus and Procedure*

In Experiment 1 and 2, participants took part in a series of 320 RSVP trials. The general procedure was as outlined above with the following details. The RSVP characters were displayed against a uniform grey field (9.1 cd/m<sup>2</sup>) which subtended 16.3° by 12.5°. The T1 items were white (32.9 cd/m<sup>2</sup>) and the rest of the stream items (including the T1 distractors) were black. All of the RSVP items were displayed for 27 ms with an ISI between the T1 - T1+1 and the T2 - T2 +2 items of 53 ms. For both Experiments 1 and 2, the item sets were as follows: T1 {G, I, L and P}, T1+1 {D, J, T and U}, T2 {A, C, F, R, X}, and T2+1 {B, K, S and W}. The T1 item set contained the four letters in both black (as distractors) and white (as targets).

### *Results and Discussion*

*T1 detection.* The T1 item was correctly detected on 89% of the trials. The false alarm rate was 5%, yielding an *a'* value of .96. Participants had no difficulty detecting the T1 item.



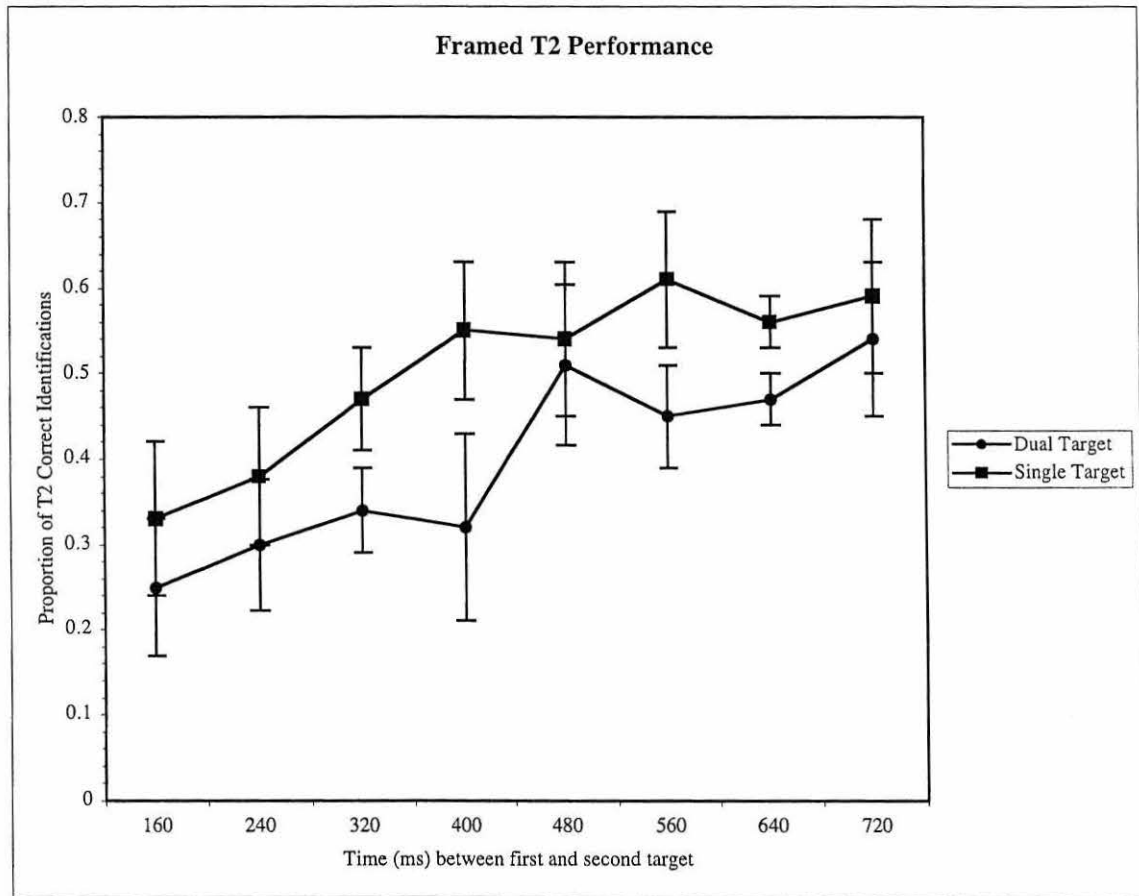


Figure 8: The correct T2 identification as a function of SOA for the two target items in Experiment 1 (framed T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 8. Table 1 shows the single target and dual target differences across all eight SOAs for each of the five possible report types. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 1

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2Correct	.08	.08	.13 *	.23 *	.03	.16 *	.09 *	.05		
T2+1	-.05	-.08	-.10 *	-.20 *	-.07	-.17 *	-.10 *	-.05		
T1	-.01	-.00	-.00	-.02	-.00	-.00	0	-.02		
T1+1	-.08	-.04	-.05	-.05	-.01	-.03	-.04 *	-.05 *		
Importations	.02	-.00	-.03	-.00	-.00	-.01	.00	.02		

(A positive score indicates better or higher performance in the single target task, while a negative score indicates better or higher performance on the dual target task.

A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

The most important thing to note from this table is that the only report items which differ significantly from zero are the T2 correct report item differences and the T2 +1 intrusion differences. What this means is that in this experiment, where the T2 item was delimited by the addition of a feature, a box surrounded the T2 item, the only errors which were systematically made were the errors which are the most common errors observed in the single target RSVP research (e.g. Botella & Erickson, 1992), the item immediately following the targeted item. Although the other report items do not differ from zero, it is important to notice both the size and direction of the errors. The importations are both positive and negative and cluster very close to zero. This pattern for importation differences was repeated in every experiment that will be presented, indicating that the number of guesses participants made was evenly distributed between the single and dual trials. Although I will continue to present the importation differences in the tables for the other experiments, I will not comment on them further. The T1 item difference is intruded more often in the dual target trials (hence the negative values), but the values are very close to

zero (never exceeding a 2% difference). The T1 +1 item difference is also very close to zero, but the magnitude of the errors are greater, at several SOAs approaching 5%.

#### Experiment 2: Subtractive-Feature T2, Unframed Item

T2 identification responses in Experiment 1 primarily reflected a larger proportion of correct T2 identifications in the single target trials than in the dual target trials. When dual target errors occurred, they primarily appeared to be T2 +1 intrusion errors. By contrast, in Isaak et al. (1999, Experiment 1), T2 identification errors were not confined mainly to T2 +1 intrusions, but instead reflected an almost even distribution of importations and T1, T1 +1 and T2+1 intrusions. A potential explanation for this discrepancy is that the T2 items in Isaak et al.'s experiment were defined by a subtractive rather than an additive or unique feature: Their T2 items were smaller in size than the other critical items.

Experiment 2 uses a subtractive T2 item rather different from the smaller size used in Isaak et al. (1999). Experiment 2 may be thought of as the inverse of Experiment 1. There, the T2 item was the only item enclosed in a frame; here, the T2 item is the only item not enclosed in a frame. Thus the same feature detectors are activated here as in Experiment 1; now, however, they are essentially active throughout each RSVP sequence, rather than only when the T2 item occurs, as in Experiment 1.

*Methods*

Seventeen University of Calgary undergraduates (10 women, 7 men) ranging in age from 19 to 32 years (mean = 22.2 years, *S.D.* = 3.13 years) participated. Ten participants were assigned to the T1 detection condition; the remainder participated in the ignore-T1 condition. Participants in the T1 detection condition were instructed to determine whether a white letter (T1) was present and to identify the letter that was not framed (T2). They were not required to identify the T1 item. Participants in the ignore-T1 condition were instructed to ignore the white items and to identify the letter without a frame.

*Results and Discussion**AB Effects*

*T1 Detection.* T1 items were correctly detected on 95% of the trials. The false alarm rate was 3%, yielding an  $a'$  value of .98. The T1 detection task posed no difficulty.

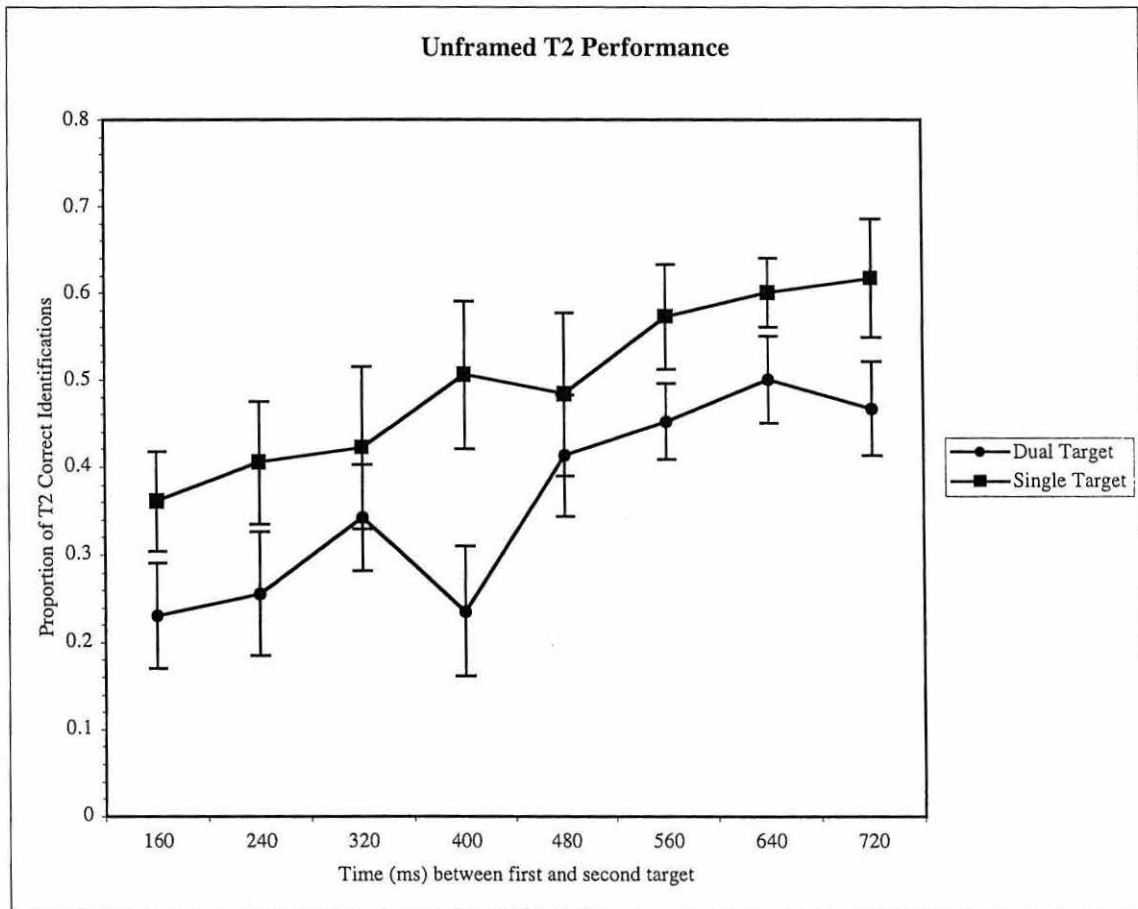


Figure 9: The correct T2 identification as a function of SOA for the two target items in Experiment 2 (unframed T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 9. Table 2 shows the single target and dual target differences across all eight SOAs for each of the five possible report types. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 2

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2Correct	.13 *	.15 *	.08	.27 *	.07	.12 *	.10 *	.15 *		
T2+1	-.06	-.11 *	.00	-.04	.02	.01	.05	.06		
T1	-.07	-.04	-.07	-.11 *	-.09	-.06	-.11 *	-.08 *		
T1+1	-.03	.02	.00	-.08	-.03	-.06 *	-.04 *	-.07 *		
Importations	-.00	-.04	-.03	-.05 *	.02	-.02	-.01	-.05		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

The most predominant intrusion error observed in this experiment is the T1 intrusion, although at most SOAs the difference scores were not significantly different from zero. This was evidenced by a repeated measures analysis of variance (ANOVA) which revealed a significant intrusion error by SOA interaction,  $F(21, 189) = 1.99, p < .05$ . There are no other systematic patterns to observe.

*Framed and Unframed comparisons: the first between systems versus within systems analysis.*

An overall mixed model ANOVA comparing the intrusion type difference scores across the unframed results revealed a significant experimental effect,  $F(1,18) = 21.79, p < .05$ , no effect of SOA,  $F(7, 126) < 1$ , a significant effect of intrusion type,  $F(3, 54) = 21.75, p < .05$ , no significant experimental effect by SOA interaction,  $F(7, 126) < 1$ , a significant experimental effect by intrusion interaction,  $F(3,54) = 3.61, p < .05$ , a significant intrusion by SOA interaction,  $F(21, 378) = 2.56,$

$p < .05$ , but no experimental effect by SOA by intrusion interaction,  $F(21, 378) = 1.18, p < .05$ . The significant experimental effect by intrusion interaction indicates that the intrusion pattern differed between the two experiments. This effect is important in the discussion to follow.

For each of the four critical T2 report item differences (importations are not compared or discussed as they were virtually identical for every experiment), a full set of analyses are presented. A repeated measures ANOVA conducted on the correct T2 report revealed no differences in the experimental condition main effect,  $F(1,18) < 1$ , but did reveal a significant main effect of SOA,  $F(7,126) = 3.92, p < .05$ , but no significant experimental

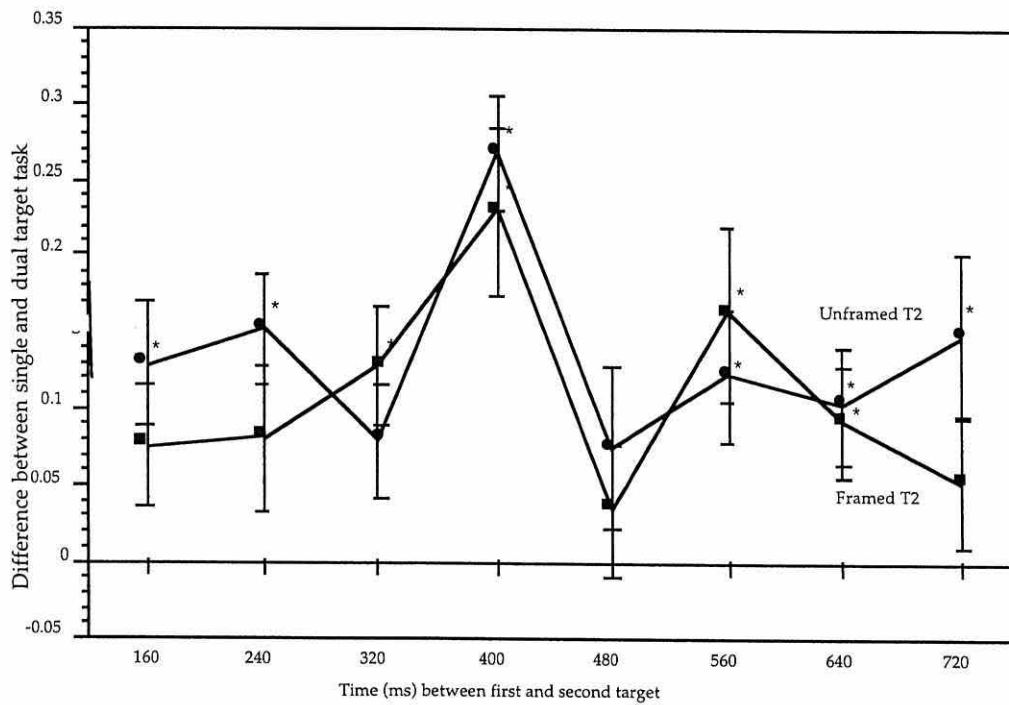


Figure 10: The difference scores for correct T2 identification as a function of SOA for the two target items in Experiment 1 (framed T2) and Experiment 2 (unframed T2). Squares represent Experiment 1 while the circles represent the Experiment 2 scores. Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the symbol indicates that the point is significantly different from zero ( $p < .05$ ). An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

condition by SOA interaction,  $F(7,126) = 1.28$ ,  $p < .05$ . The non-significant main effect of experimental condition indicates that there is no difference in the size of the AB between the framed and unframed T2 conditions (see Figure 10). The significant SOA effect normally indicates the recovery from an AB, but for these experiments, this is not the case. A full recovery from the effects of the AB is indicated by the difference scores dropping to zero as the time between the two targets increased: this does not happen. It appears that the SOA effect is the result of the spike in the difference scores at 360 ms, which occurs at the depth of



the blink, with recovery following. Although the difference scores do not recover to zero by 720 ms, there is clear indication of a deficit at 450 ms.

A mixed model ANOVA for the T2 +1 item differences at each SOA reveals a significant main effect of experimental condition,  $F(1,18) = 6.33, p < .05$ , a significant SOA main effect,  $F(7,126) = 2.32, p < .05$ , and a marginally non-significant experimental condition by SOA interaction,  $F(7,126) = 1.92, p < .07$ . The significant main effects of experimental condition and SOA are in this case supplanted by the marginal non-significant experimental condition by SOA interaction. The interaction indicates that there is a difference between the rate of intrusions for the framed and unframed conditions, but that the difference is not constant across all SOAs. This can be seen with reference to Figure 11. Whereas the T2 +1 intrusions in the unframed condition hover around zero at all SOAs, suggesting that the T2 +1 intrusions do not account for errors made in identifying the T2 item, the T2 +1 intrusions in the framed condition account for a substantial number of errors made in mis-identifying the T2 item. This means that the AB observed in the two conditions, as measured by the proportion of correct T2 reports, although quantifiably identical (see Figure 11), are composed of different types of errors.

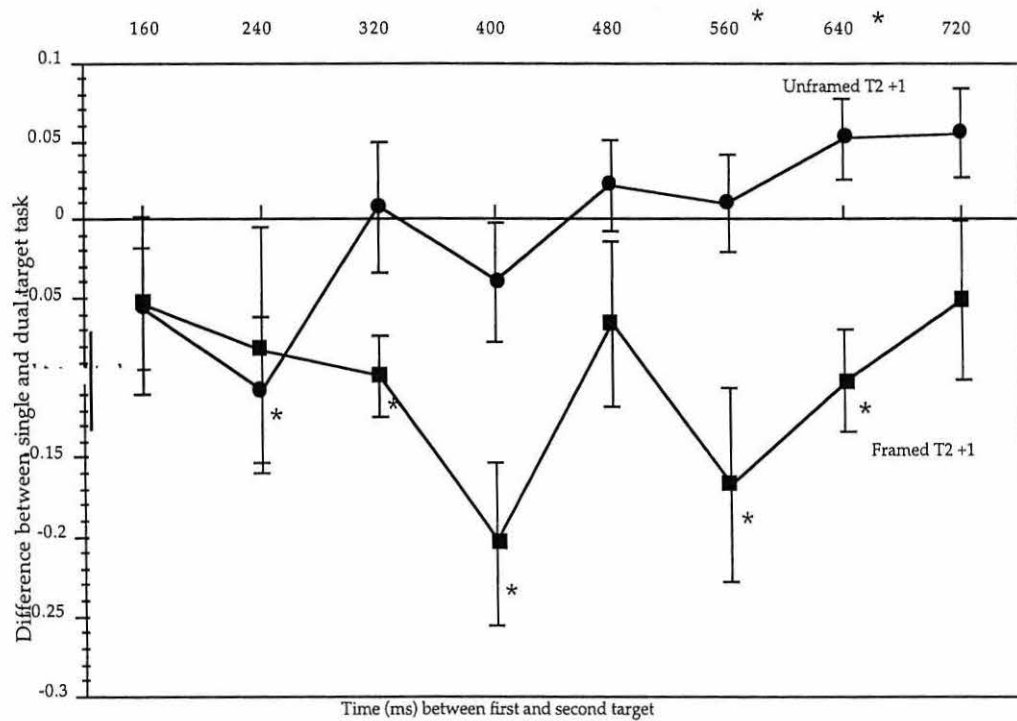


Figure 11: The difference scores for correct T2 +1 intrusions as a function of SOA for the two target items in Experiment 1 (framed T2) and Experiment 2 (unframed T2). Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the symbol indicates that the point is significantly different from zero ( $p < .05$ ). An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

When the rates for the T1 intrusion difference scores are considered, the error pattern is clarified. A mixed model ANOVA for the third type of intrusion uncovered a significant main effect of experimental condition,  $F(1,18) = 4.99$ ,  $p < .05$ , but non significant differences for both the main effect of SOA,  $F(7,126) < 1$ , and the interaction of the experimental condition and the SOA effects,  $F(7,126) < 1$ . This significant main effect of experimental condition, as illustrated in Figure 12, indicates that for the framed T2 condition, there is virtually no difference between the dual and single target trials (the scores are all very close to zero),

whereas there are many more T1 intrusions in the unframed T2 experimental condition when participants were confronted with a dual target trial than when they were carrying out the single target trials.

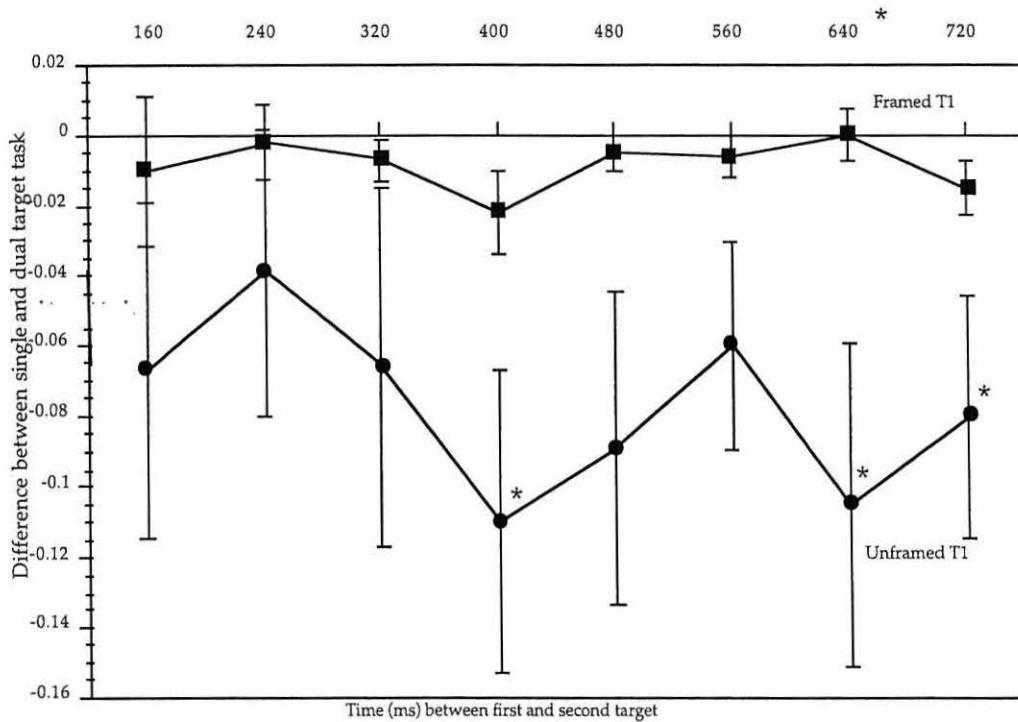


Figure 12: The difference scores for T1 intrusions as a function of SOA for the two target items in Experiment 1 (framed T2) and Experiment 2 (unframed T2). Vertical bars represent  $\pm 1$  standard error of the mean. An asterix next to the symbol indicates that the point is significantly different from zero ( $p < .05$ ). An asterix next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

An examination of the intrusion rates for the T1+1 item differences using a mixed model ANOVA indicated no significant differences for either of the main effects; nor did it indicate a significant interaction (all of the  $F$  values were either equal to or less than 1). Because the scores were almost all negative (see Figure

13), this result points to a dual target deficit which is unaffected by whether the task involves subtractive or additive features.

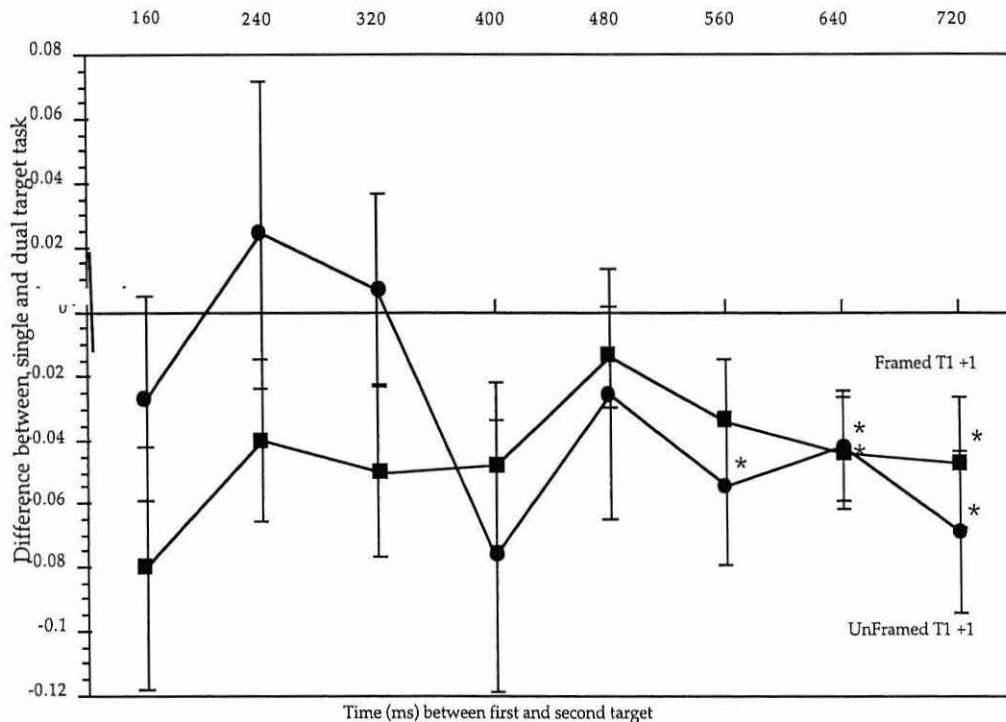


Figure 13: The difference scores for T1+1 intrusions as a function of SOA for the two target items in Experiment 1 (framed T2) and Experiment 2 (unframed T2). Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the symbol indicates that the point is significantly different from zero ( $p < .05$ ). An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

#### *Discussion of Framed and Unframed Results*

In the comparisons of the T2 report items between the framed T2 and the unframed T2, several points emerge. The first is that there is no difference in the number of T2 items correctly reported. By all traditional accounts, there is no difference in the AB between the two experiments. The second is that there are

more T2 +1 intrusions when the T2 item is defined by an additive feature than when it is defined by a subtractive feature. In contrast, there are more T1 intrusion errors when the T2 item is defined by a subtractive feature than when it is defined by an additive feature.

This pattern of results is supportive of an interference theory based on Duncan's (1996) integrated competition theory of processing. In both Experiment 1 and 2, the T1 task was identical and simple, the detection of a white item. In Experiment 1, the T2 item was defined by the addition of a feature (a frame) which is processed by processing modules not involved in the processing of any other items in the stream. Activation within the processing modules associated with detecting whiteness would signal the selection of the T1 item, while activation within the units detecting the presence of the frame would signal the selection of the T2 item for identification. Because the signals from the two items arise from independent sources, and they share few common processing modules, there is little interference caused by the processing of the T1 item, simply an overall delay in consolidating the T2 item with the defining frame. As a result, either the correct identity of the T2 item enters VSTM to be reported or the delay causes the T2 +1 item to be identified as the T2 item, and it enters VSTM to be reported as the T2 item. The result of the latter is a T2 +1 intrusion arising as a conjunction error.

When the T2 item is defined as the lack of a feature, or by a subtractive feature as was the case in Experiment 2, where the T2 item was defined as the only item which did not have a frame around it, a different result is expected. The processing modules associated with detecting the presence of the frame is

activated for all of the items except the T2 item. The task would involve detecting a drop in activation for those processing modules during a 80 ms window of time. The task is difficult because the restricted time available for detecting the presence of the T2 defining feature (the absence of a frame) is close to the time required for the processing module to settle into a state of resting activation. The system must decide if the decrease in activation is a result of no stimuli being present (in which case a target has been detected), or if it is simply a normal fluctuation in activation levels. Because of this difficulty, the selection of the T2 item cannot be easily made. Because the T1 item is selected as a critical item, and there is no unambiguous T2 item selected, the identity of the T1 item is more likely to be reported as the T2 item when the T2 item cannot be easily selected. Thus it appears that the heightened activation of the T1 item in the dual target trials is enough to initiate its selection for report as the T2 item.

The model presented earlier in the thesis made three predictions with regard to dual target performance in an RSVP task. The first was that, if the processing module necessary for detecting the presence of a selection flag is engaged in processing the first target, the selection cue will be missed. Evidence for this in Experiments 1 and 2 would be found if there is a significant interaction between the T1 and correct T2 report in the two experiments. This analysis revealed a marginally significant difference,  $F(1,18) = 3.5, p < .07$ . Because the processing module necessary to detect the subtractive feature in Experiment 2 is used in the processing of every item in the stream, in many instances the T2 key feature was simply not processed. As a result, the item reported as the T2 item

in the dual target task was the only item for which an identity was available, the T1 item. This was not the case when the T2 key feature was additive.

The second prediction was that if the selection cue is processed, but the task demands are such that the same modules are required for both targets, the simple primacy of the first target into the system will effectively interfere with the second target, preventing it from receiving the resources required for full processing. This type of interference was not predicted in either of these experiments, and there is no evidence to suggest that it has been observed. This type of interference is expected in a more traditional detect T1 identity, detect T2 identity (was there a white "s", and was there a black "X" present in the RSVP stream). These experiments were designed to minimise the occurrence of this type of interference.

The third prediction stated that if the selection cue is processed, and the necessary information for the first target has already been processed, the second target can be processed, although with some interference as it must overcome the ascendancy enjoyed by the first target which is already being processed. This is the interference observed in the first experiment with an additive key feature. The frame could be detected with no difficulty, and the identity of the T2 item could then be processed. Due to the ascendancy of the features belonging to the T1 item (having been selected due to its being the T1 item) in the processing modules necessary to evaluate the identification of the T2 item, the item most often reported as the T2 item was the T2 +1 item, or the item that immediately followed the T2 item. Participants improperly conjoined the frame to the T2 +1 item.

### Experiment 3: Convergent Interference

Experiment 3 is designed to observe the effects of processing two items within the same processing system (colour<sup>3</sup>). When two targets were processed within the same processing system, I expect to see similar results to the case when the key feature for the T2 item was a subtractive feature as in Experiment 2. When the processing system for the key feature is being used by both the T1 and the T2 item templates, interference should result. Participants in Experiment 3 were required to detect the presence of a coloured item (T1 task) and then identify a different coloured item (T2 task). Since both tasks required the processing of colour information, interference should be observed.

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<sup>3</sup> To ensure that colour functioned as a unique feature, I presented eight additional participants with 300 ms visual search displays containing either two, five, eight, or eleven letters. On half the trials, one letter was green, whereas on the other trials, all the letters were black. Participants responded via key-presses whether a green target was present or absent. When a green target was present, there was no effect of display size (mean search rate = 0.5 ms/item; intercept = 455 ms): As I expected, the green letter popped out. When the green letter was absent, there was again no effect of display size (mean search rate = 1.4 ms/item; intercept = 468 ms). The combination of target-present pop-out and the approximate 2:1 ratio between target-absent and target-present search rates indicates that the colour activates a unique set of feature detectors (Treisman and Gormican, 1988).



*Experiment 3, 4 and 5 Stimuli*

Apart from the stimuli used, the procedure for Experiments 3, 4 and 5 was similar to the procedure used in Experiments 1 and 2. For all conditions in both Experiments 3 and 4, the T1 items were drawn from the letter set {Q, P, O, L, I, G, and E}; the T1 +1 letter set included the letters {U, T, M, J, H, and D}; the T2 letter set included {A, N, R, X, Y, C, and F}; and the T2 +1 letter set included the letters {Z, W, V, S, K, and B}. The background field for these experiments was black. The distracter letters were grey letters of randomly selected luminances. When the key feature for either target was red, the luminance of the red item was randomly selected from the three available luminance values for each item. Similarly, when either target key feature was green the luminance values were randomly selected. Each letter in the item letter set was represented at every luminance level for each colour. The presentation of random luminance values for every item ensured that the participants were not able to rely on luminance values for target selection when luminance was not the key feature. The large letters used in Experiment 5 were 0.5° high compared to the 0.4° of the standard letters, and 0.35° wide compared to the 0.25° width of the standard letters.

## Experiment 3a: Detect Red, Identify Green

*Participants*

Ten University of Wales, Bangor psychology students from the undergraduate participant pool (six women, four men) ranging in age from eighteen to 36 years (mean = 25.6 years, *S.D.* - 6.8 years) participated. In Experiment 3a, participants

were instructed to determine whether a red letter (T1) was present and to identify the letter that was green (T2). They were not required to identify the T1 item.

### Results and Discussion

#### Attentional Blink Effects

*T1 Detection.* T1 items were correctly detected on 94% of the trials. The false alarm rate was 5%, yielding an  $a'$  value of .97. The T1 detection task posed no difficulty.

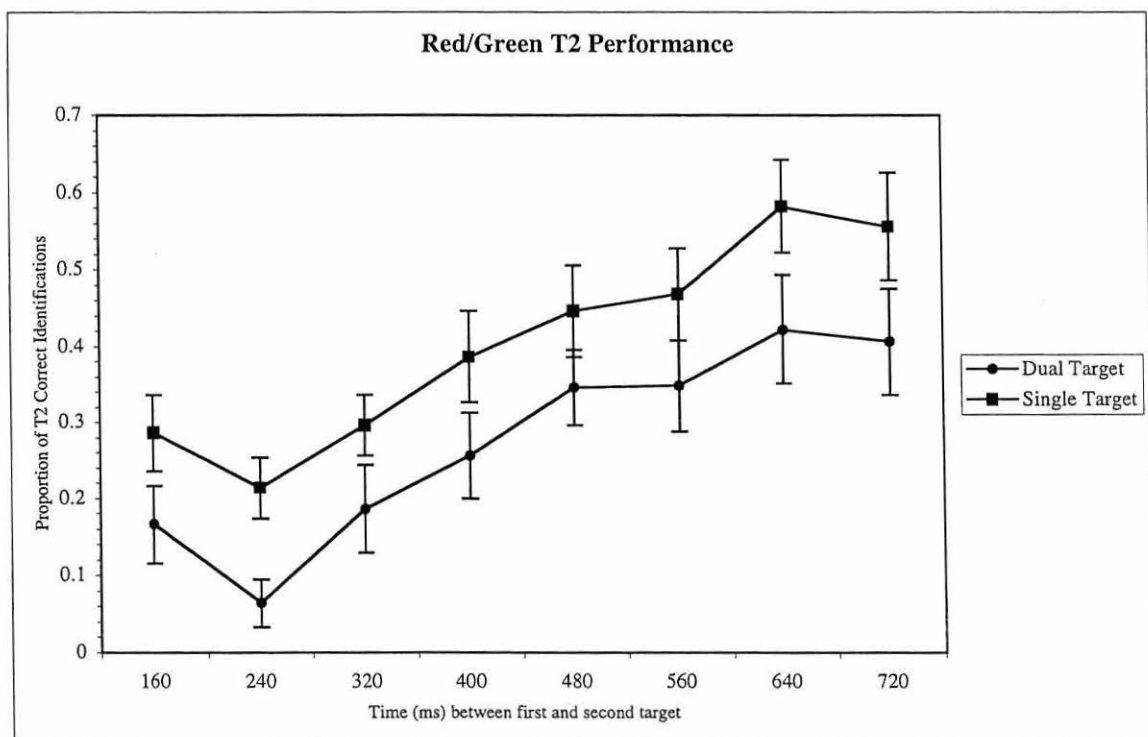


Figure 14: The correct T2 identification as a function of SOA for the two target items in Experiment 3a (Red T1, Green T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 14. Table 3 shows the single target and dual target differences across all eight SOAs for each of the five possible report types. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 3

	SOA(ms)								
	160	240	320	400	480	560	640	720	
T2 Correct	.12 *	.15 *	.11 *	.13 *	.10 *	.12 *	.16 *	.15 *	
T2+1	.10	.07	.14	.08	.05	.04	.03	.12	
T1	-.18	-.16	-.14	-.16	-.16 *	-.12	-.14	-.17	
T1+1	-.07 *	-.10 *	-.13 *	-.08	-.07	-.09 *	-.09	-.08	
Importations	.02	.03	.02	.02	.06	.03	.03	-.03	

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

The highest number of intrusion errors, as measured by the difference scores, which occurred in this experiment were T1 intrusions as revealed by a significant interaction between the intrusion type and SOA,  $F(3,27) = 3.49$ ,  $p < .05$ . This is similar to the pattern observed when the T2 item was unframed, or was subtractively defined. As both the T1 and the T2 items were defined by a colour change, at some level the processing module used for detecting colour is activated, and the colour processing associated with the two critical items demonstrates interference. The interference is expressed as intrusions of the T1 item when the T2 item is to be reported. It is interesting to note that there are more T2 +1 intrusion error differences in the single target condition than in the

dual target condition as evidenced by the positive values. This observation could be made in Experiment 2 at the longer SOAs.

Experiment 3b is a repeat of Experiment 3a, but the colours associated with the critical items have been reversed. The T1 item is now defined as the green item, while the T2 item is defined as the red item. This reversal is necessary to control for the possibility that the results are attributable to the selection of colours. It is expected that the same interference observed in Experiment 3a will be observed in Experiment 3b.

### Experiment 3b: Detect Green, Identify Red

#### *Participants*

Ten University of Wales, Bangor psychology students from the undergraduate participant pool (nine women, one man) ranging in age from 18 to 36 years (mean = 21.6 years, *S.D.* = 5.3 years) participated. In Experiment 3b, participants were instructed to determine whether a green letter (T1) was present and to identify the letter which was red (T2). They were not required to identify the T1 item.

*Results and Discussion*

## Attentional Blink Effects

*T1 Detection.* T1 items were correctly detected on 93% of the trials. The false alarm rate was 8%, yielding an  $a'$  value of .96. The T1 detection task posed no difficulty.

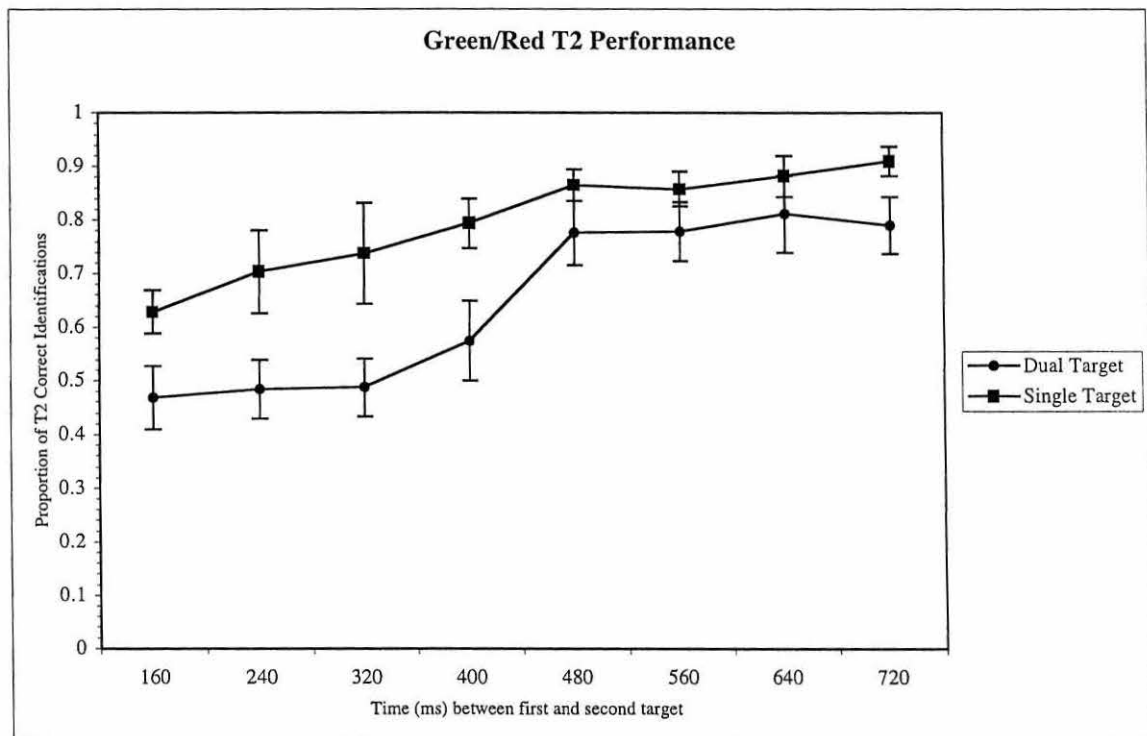


Figure 15: The correct T2 identification as a function of SOA for the two target items in Experiment 3b (Green T1, Red T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 15. Table 4 shows the single target and dual target differences across all eight SOAs for each of the five possible report types. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 4

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2Correct	.16 *	.22 *	.25 *	.22 *	.09	.08	.07	.12 *		
T2+1	-.08 *	-.08	-.11 *	-.08 *	-.05	-.04	-.03	-.04		
T1	-.07	-.15 *	-.07 *	-.08	-.08 *	-.05	-.02	-.03		
T1+1	-.05	-.02	-.06	-.04	0	-.00	-.02	-.05 *		
Importations	.04	.02	-.02	-.03	.02	.01	-.02 *	.02		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

Once again, the T1 intrusion rates as illustrated in the difference scores, figure largely in this experiment. Although the T1 intrusions are not the predominant intrusion error, as in Experiment 3a, they are significantly different from zero in three of the four time lags following the T1 item during which the most interference is expected from an AB (240 ms, 320 ms and 480 ms). This is consistent with the idea that when the key features for both target items are defined along the same dimension, interference will be observed.

#### *Comparison of Experiments 3a and 3b*

For each of the four critical items (T2, T2 +1, T1, and T1 +1), comparisons are made between the two experiments. As expected, very few differences were found. A mixed model ANOVA performed on the correct T2 report differences by SOA found no main effect of experimental condition,  $F < 1$ , or of SOA,  $F(7,126) = 1.76, p < .05$ . However, there was an experimental condition by SOA interaction,  $F(7,126) = 2.08, p < .05$  (see Figure 16). For each of the other critical

item difference scores (T2 +1, T1, and T1 +1), no differences were found when an ANOVA was carried out. The experimental condition by SOA interaction observed here shows that there is a difference in the ease with which a participant can see the colours used as key features. In other words, a red T2 is easier to detect and identify than a green T2, a finding also observed by Ross and Jolicoeur (1999). Although a potentially interesting observation, this finding is not of interest for the purposes of this investigation. Since no other differences were observed, these two experiments will be treated as one and referred to as Experiment 3.

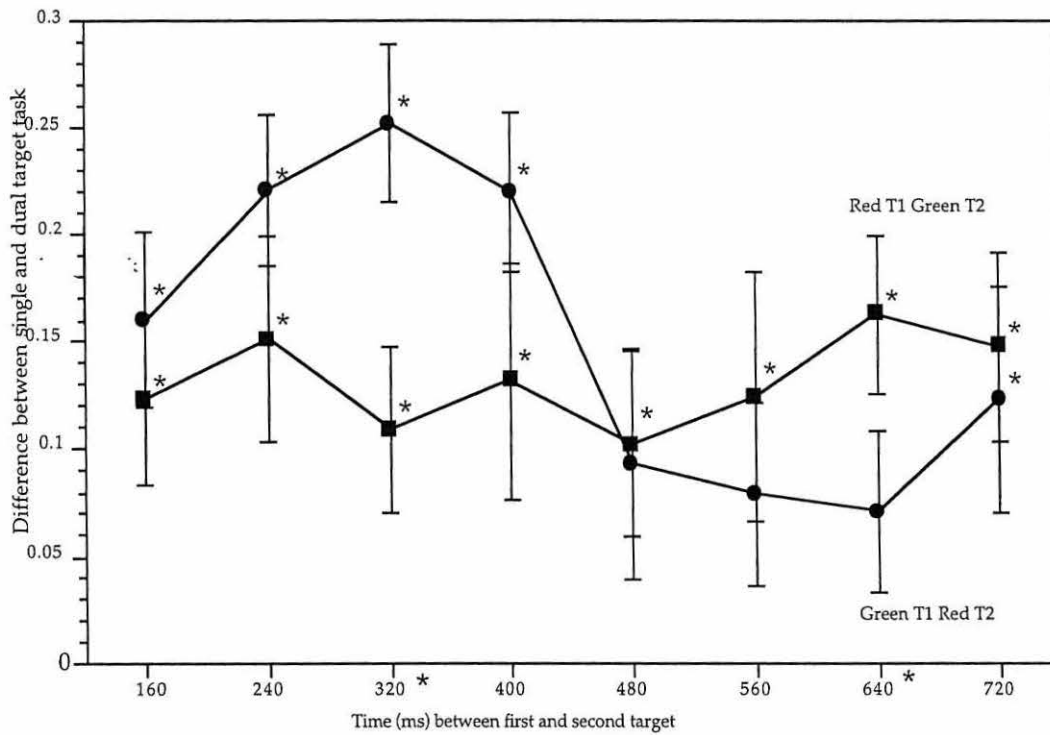


Figure 16: The difference scores for correct T2 identification as a function of SOA for the two target items in Experiment 3a and 3b. Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the symbol indicates that the point is significantly different from zero ( $p < .05$ ). An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

Experiment 3 performance showed a general pattern of results reminiscent of the pattern found in Experiment 2 (unframed T2). The T2 performance was about 15% higher on the single target trials than the dual target trials; T2 +1 intrusions were virtually identical between the dual and single target trials; a large number of T1 intrusions in the dual target task when compared to the single target task; and more T1 +1 intrusions in the dual target trials than in the single target trials (see Table 5 below).



Table 5

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2 Correct	.15 *	.19 *	.18 *	.18 *	.10 *	.10 *	.12 *	.13 *		
T2+1	.00	-.00	.01 *	-.00 *	.00	.00	.00	.04		
T1	-.12 *	-.16 *	-.11 *	-.12 *	-.12 *	-.09 *	-.08	-.10		
T1+1	-.06 *	-.06 *	-.09 *	-.06 *	-.04	-.05 *	-.05	-.06		
Importations	.03	.03	-.00	-.00	.04	.02	.00	-.02		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

These results are consistent with the idea that, when two tasks need to be performed which use the same resources, interference will be observed. Both the T1 item and the T2 item were denoted by a colour, and the intrusion rate for the T1 item when the T2 item is mis-identified is higher than the intrusion rate of any of the other items present in the RSVP stream. Because the T1 item is a critical item which demands processing (detect presence of a colour), it is not surprising that the identity of the T1 item is used in place of the item which is supposed to be identified. It would be surprising if this were not the case for all conditions. This was tested in the next two experiments which looked at the intrusion rates for experiments designed to require processing from either independent or quasi-independent processing modules.

#### Experiment 4: Between System Processing - Colour and Luminance

Experiments 1 and 2 dealt with the unique activation afforded an additive feature when compared to the subtractive feature task of detecting reduced activation

against a high activation backdrop. Experiments 3, 4 and 5 were designed to test whether the amount of interference varied when both target tasks in an AB experiment either use the same (generic colour module) or different processing resources (colour module or other key feature module). According to the hypothesis presented in this thesis, interference will increase when both tasks are competing for the same processing system resources; conversely when the two tasks are processed by largely separate systems, the observed interference should be minimised.

In Experiment 4 the target key features were either luminance or colour. It was expected that the pattern of errors produced when the key features were from the different dimensions, and as a result using different processing systems, would resemble the pattern of errors found in Experiment 1 (framed T1), and part of Experiment 5 (colour and size T1/T2). This T2 report error pattern showed a predominance of T2+1 intrusions, with very few T1 and T1+1 intrusions. This is a different pattern from what was observed in Experiment 3, in which the pattern of intrusions reflected the pattern found in Experiment 2 and the errors were predominantly T1 and T1+1 reported as the T2 item.

Experiment 4 resembled Experiment 1 wherein we were testing what we expected to be non-interfering processes. The T1 key feature was selected to use resources from a different processing system (dimension) than the T2 key feature. In Experiment 4a, the T1 key feature was the presence of a white item and the T2 key feature was the colour red; Experiment 4b used a white T1 and a green T2; Experiment 4c used a red T1 and a white T2; Experiment 4d used a green T1 and a white T2. In each condition the key feature for the T1 was

thought to be using different processing resources than the key feature for T2. Although colour and luminance are integral dimensions of processing (e.g. Callaghan, 1984), and not really independent, it was expected that the modules used in processing luminance differences and the presence of colour information would not interfere with each other.

### Experiment 4a: Detect White, Identify Red

#### *Participants*

Twelve University of Wales, Bangor psychology students from the undergraduate participant pool (seven women, five men) ranging in age from 18 to 30 years (mean = 21 years, *S.D.* 4.0 years) participated. Two participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 4a, participants in the T1 detection condition were instructed to determine whether a white letter (T1) was present and to identify the letter that was red (T2). They were not required to identify the T1 item.

#### *Results*

##### *Attentional Blink Effects*

*T1 Detection.* T1 items were correctly detected on 83% of the trials. The false alarm rate was 17%, yielding an *a'* value of .89. Detecting the presence of a white target is not a difficult task while attempting to identify a red target following in close temporal proximity.

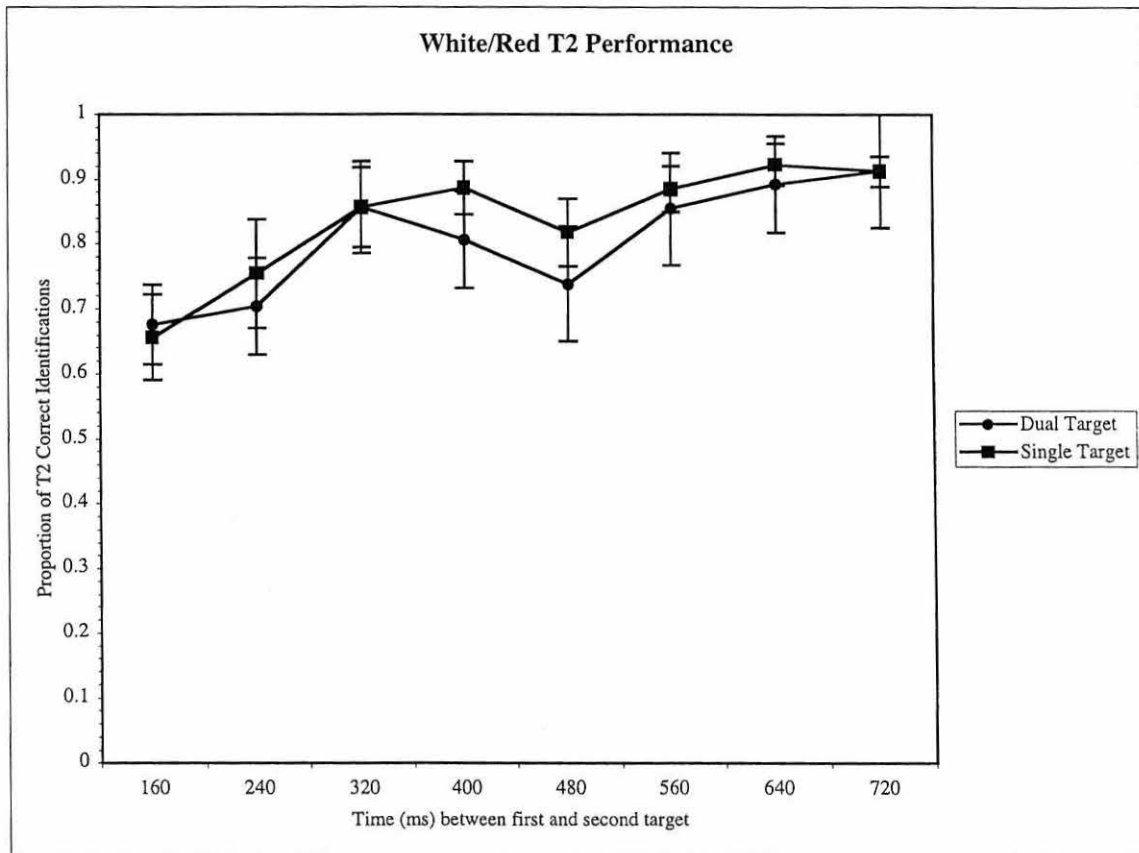


Figure 17: The correct T2 identification as a function of SOA for the two target items in Experiment 4a (White T1, Red T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 17. Table 6 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 4a. An asterix following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 6

	SOA(ms)							
	160	240	320	400	480	560	640	720
T2Correct	-.02	.05	.00	.08	.08	.03	.03	0
T2+1	.04	.05	-.01	-.03	-.04	-.03	-.04	-.01
T1	-.04	-.04	-.03	.02	.01	-.07	-.00	-.00
T1+1	.01	-.03	.00	-.02	-.02	-.03	.02	.00
Importations	.01	-.03	.04	-.05	-.03	.05	-.00	.00

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

For Experiment 4a, there is virtually no difference in T2 performance, as measured by the difference scores, when the participants were performing single target trials as compared to when they were performing dual target trials. There was no AB, as evidenced by the lack of a difference in T2 performance, and there were no systematic errors. This experiment supplies evidence that when the two tasks require different processes, the observed errors in identifying the T2 item are not related to the T1 item, even though the T1 item requires selection along some dimension (detect white).

Because of the difficulty of the task (as evidenced by the general poor T2 report accuracy), there was concern that the lack of an AB was due to a floor effect. An examination of the raw data ruled out a floor effect as an adequate explanation. The T2 performance varied by participant from high accuracy and low accuracy within the AB time frame. Some of the participants found the task easy, while the majority of the participants found the task difficult. What was observed was, regardless of whether the participants found the task easy or

difficult, that there was very little difference in single and dual target performance.

### Experiment 4b: Detect White, Identify Green

#### *Participants*

Fourteen University of Wales, Bangor psychology students from the undergraduate participant pool (eight women, six men) ranging in age from 18 to 34 years (mean = 21.3 years, *S.D.* = 6.23 years) participated in Experiment 4b. Four participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 4b, participants in the T1 detection condition were instructed to determine whether a white letter (T1) was present and to identify the letter that was green (T2). They were not required to identify the T1 item.

#### *Results*

##### *Attentional Blink Effects*

*T1 Detection.* T1 items were correctly detected on 75% of the trials. The false alarm rate was 12%, yielding an *a'* value of .89. Detecting the presence of a white target is quite easy when followed by a green target.

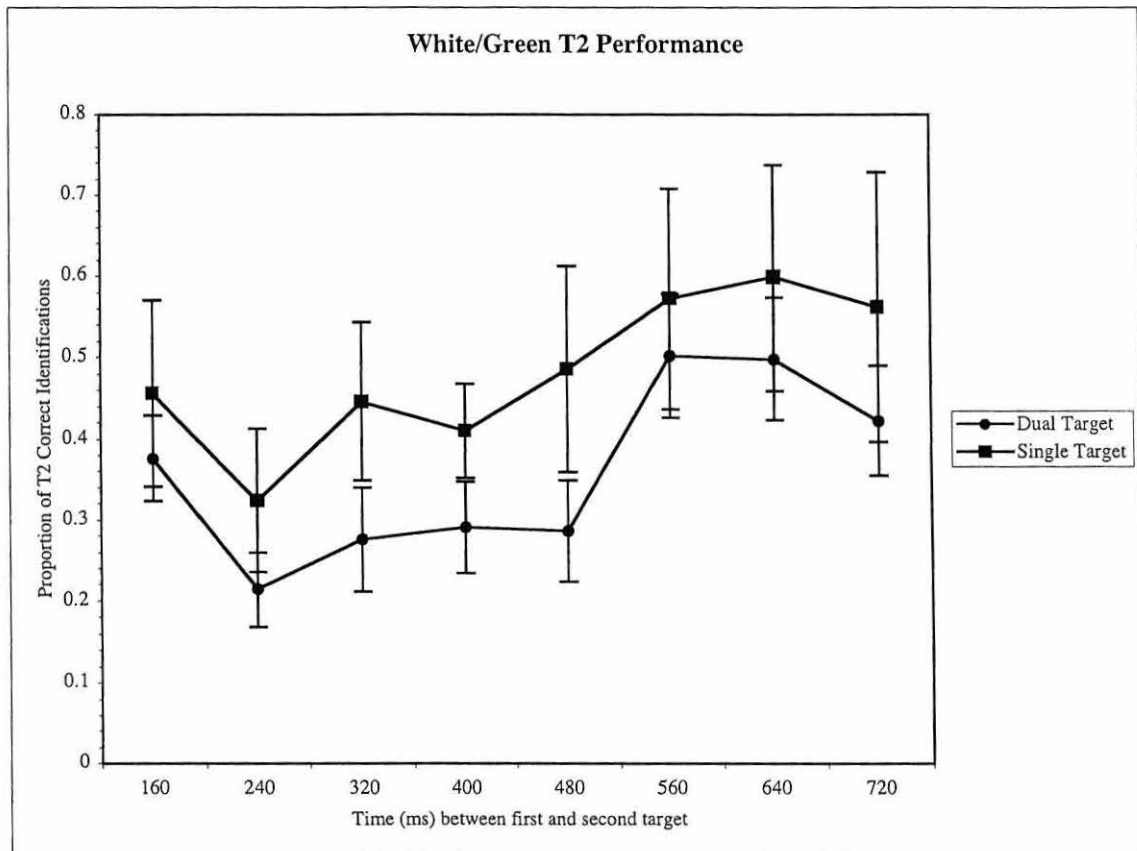


Figure 18: The correct T2 identification as a function of SOA for the two target items in Experiment 4b (White T1, Green T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 18. Table 7 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 4b. An asterix following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 7

	SOA(ms)								
	160	240	320	400	480	560	640	720	
T2 Correct	.08	.11	.17 *	.12 *	.20 *	.07	.10	.14	
T2+1	.00	.00	-.09	-.16 *	-.14 *	-.07	-.07	-.07	
T1	-.02	-.04	-.05 *	.02	-.01	-.03	-.00	-.03	*
T1+1	-.01	-.05	-.03	-.00	-.06	-.03	-.01	-.02	
Importations	-.04	-.01	-.01	.02	-.00	-.00	-.02	-.03	

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

In this experiment, there appears to be an AB, as evidenced in the difference between single and dual target performance on T2, between 320 and 480 ms. The majority of the errors which contribute to the AB in this experiment are intrusions of the T2 +1 item. Only at 320 ms does there appear to be a significant number of T1 intrusions, and in real terms, the number of intrusions is small. Once again, it appears that when the T1 and T2 tasks require separate streams of processing, they can be processed with a minimal level of interference.

#### Experiment 4c: Detect Red, Identify White

##### *Participants*

Fifteen University of Wales, Bangor psychology students from the undergraduate participant pool (six women, nine men) ranging in age from 18 to 35 years (mean = 21.2 years, *S.D.* = 4 years) participated in Experiment 4c. Five



participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 4c, participants in the T1 detection condition were instructed to determine whether a red letter (T1) was present and to identify the white letter (T2). They were not required to identify the T1 (red) item.

## *Results*

### *Attentional Blink Effects*

*T1 Detection.* T1 items were correctly detected on 95% of the trials. The false alarm rate was 1%, yielding an  $a'$  value of .98. Once again, detecting the presence of a coloured target followed by a white T2 item in an standard AB task is not difficult.

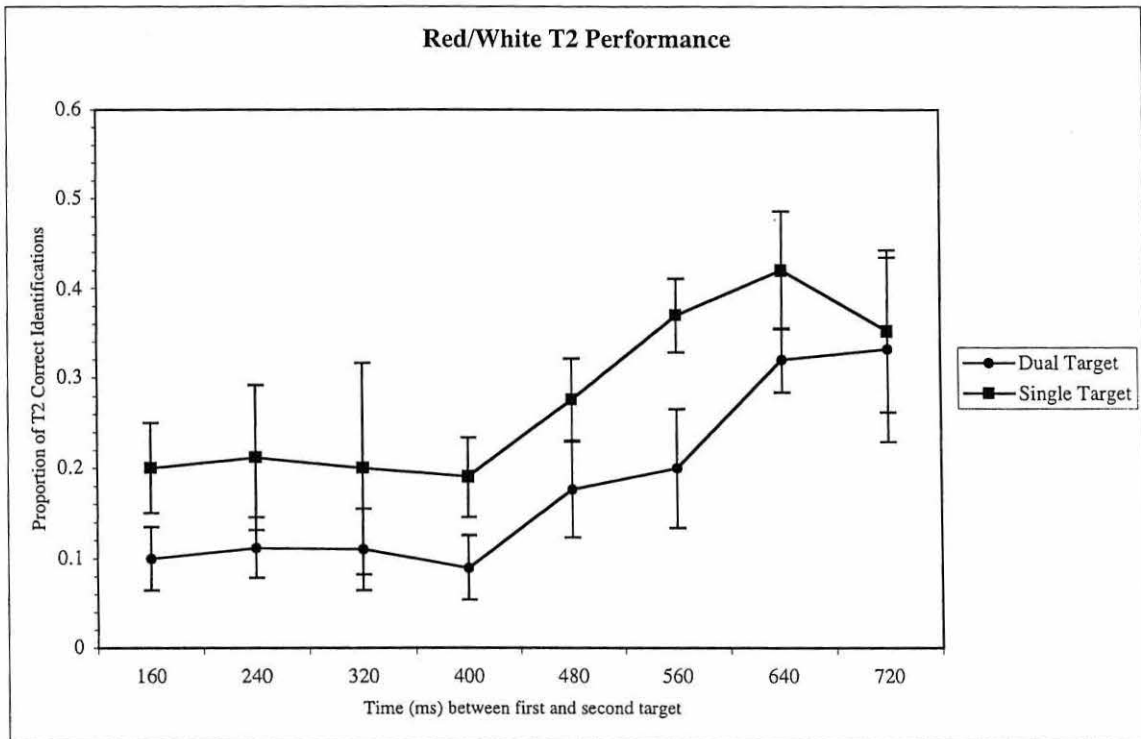


Figure 19: The correct T2 identification as a function of SOA for the two target items in Experiment 4c (Red T1, White T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 19. Table 8 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 4c. An asterix following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 8

	SOA(ms)								
	160	240	320	400	480	560	640	720	
T2 Correct	.10 *	.10	.09	.1 *	.10 *	.17 *	.10 *	.02	
T2+1	-.02	.01	-.01	-.01	-.02	-.13	-.08	-.08	
T1	-.03	-.05 *	-.01	-.02	-.06 *	-.00	-.00	-.02	
T1+1	-.02	-.07 *	-.05	-.06 *	-.02	-.04 *	-.03	-.02	
Importations	-.04	-.00	-.02	-.02	-.02	-.01	.00	.01	

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

When the T2 key feature is a white item after a coloured item has been detected, there is a slight significant AB as measured by the difference scores, but with no systematic error pattern. Although there are some T1 and T1 +1 intrusion differences that were significantly different from zero, they do not fall into a well defined pattern, nor is the magnitude of differences great (from -0.04 to -0.07). Although the results are not as clear as those found in Experiments 4a and 4b, this pattern of results lends support to a hypothesis of non-interference.

#### Experiment 4d: Detect Green, Identify White

##### *Participants*

Fifteen University of Wales, Bangor psychology students from the undergraduate participant pool (10 women, 5 men) ranging in age from 18 to 38 years (mean = 21.4 years, *S.D.* = 5.2 years) participated in Experiment 4d. Five participants were dropped from the study when their T1 false alarms exceeded

30%. In Experiment 4d, participants in the T1 detection condition were instructed to determine whether a green letter (T1) was present and to identify the white letter (T2). They were not required to identify the T1 (green) item.

## Results

### Attentional Blink Effects

*T1 Detection.* T1 items were correctly detected on 83% of the trials. The false alarm rate was 4%, yielding an  $a'$  value of .95. Detecting the presence of a green target while identifying a white T2 item following in close temporal proximity is not a difficult task.

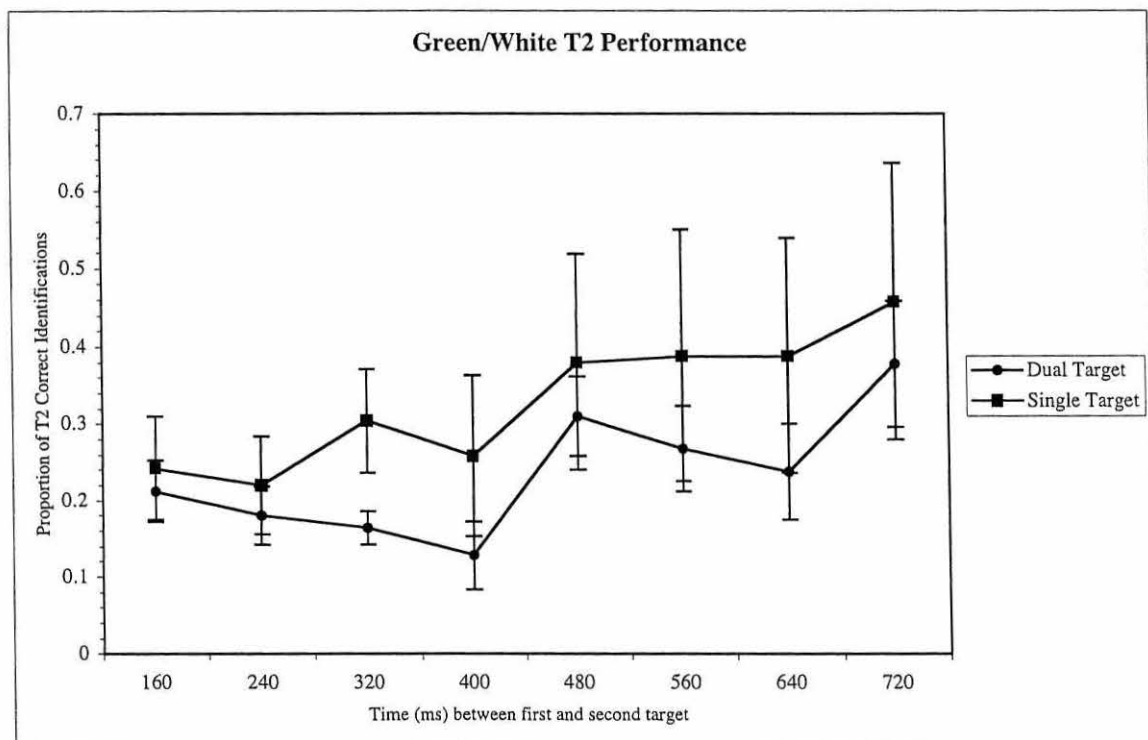


Figure 20: The correct T2 identification as a function of SOA for the two target items in Experiment 4d (Green T1, White T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 20. Table 9 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 4d. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 9

	SOA(ms)							
	160	240	320	400	480	560	640	720
T2Correct	.03	.04	.14 *	.13	.07	.12	.15	.08
T2+1	.06	-.06	-.16	-.13	-.08	-.06	-.06 *	-.04
T1	-.04	-.03	-.03 *	-.05	-.02	-.04	-.06	-.02
T1+1	.00	-.03	-.02	-.03	-.01	-.08 *	-.06	-.03
Importations	-.02	.07	.05	.09 *	.04	.07	.03	.02

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

The results for this experiment are similar to the results observed in Experiment 4c when the T2 key feature was a white item. Although there is an AB, as defined by a significant difference in performance for T2 identification at 320 ms, it is only a small difference in a single position. There is no systematic pattern of intrusion differences, as every possible type of error has a single (though different) point where the differences between the single and dual target tasks is greater than chance. These results are supportive of a lack of interference when different processing systems are required for the two tasks.

*Comparison of Experiments 4a to 4d*

For each of the four critical items (T2, T2 +1, T1, and T1 +1), comparisons were made for the four experiments. A mixed model ANOVA carried out on the T2 correct reports found that there was no significant main effect of group,  $F(3,36) = 1.26, p < .05$ , SOA,  $F(7,252) = 1.32, p < .05$ , or group by SOA interaction,  $F(21,252) < 1$ . A mixed model ANOVA carried out on the T2 +1 intrusions revealed that there was no significant main effect of group,  $F(3,36) < 1$ , a significant main effect of SOA,  $F(7,252) = 2.13, p < .05$ , and no significant group by SOA interaction,  $F(21,252) < 1$ . A mixed model ANOVA carried out on the T1 intrusions revealed both a non-significant main effect of group,  $F(3,36) < 1$ , SOA,  $F(7,252) = 1.3, p < .05$ , and a non-significant group by SOA interaction,  $F(21,252) = 1.28, p < .05$ . Analysis of the T1 +1 intrusion errors revealed non-significant effect for group,  $F(3,36) = 2.44, p < .05$ , SOA,  $F(7,252) < 1$ , and a non-significant group by SOA interaction,  $F(21,252) < 1$ . Since there are no significant differences among the Experiments 4a, 4b, 4c, and 4d for any of the critical items, they shall be collapsed and referred to as Experiment 4.

## Experiment 5: Between System Processing - Colour and Size

Experiments 1 and 2 dealt with the unique activation afforded an additive feature when compared to the subtractive feature task of detecting reduced activation against a high activation backdrop. Experiments 3 and 4 were designed to explicitly test whether the amount of interference would vary when both target tasks in an AB experiment either use the same or different processing resources.

According to the present hypothesis, interference will increase when both tasks are competing for the same processing system resources, whereas when the two tasks are processed by largely separate systems, the observed interference should be minimised.

In Experiment 5 the target key features were either size or colour. Colour is processed in a visual system module that is centred in the V4 area of the brain (Livingstone & Hubel, 1988). In order to detect the largest item from among a set, size processing is a relative comparison (cf. Epstein, 1965; Ittelson & Kilpatrick, 1951; Schiffman, 1967). If the system is attempting to select the larger of two (or more) items, the size of each item processed must be used as a comparator until the largest (or larger) item is found.

In this final experiment, based on the interference continuum model proposed in this thesis, it is expected that we will observe an asymmetry in processing which will depend on the order of the tasks. When the first task (T1) is a size judgement, the size difference should become apparent when the item following the T1 item appears. Although the size of the rest of the items will be processed automatically (cf. Duncan, 1979), the size processing will not be obligatory, and as a result the T2 task (identify the coloured item) will be processed without interference. The results when the large item is the T1 task should be similar to the results found in Experiments 2 and 3. When the tasks are reversed, the opposite is expected.

When the large item is a key feature for the T2 task, the size of all the preceding items must be kept active in order for the size comparison to be successfully completed. Since the processing of every item will engage the same

processing module (size), the pattern of errors should reflect the experiments when interference is maximised (Experiments 1 and 4).

Experiment 5a and 5b are similar to Experiments 4 and 3 (minimal interference) because of the task order. Experiments 5c and 5d resemble Experiments 1 and 4 (maximised interference) because the large item is the T2 task. In both cases, the T1 key features are using resources from different processing modules (dimension) than the T2 key feature, but the difference expected involves whether the item requiring a comparison (largest) appears as the first item in the stream or if it is embedded among the other items. In Experiment 5a, the T1 key feature is the presence of a large item and the T2 key feature is the colour red; Experiment 5b uses a large T1 and a green T2; Experiment 5c uses a red T1 and a large T2; Experiment 5d uses a green T1 and a large T2.

#### Experiment 5a: Detect Large, Identify Red

##### *Participants*

Twenty-one University of Wales, Bangor psychology students from the undergraduate participant pool (16 women, 5) ranging in age from 19 to 42 years (mean = 23.4 years, *S.D.* = 6.05 years) participated. Eleven participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 5a, participants in the T1 detection condition were instructed to determine whether a large letter (T1) was present and to identify the letter that was red (T2). They were not required to identify the T1 item.



*Procedure*

The basic procedure for Experiment 5 (Experiments 5a, 5b, 5c and 5d) was the same as the procedure used in the previous four experiments. Each participant took part in a series of RSVP trials. Each trial consisted of four successive block-style alphabetic characters designated the T1, T1+1, T2, and T2+1 items. The characters were displayed singly at the centre of a uniform field. All standard sized characters were 0.4° in height and approximately 0.25° in width. The difference between Experiment 5 and the other experiments is that there was a larger item (10% larger in both height and width) presented on one of the trials. All stimulus and ISI duration's were determined by the refresh rate of the computer screen.

On a random half of the trials, an item randomly selected from the T1 set of larger items (in Experiments 5a and 5b while in Experiments 5c and 5c the T2 item was delineated by being the larger item). On the remaining trials, an item from the same T1 set of items, but in the same size as the other items presented. The subsequent T1+1, T2 and T2+1 items were randomly drawn from their respective letter sets. The item sets were mutually exclusive to ensure that none of the items would reoccur in the RSVP stream and to ensure that T2 identification errors could be unambiguously attributed to intrusions by T1s, T1+1s, T2+1s, and importations. In all other respects, the procedure used in Experiment 5 was identical to the procedure used in the preceding four experiments.

*Results**Attentional Blink Effects*

*T1 Detection.* T1 items were correctly detected on 66% of the trials. The false alarm rate was 9%, yielding an  $a'$  value of .87. Detecting the presence of a large target is a difficult task while attempting to identify a red target following in close temporal proximity. This conclusion is supported by the fact that over half of the participants had false alarm rates above the threshold set for these tasks (30%); data from these participants was dropped from the analyses. The difficulty of detecting the larger size of the T1 item confidently anticipates the overall results of this set of experiments. Although the experiments demonstrated the overall point, the overall success of the series of experiments was diminished because of the difficulty participants had discriminating the size difference.

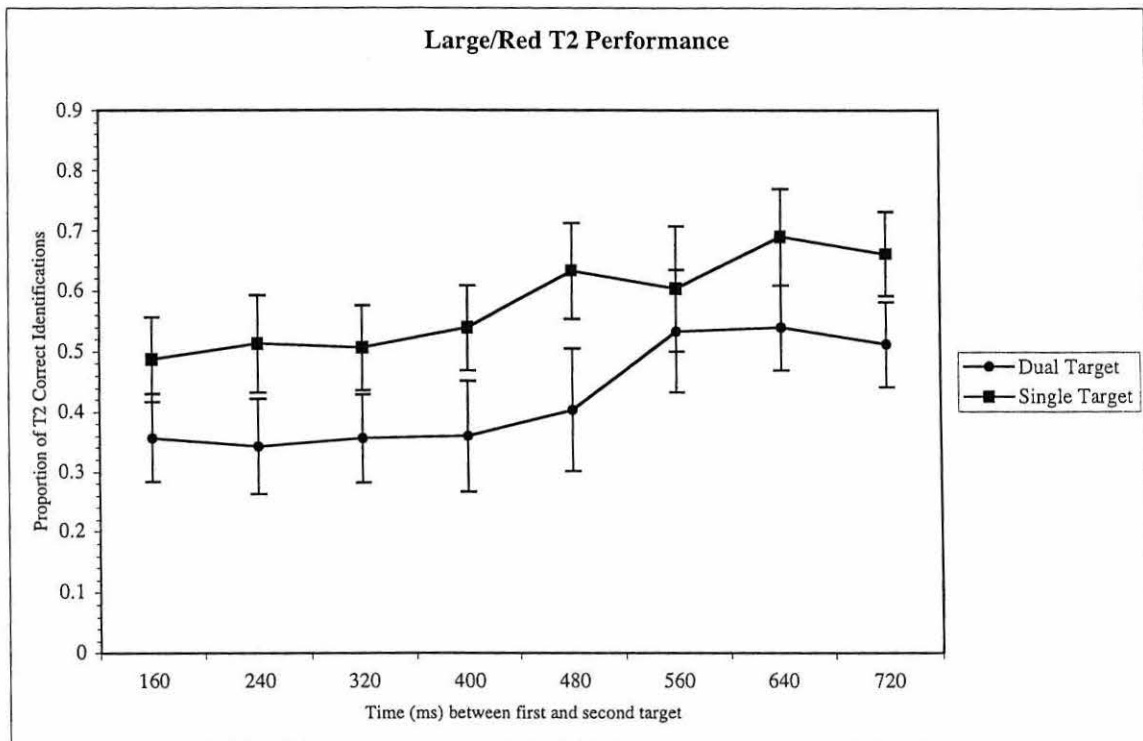


Figure 21: The correct T2 identification as a function of SOA for the two target items in Experiment 5a (Large T1, Red T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 21. Table 10 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 5a. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 10

	SOA(ms)								
	160	240	320	400	480	560	640	720	
T2Correct	.13 *	.17 *	.15 *	.18 *	.23 *	.07	.15 *	.15 *	
T2+1	-.06	-.18 *	-.06	-.09	-.14 *	-.08 *	-.12 *	-.13	
T1	-.04	.00	-.06 *	-.06 *	-.03	-.02	-.04	-.03	
T1+1	-.03	-.00	-.03	-.00	-.02	.04	.01	.02	
Importations	-.00	.00	.00	-.02	-.03	-.02	-.00	-.03	

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

In this experiment, we see the T2+1 intrusion error differences as the predominant error. The T1 intrusions are almost completely non-existent, with only positions three and four being significantly different from zero. This pattern of intrusion differences resembles more closely the pattern of errors observed in Experiment 1 when the T2 item was delimited by a frame around the letter, and Experiment 4 when the T1 and T2 tasks involved either colour or luminance. In Experiments 1 and 4, it was thought that a feature added to an item is processed using different resources from the item itself, and therefore the interference observed is expressed as T2 +1 errors. It appears that for this experiment, we are seeing the same kind of processing. When the two tasks require different processes, the observed errors in identifying the T2 item are not related to the T1 item, even though that item requires selection along some dimension.

## Experiment 5b: Detect Large, Identify Green

*Participants*

Nineteen University of Wales, Bangor psychology students from the undergraduate participant pool (10 women, 9 men) ranging in age from 19 to 48 years (mean = 25.3 years, *S.D.* = 6.03 years) participated in Experiment 5b. Nine participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 5b, participants in the T1 detection condition were instructed to determine whether a large letter (T1) was present and to identify the letter that was green (T2). They were not required to identify the T1 item.

*Results**Attentional Blink Effects*

*T1 Detection.* T1 items were correctly detected on 60% of the trials. The false alarm rate was 6%, yielding an  $a'$  value of .86. Detecting the presence of a large target is a difficult task while attempting to identify a green target following in close temporal proximity.

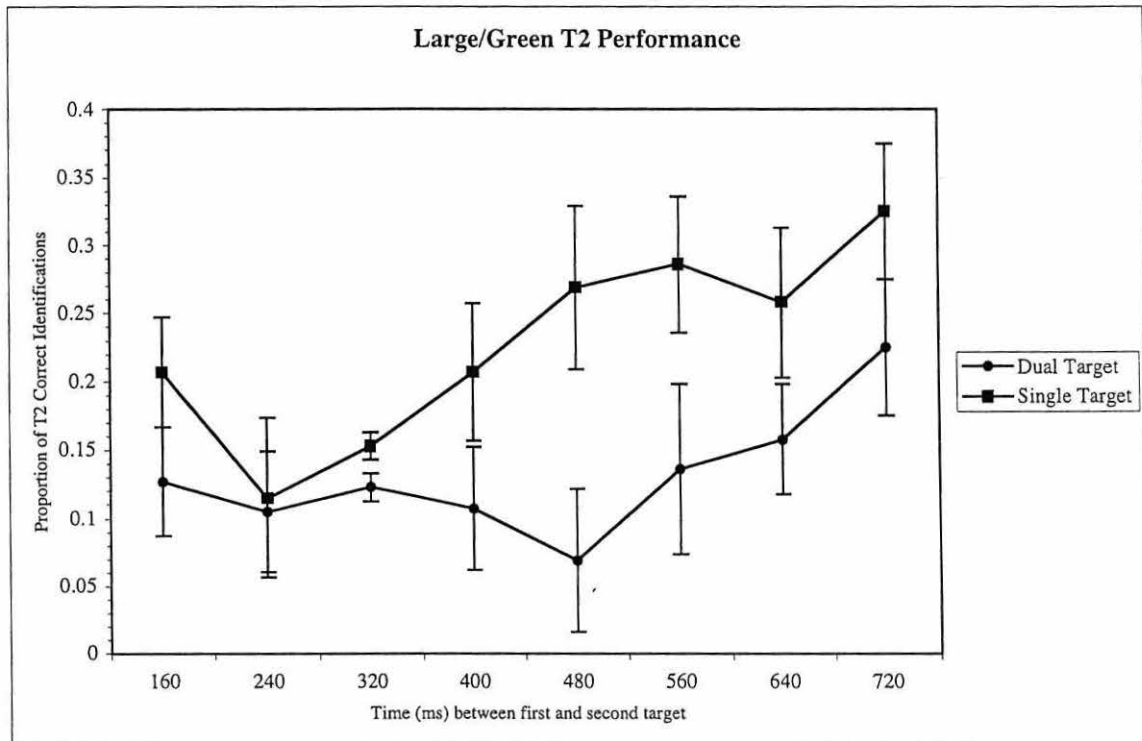


Figure 22: The correct T2 identification as a function of SOA for the two target items in Experiment 5b (Large T1, Green T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 22. Table 11 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 5b. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 11

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2Correct	.08 *	.01	.03 *	.10 *	.20 *	.15 *	.10 *	.10 *		
T2+1	-.13	-.04	-.05	-.04	-.18 *	-.10	-.11 *	-.05		
T1	-.03	.00	-.02	-.03	-.02	.00	-.02	-.03 *		
T1+1	.05 *	.01	-.02	-.03	-.00	-.03	.02	-.03		
Importations	.03	.01	-.05	-.02	-.02	-.02	0	.02		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

As expected, in this experiment the T2+1 intrusion error differences are the predominant intrusion error. The T1 intrusions almost completely disappear. This pattern of intrusions is consistent with the two tasks requiring different resources which has been observed in both Experiments 1 and 4.

### Experiment 5c: Detect Red, Identify Large

#### *Participants*

Eleven University of Wales, Bangor students from the undergraduate participant pool (nine women, two men) ranging in age from nineteen to 48 years (mean = 24 years, *S.D.* = 8.4 years) participated in Experiment 5c. One participant was dropped from the study when their T1 false alarms exceeded 30%. In Experiment 5c, participants in the T1 detection condition were instructed to determine whether a red letter (T1) was present and to identify the letter that

was larger than the rest (T2). They were not required to identify the T1 (red) item.

## Results

### Attentional Blink Effects

*T1 Detection.* T1 items were correctly detected on 93% of the trials. The false alarm rate was 3%, yielding an  $a'$  value of .97. Detecting the presence of a red target while attempting to identify a large target following in close temporal proximity is not a difficult task.

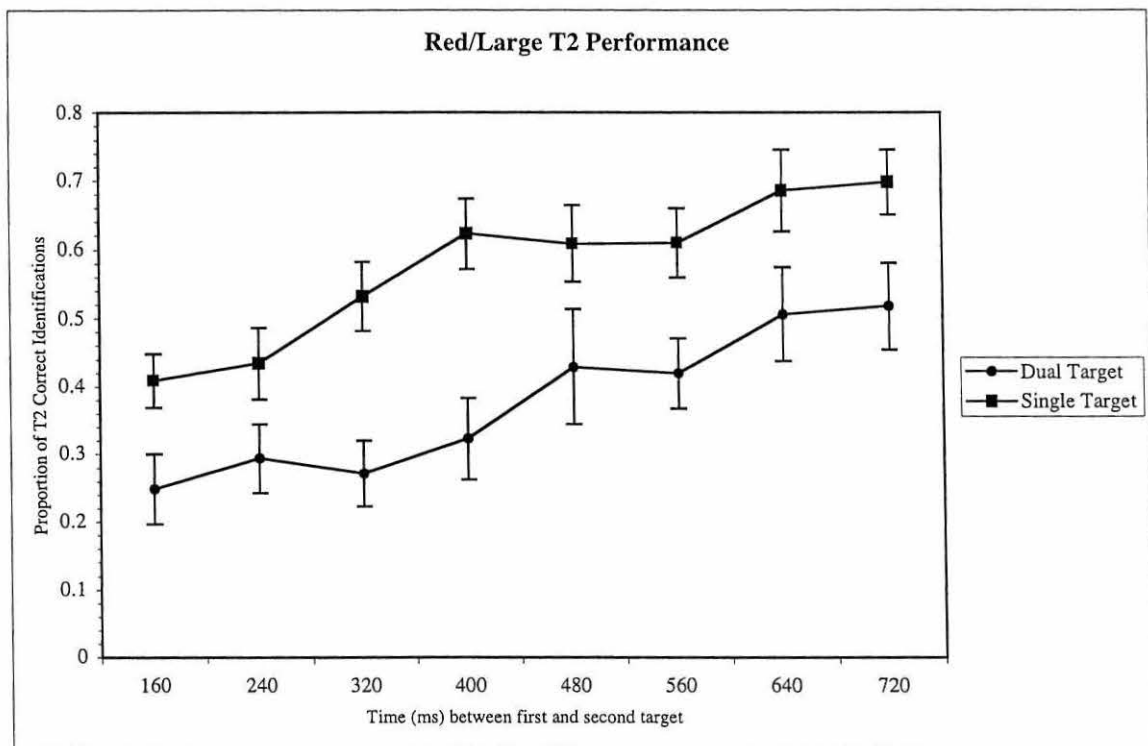


Figure 23: The correct T2 identification as a function of SOA for the two target items in Experiment 5c (Red T1, Large T2). Vertical bars represent  $\pm 1$  standard error of the mean.



*T2 report.* The raw T2 single and dual task data are illustrated in Figure 23. Table 12 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 5c. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 12

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2 Correct	.16 *	.14 *	.26 *	.30 *	.18 *	.19 *	.18 *	.18 *	.18 *	.18 *
T2+1	-.11	.02	-.14 *	-.13 *	-.07	-.15 *	-.08	-.08	-.06	
T1	-.10 *	-.13 *	-.12 *	-.07 *	-.08 *	-.07 *	-.07 *	-.07 *	-.03 *	-.03 *
T1+1	.02	-.01	-.02	-.08 *	-.09 *	-.07 *	-.05 *	-.10 *		
Importations	.03	-.03	.01	-.04	.06	.10 *	.03	.00		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

When the T2 key feature is a larger item, and presumably draws on different processing modules from those used to detect the presence of a coloured T1 item, it was expected that the intrusions from the T1 and T1+1 items would be very low; this is not the case. In order to successfully complete the task of determining the largest item, the size of each item must be processed and kept active so size comparisons can be carried out. This processing is necessary for each item until the key feature (a larger item) is detected. Since the detection of a larger item embedded in the stream involves the processing of every item using the same resources, it is not surprising that the results do not support

independent processing modules. At every SOA, the number of T1 intrusions is significantly different from zero, and for each SOA greater than 400 ms, the number of T1 +1 intrusions is different from zero. The results support the case of maximised interference found when items demand the same resources for task completion.

When the T2 key feature in the Isaak et al. (1999) was a size judgement (a smaller item), a similar pattern of results was observed. The explanation proposed by Isaak et al. was that when the T2 key feature is not processed, there are a number of possible identities to choose from. Since there is no clear T2 item, any one of the four items shown in the stream can be chosen. An equally plausible explanation is the one proposed above. Because all the items must be processed using the same resources in order to detect a size difference, interference is expected to manifest itself as the intrusion of items kept activated.

#### Experiment 5d: Detect Green, Identify Large

##### *Participants*

Sixteen University of Wales, Bangor psychology students from the undergraduate participant pool (1 women, 5 men) ranging in age from 19 to 38 years (mean = 24 years, *S.D.* = 6.1 years) participated in Experiment 5d. Six participants were dropped from the study when their T1 false alarms exceeded 30%. In Experiment 5d, participants in the T1 detection condition were instructed to determine whether a green letter (T1) was present and to identify the letter

that was larger than the rest (T2). They were not required to identify the T1 (green) item.

## Results

### Attentional Blink Effects

*T1 Detection.* T1 items were correctly detected on 83% of the trials. The false alarm rate was 3%, yielding an  $a'$  value of .95. As in Experiment 3, detecting a coloured T1 is not a difficult task.

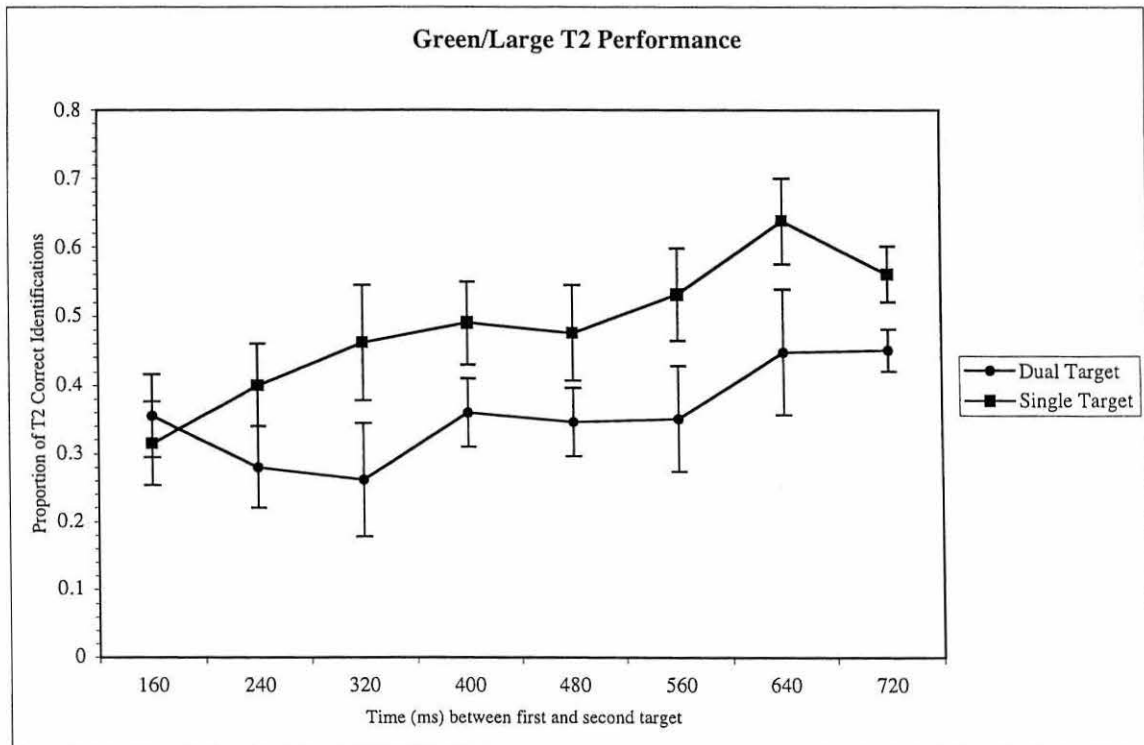


Figure 24: The correct T2 identification as a function of SOA for the two target items in Experiment 5d (Green T1, Large T2). Vertical bars represent  $\pm 1$  standard error of the mean.

*T2 report.* The raw T2 single and dual task data are illustrated in Figure 24. Table 13 shows the single target and dual target differences across all eight SOAs for each of the five possible report types in Experiment 5d. An asterisk following a number indicates that it is significantly different from zero at less than 0.05 probability.

Table 13

	SOA(ms)									
	160	240	320	400	480	560	640	720		
T2Correct	-.04	.12 *	.20 *	.13 *	.13 *	.18 *	.19 *	.11 *		
T2+1	-.00	.03	-.06	.04	.01	-.02	-.10 *	.08		
T1	-.08	-.06	-.10	-.09 *	-.08 *	-.09 *	-.09 *	-.09 *		
T1+1	0	-.10 *	-.07 *	-.05	-.12 *	-.05	-.04	-.10 *		
Importations	.12 *	.00	.02	-.03	.04	-.03	.03	-.01		

(A positive score indicates higher performance in the single target task, while a negative score indicates higher performance on the dual target task. A score of .00 indicates a non-zero value between  $\pm 0.01$  and zero.)

The results for this experiment are similar to the results observed in Experiment 5c when the T2 key feature was a large item. Once again, it appears that, when the T2 key feature is a comparative judgement involving the other items, a high rate of intrusions for the preceding items (T1 and T1 +1) is expected.

#### *Comparison of Experiments 5a to 5d*

Comparisons follow for each of the four critical item differences (T2, T2 +1, T1, and T1 +1) across the four experiments. A mixed model ANOVA carried out on the T2 correct reports found that there was no significant main effect of

group,  $F(3,36) = 1.35$ ,  $p < .05$ , a significant main effect of SOA,  $F(7,252) = 2.52$ ,  $p < .05$ , and no significant group by SOA interaction,  $F(21,252) = 1.27$ ,  $p < .05$ . The significant SOA effect indicates that the T2 item was reported less often in the dual target trials for short SOAs (about 8% difference) than for the longer SOAs (about 14% difference).

A mixed model ANOVA carried out on the T2 +1 intrusions revealed that there was no significant main effect of group,  $F(3,36) = 1.93$ ,  $p < .05$ , no main effect of SOA,  $F(7,252) < 1$ , and no significant group by SOA interaction,  $F(21,252) = 1.34$ ,  $p < .05$ .

A mixed model ANOVA carried out on the T1 intrusions did reveal a significant main effect of group,  $F(3,36) = 3.29$ ,  $p < .05$ , but no significant effect of SOA,  $F(7,252) < 1$ , or group by SOA interaction,  $F(21,252) < 1$  (see Figure 25).

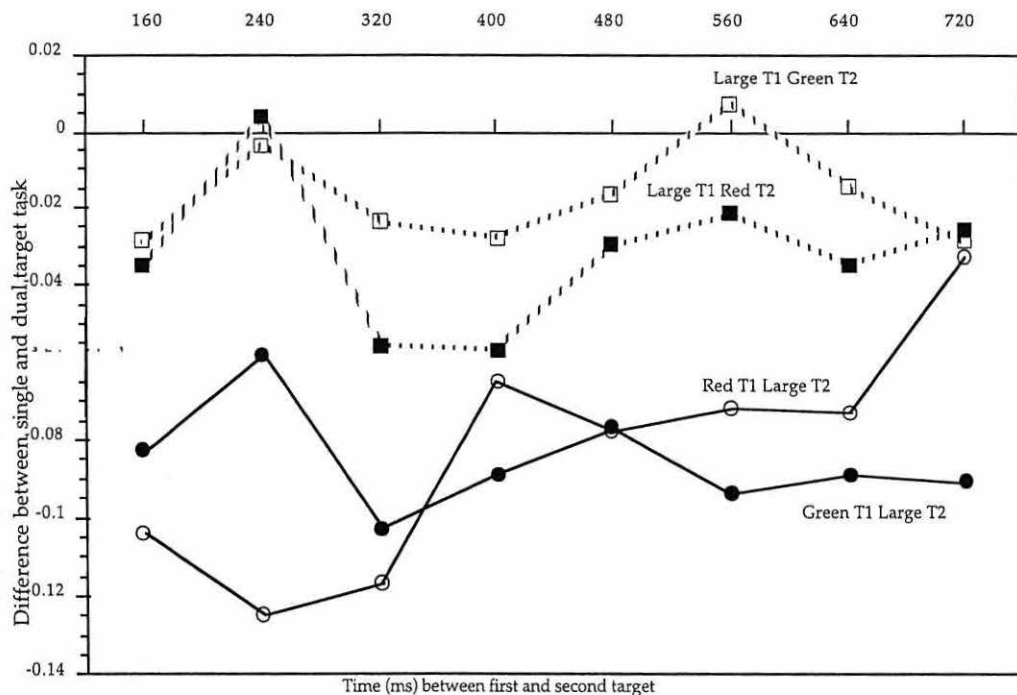


Figure 25: The difference scores for T1 intrusion errors as a function of SOA for the two target items between Experiments 4a, 4b, 4c, and 4d. The dotted line groups the conditions when the T1 task was to detect the presence of a large item and the T2 task was to identify a coloured letter. The solid line represents the reversal of the tasks. Because of the large variability values, no error bars are shown.

Analysis of the T1 +1 intrusion errors also revealed a significant effect of group,  $F(3,36) = 5.93, p < .05$ , SOA,  $F(7,252) = 3.59, p < .05$ , and a group by SOA interaction,  $F(21,252) = 1.75, p < .05$  (see Figure 26).

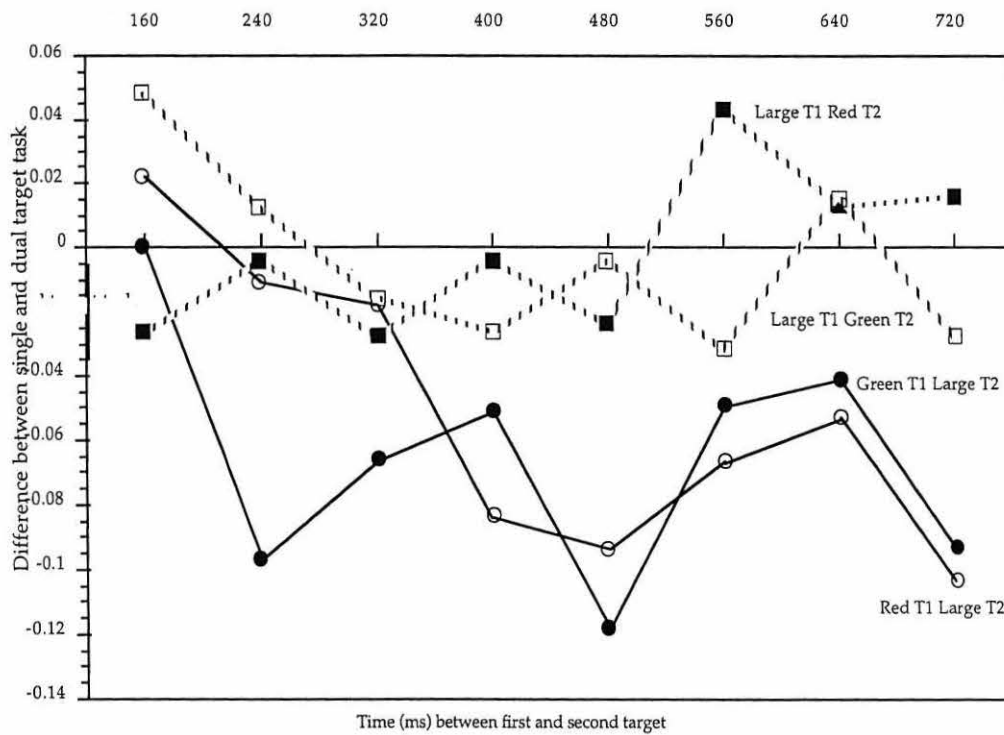


Figure 26: The difference scores for T1 +1 intrusion errors as a function of SOA for the two target items between Experiments 4a, 4b, 4c, and 4d. The dotted line groups the conditions when the T1 task was to detect the presence of a large item and the T2 task was to identify a coloured letter. The solid line represents the reversal of the tasks. Because of the large variability values, no error bars are shown.

A mixed model ANOVA was carried out on task order (colour first or large first) for both the T1 and T1 +1 intrusion error differences. When the T1 errors were examined a significant main effect of order in the T1 intrusions,  $F(1,38) = 10.03, p < .05$ , but no effect of SOA,  $F < 1$ , or order by SOA interaction,  $F < 1$  was observed. The T1 +1 analysis showed that there was a significant main effect of order,  $F(1,28) = 17.98, p < .05$ , a significant main effect of SOA,  $F(7,266) = 3.47, p < .05$ , and a marginally significant order by SOA interaction,  $F(7,266) = 1.83, p < .08$ .

The task order effects, along with the group effects for the T1 and T1 +1 intrusions found in Experiment 5 confirms the expected processing asymmetry when the large item appeared either as the first item in the RSVP stream or embedded in the RSVP stream.

#### *Within System and Between System Processing Analyses*

To begin with, the data from Experiments 3 (colour/colour), 4 (luminance/colour), and 5 (large/colour) will be included as components of an analysis, followed by an analysis comparing the two non-interference based experiments (Experiments 4, 5c and 5d) with Experiment 3.

#### *Analysis of T2 Performance*

A mixed model ANOVA on T2 performance on the data from the three experiments revealed a non-significant effect of group,  $F(2,77) = 2.11, p < .05$ , SOA,  $F(7,539) = 1.40, p < .05$ , and group by SOA interaction,  $F(14,539) = 1.33, p < .05$  (see Figure 27). In following up the significant group by SOA interaction two differences were found which were not of interest to this thesis; in the comparison between Experiment 4 (luminance/colour) and Experiment 5 (large/colour), a significant effect of SOA was observed,  $F(7,406) = 2.25, p < .05$ , and in the comparison between Experiment 3 (colour/colour) and Experiment 5 (large/colour), a significant group by SOA interaction was found,  $F(7,266) = 2.08, p < .05$ .



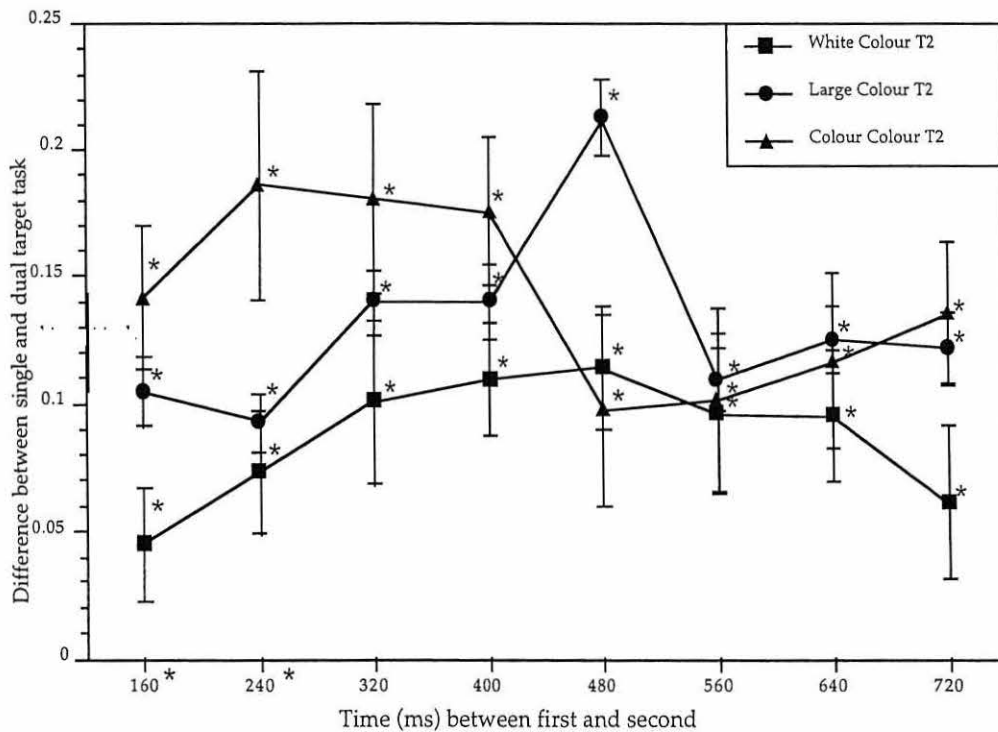


Figure 27: An Asterisk next to the symbol indicates that the point is significantly different from zero. An asterisk next to the SOA value indicates a significant difference between the White Colour (between) and the Colour Colour (within). An ampersand next to the SOA value indicates a significant difference between Large Colour (between) and the Colour Colour (within) conditions. All significant differences are at the  $p < .05$  level.

### Analysis of T2 +1 Intrusions

A mixed model ANOVA on T2 +1 intrusions on the data from the three experiments revealed a significant effect of group,  $F(2,77) = 3.09$ ,  $p < .05$ , but a non-significant SOA effect,  $F(7,539) < 1$ , and non-significant group by SOA interaction,  $F(14,539) = 1.03$ ,  $p < .05$  (see Figure 28). Planned pairwise comparisons for the experiments revealed a single significant finding; in the comparison between Experiment 3 (colour/colour) and Experiment 5 (large/colour), a significant group effect was observed,  $F(1,38) = 4.49$ ,  $p < .05$ .

This difference indicates that there are more T2 +1 intrusions in the dual target task than the single target task for Experiment 5 (large/colour) than for Experiment 3 (colour/colour) (see Figure 28).

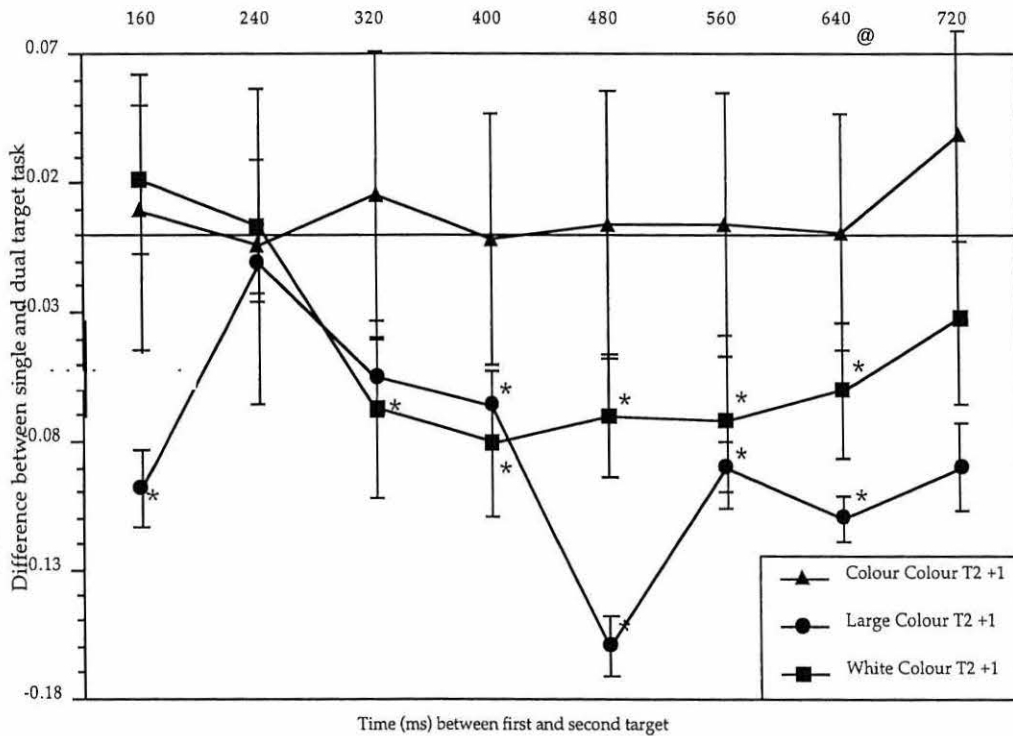


Figure 28: An Asterisk next to the symbol indicates that the point is significantly different from zero. An asterisk next to the SOA value indicates a significant difference between the White Colour (between) and the Colour Colour (within). An ampersand next to the SOA value indicates a significant difference between Large Colour (between) and the Colour Colour (within) conditions. All significant differences are at the  $p < .05$  level.

### Analysis of T1 Intrusions

A mixed model ANOVA on T1 intrusions on the data from the three experiments revealed a significant effect of group,  $F(2,77) = 5.89, p < .05$ , but a non-significant SOA effect,  $F(7,539) = 1.79, p < .05$ , and non-significant group by

SOA interaction,  $F(14,539) = 1.62, p < .05$  (see Figure 29). Planned pairwise comparisons revealed significant group differences in both comparisons looking at between and within system processing. The differences in comparing Experiments 3 (colour/colour) and 5 (large/colour) were significant,  $F(1,38) = 4.05, p < .05$ , and the differences between Experiments 3 (colour/colour) and 4 (luminance/colour) were also significant,  $F(1,58) = 8.15, p < .05$  (see Figure 29). In addition, there was a significant SOA effect in the comparison between Experiments 3 (colour/colour) and 4 (luminance/colour),  $F(7,406) = 3.44, p < .05$ .

The significant group differences suggest that for both the between system processing experiments, the differences in T1 intrusions between dual and single task are almost nil. This can be seen in Figure 29 where the square and circle symbols are very near zero. In contrast, when both the target key features demand the same, or similar resources, when the identity of the T2 item is missed, it is more likely that the identity for the T1 item is selected. This result lies at the heart of the interference theory. When the two items use the same processing resources, they will interfere with each other. When they do not require the same resources for processing, there will be much less interference observed between the two items.

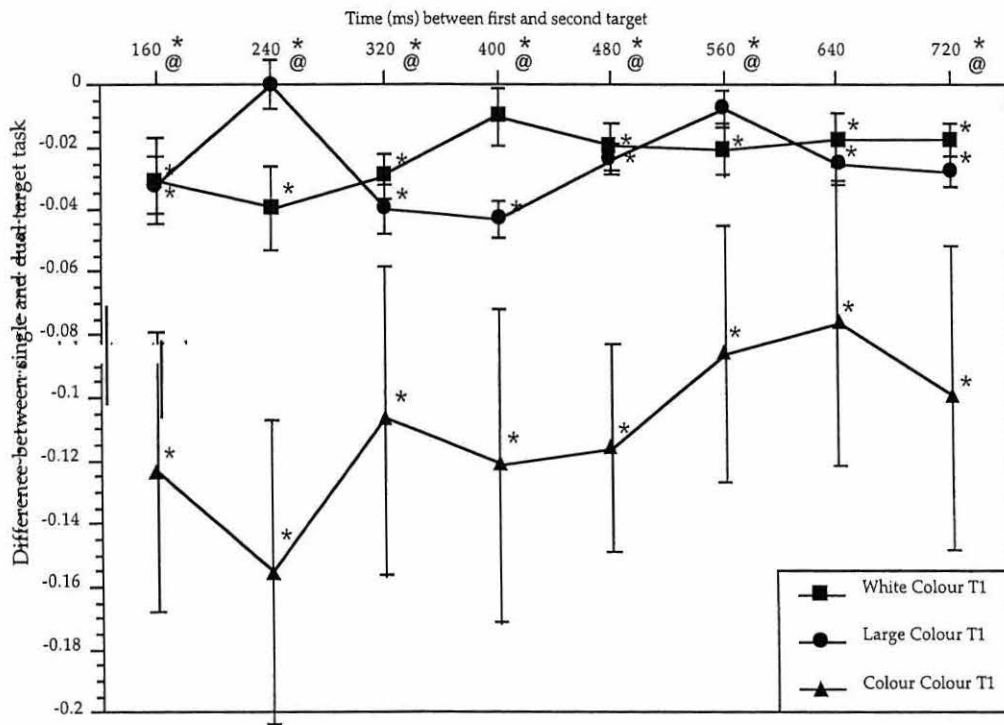


Figure 29: An Asterisk next to the symbol indicates that the point is significantly different from zero. An asterisk next to the SOA value indicates a significant difference between the White Colour (between) and the Colour Colour (within). An ampersand next to the SOA value indicates a significant difference between Large Colour (between) and the Colour Colour (within) conditions. All significant differences are at the  $p < .05$  level.

### Analysis of T1 +1 Intrusions

A mixed model ANOVA on T1 +1 intrusions on the data from the three experiments revealed a significant effect of group,  $F(2,77) = 5.37, p < .05$ , but a non-significant SOA effect,  $F(7,539) < 1$ , and non-significant group by SOA interaction,  $F(14,539) < 1$  (see Figure 30). Once again, the planned pairwise comparisons revealed significant group differences in both comparisons looking at between and within system processing found the expected differences; there would be a significant difference in the T1 +1 intrusion errors between the

interference and non-interference experiments, but not between the two non-interference experiments. The difference between Experiments 3 (colour/colour) and 5 (large/colour) was significant,  $F(1,38) = 7.83, p < .05$ , and the difference between Experiments 3 (colour/colour) and 4 (luminance/colour) was also significant,  $F(1,58) = 4.41, p < .05$  (see Figure 30).

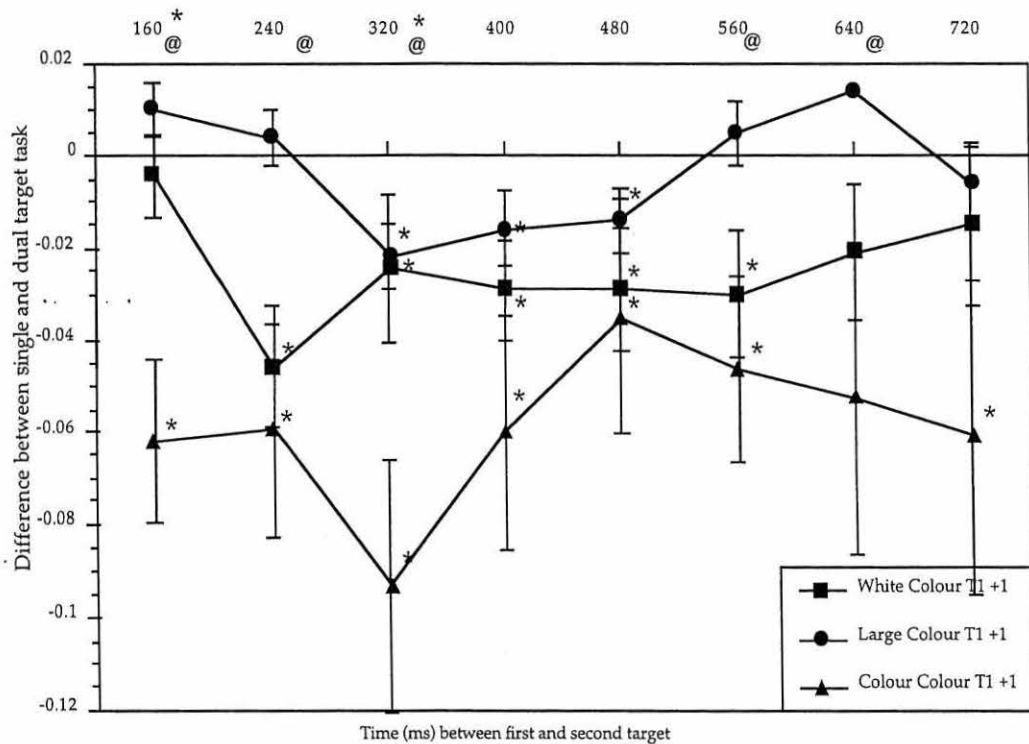


Figure 30: An Asterisk next to the symbol indicates that the point is significantly different from zero. An asterisk next to the SOA value indicates a significant difference between the White Colour (between) and the Colour Colour (within). An ampersand next to the SOA value indicates a significant difference between Large Colour (between) and the Colour Colour (within) conditions. All significant differences are at the  $p < .05$  level.

*Analysis of interference and non-interference processes*

The immediately preceding set of analyses concerns the experiments designed to test whether processes which compete for the same resources would show a higher degree of interference than those which are processed using different resources. This hypothesis is supported by the results of Experiments 3, 4, and 5. Experiment 1 and 2 were carried out examining the effects of additive and subtractive key features. These too, can be thought of as manipulations that vary whether processes compete for resources or are processed in separate systems. In the final analysis, all the experiments, including Experiments 1 and 2 (which were carried out using a different rationale) will be categorised according to whether the manipulation was intended to minimise or maximise interference. The experiments will be divided in the following manner. Experiments 1 (framed T2), 5c, 5d (large/colour), and 4 (colour/luminance) will be grouped as the non-competitive experiments, while Experiments 2 (unframed T2) and 3 (colour/colour), and 5a, 5b (colour/large) will be classed as competitive experiments.

*Analysis of T2 Performance*

A mixed model ANOVA on T2 performance on the data for the two groups (competitiveness and non-competitiveness) revealed a non-significant effect of group  $F(1,98) = 2.72, p < .05$ , a significant effect of SOA,  $F(7,686) = 2.42, p < .05$ , and a significant group by SOA interaction,  $F(7,686) = 2.48, p < .05$  (see Figure 31).

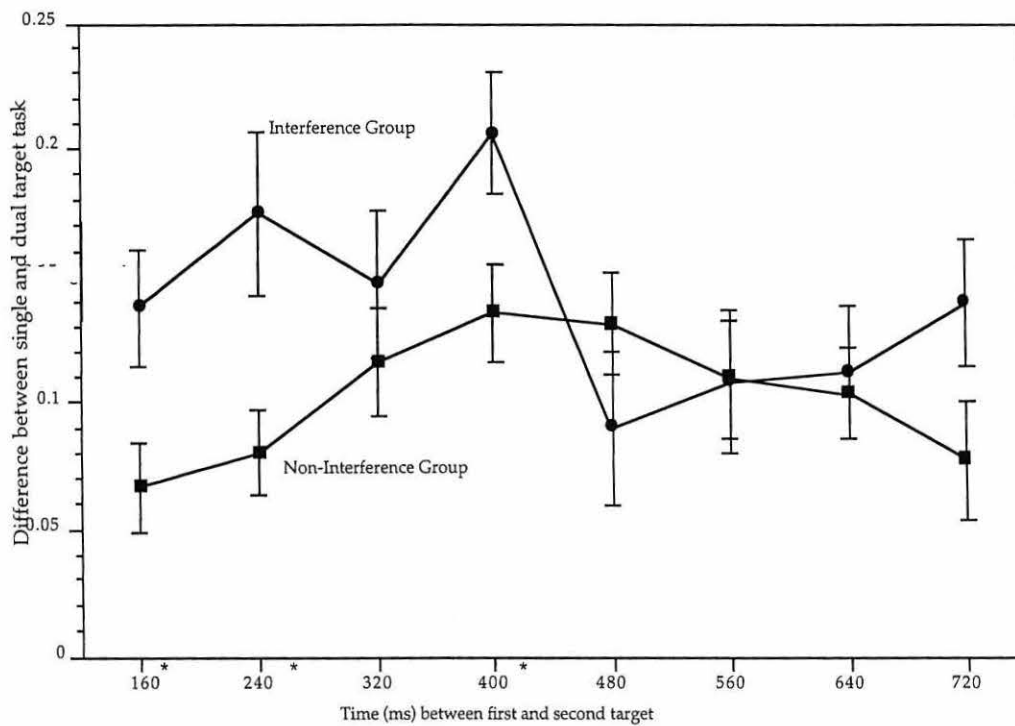


Figure 31: The difference scores for correct T2 identification as a function of SOA for the interference group of experiments (filled circles), and for the non-interference group of experiments (filled squares). Vertical bars represent  $\pm 1$  standard error of the mean. An asterix next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

Further examination of the group in SOA interaction shows that during the period of the AB (180 to 360 ms), T2 performance is worse in the interference group than in the non-interference group. When the key features for the two targets are manipulated to minimise interference, there is a reduced AB.

#### *Analysis of T2 +1 Intrusion Errors*

A mixed model ANOVA on T2 +1 intrusion errors on the data for the two groups (competitiveness and non-competitiveness) revealed a significant effect

of group  $F(1,98) = 6.66, p < .05$ , but non-significant effects of both SOA,  $F(7,686) < 1$ , and group by SOA interaction,  $F(7,686) = 1.59, p < .05$  (see Figure 32).

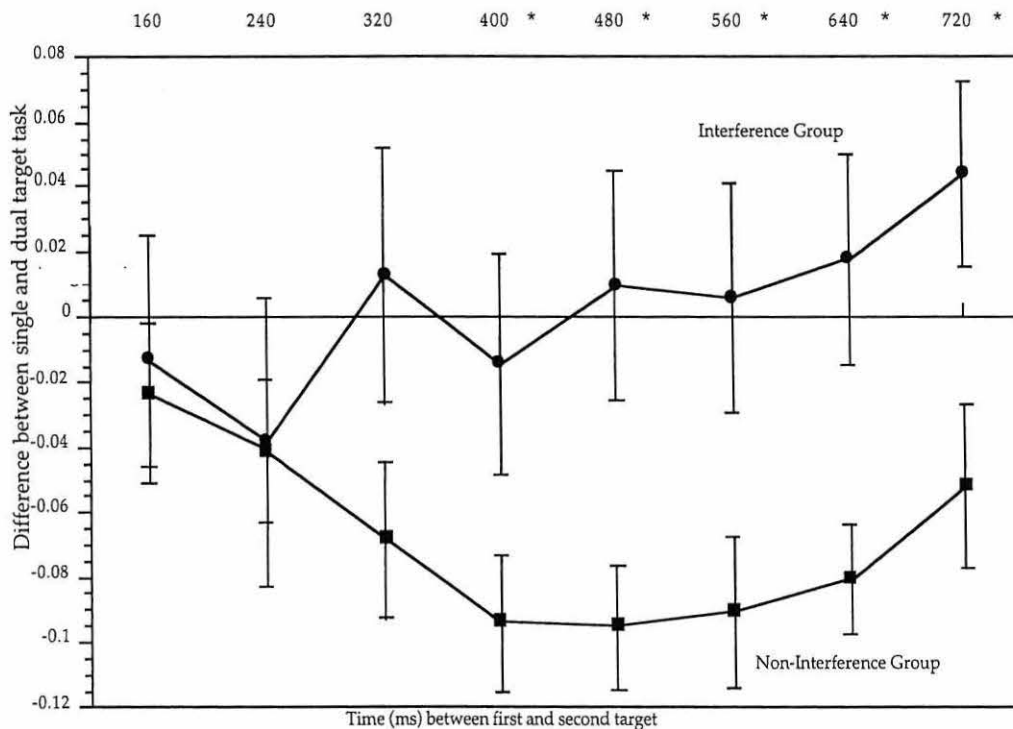


Figure 32: The difference scores for T2+1 intrusions as a function of SOA for the interference group of experiments (filled circles), and for the non-interference group of experiments (filled squares). Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

Further examination of the intrusion errors for group differences shows that there is little difference in the two groups for the SOAs immediately following the first target (160 and 240 ms), but from 320 ms until 720 ms, the two groups diverge. For SOAs greater than 320 ms, the T2 +1 intrusion errors account for a large proportion of the difference between single and dual task performance in the non-interference group. During the same time frame, there



is virtually no difference in the number of T2 +1 intrusions in single and dual target performance when the two key features are manipulated so as to maximise interference. In other words, when interference is minimised, when the T2 item is identified incorrectly as a result of having to perform a T1 task, one of the most likely candidates for providing an identity is the item immediately following the T2 item. This is not the case when the two key features are selected to maximise interference. In this case, the probability of selecting the identity of the T2 +1 item is no greater in the dual target task than it is in the single target task. The incorrect item that is replacing the correct T2 in VSTM in order to produce an AB is something other than the T2+1 item.

#### *Analysis of T1 Intrusion Errors*

A mixed model ANOVA on T1 intrusion errors on the data for the two groups (competitiveness and non-competitiveness) revealed a significant effect of group  $F(1,98) = 14.95, p < .05$ , but non-significant effects of both SOA,  $F(7,686) = 1.39, p < .05$ , and group by SOA interaction,  $F(7,686) < 1$  (see Figure 33).

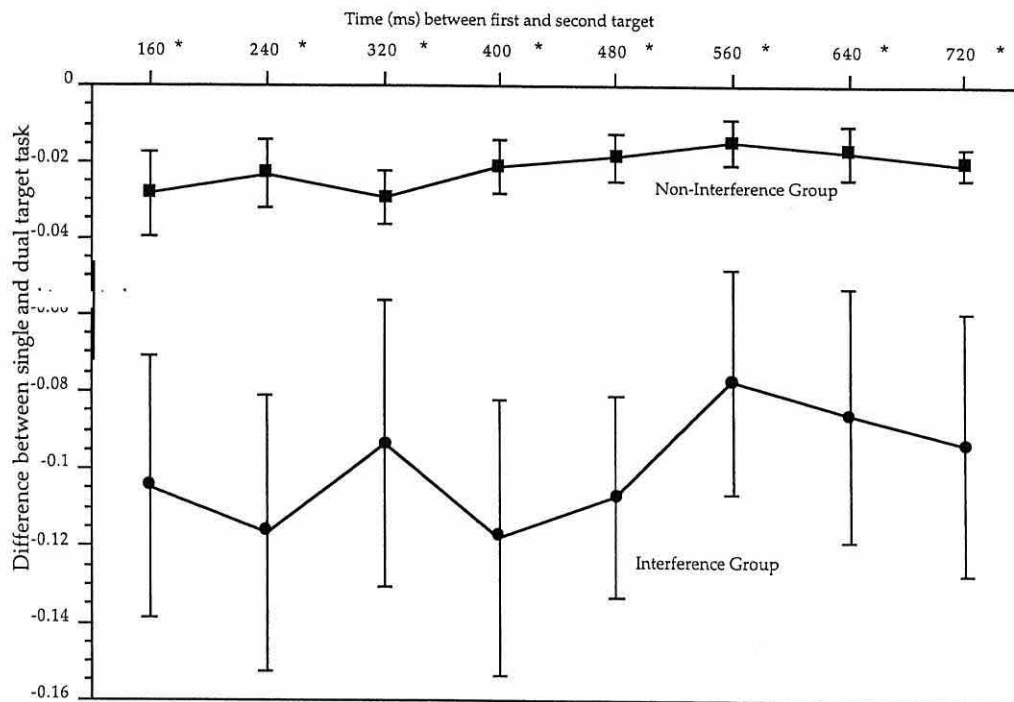


Figure 33: The difference scores for T1 intrusions as a function of SOA for the interference group of experiments (filled circles), and for the non-interference group of experiments (filled squares). Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

This is one of the two most important findings to support this thesis (the other is the T1+1 intrusion rate reported next). In both conditions (interference and non-interference), it was necessary to select the key feature of the T1 item, and then identify the item denoted by the T2 key feature. When the two key features were selected to minimise interference, the probability of reporting the identity of the T1 item in place of the T2 item was only slightly higher (2 to 3 percent) in the dual target task than in the single target task. This is in contrast with the group in which the two key features were manipulated so that they both required the same resources for processing, and were required to compete

for those resources. In the case of maximised interference, there is a much greater likelihood of reporting the identity of the T1 item when the T2 item is incorrectly identified during the dual target trials than during the single target trials. In effect, the manipulation was effective: requiring processing along the same dimension for both items resulted in a measurable increase in interference observed between the two target items.

#### *Analysis of T1 +1 Intrusion Errors*

A mixed model ANOVA on T1 +1 intrusion errors on the data for the two groups (competitiveness and non-competitiveness) revealed a significant effect of group  $F(1,98) = 6.01, p < .05$ , but non-significant effects of both SOA,  $F(7,686) < 1$ , and group by SOA interaction,  $F(7,686) < 1$  (see Figure 34).

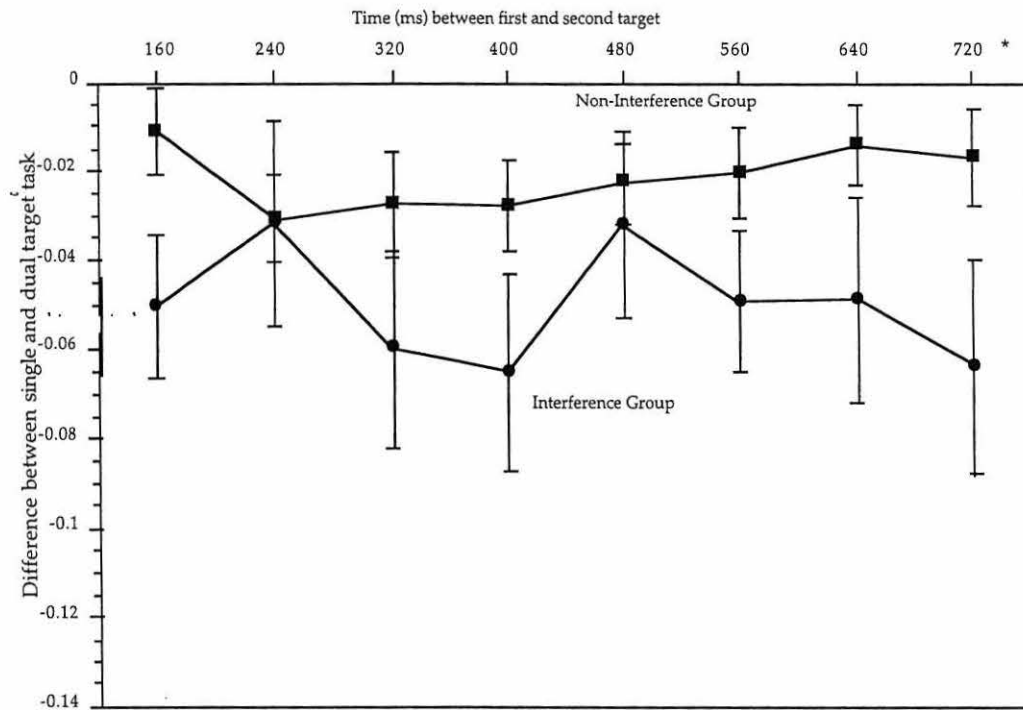


Figure 34: The difference scores for T1+1 intrusions as a function of SOA for the interference group of experiments (filled circles), and for the non-interference group of experiments (filled squares). Vertical bars represent  $\pm 1$  standard error of the mean. An asterisk next to the SOA value indicates that the two points on the graph are significantly different ( $p < .05$ ).

The likelihood of reporting the T1 +1 item in place of the T2 item was consistently greater in the interference group than in the non-interference group. Again, this finding is supportive of the thesis. The most common type of interference observed in RSVP research is the intrusion of the +1 item. By maximising interference, the item immediately preceding the T2 item is selected more often. This provides evidence for a more full processing of all the items prior to selection, whereas in the case of minimised interference, the T2 item is selected as soon as the key feature matches an internal template. This results in the intrusion errors following the T2 item (T2+1)

### General Discussion

Throughout this series of experiments, the underlying theme has been a contrast between the visual processing of two targets requiring detection or identification under conditions of either maximised or minimised interference. In the experiments designed to maximise interference, either through the detection of a subtractive feature (Experiment 2) or having both the T1 and T2 key feature drawn from the same processing dimension, e.g. colour (Experiment 3), the pattern of T2 reported items was as follows. The pattern of T2 errors followed a traditional AB pattern, with more incorrect T2 reports between 160 ms and 400 ms in the dual target task than in the single target task. The percentage of correct T2 reports reached a peak difference between single and dual target tasks of 20% at 400 ms before falling away to a difference of about 10% at 720 ms. The T2 +1 intrusions were very close to zero at every SOA indicating that there was no difference in T2+1 intrusions between the single and dual target trials. The T1 intrusion difference averaged about -10%, with little variation across SOAs; this indicates that the T1 item was systematically reported as the T2 item at a consistent rate in the dual target trials, but not in the single target trials. Finally, the T1 +1 item was reported as the T2 item with increasing frequency in the dual target trials as the SOA between the two targets increased (indicated by the sloped, negative line in Figure 34) to a maximum of about -6% at 720 ms.

When the Experiments were designed to minimise interference either through the detection of an additive feature (Experiment 1), or by specifying the

key features as coming from different processing dimensions (white and colour in Experiment 4 and large and colour as in Experiment 5), the results were different. Although there was a traditional curved AB pattern with the peak difference between single and dual target performance occurring at about the 400 ms SOA (13% difference), the blink was shallower in the minimal interference experiments, being significantly different for most of the first 400 ms. The rate of T2 +1 intrusions increased in the dual target trials to a maximum of about -10% between 400 ms and 560 ms before falling off to about -6% at the longest SOAs, while the rate of T1 and T1 +1 intrusions in the dual target trials were both very low and with a flat function at each SOA (around -3%). When the interference was minimised, the selection of the critical feature belonging to the T1 item necessary for successful completion of the T1 task did not result in an increase in the number of T1 intrusions when the identity of the T2 item was unavailable. This is in contrast to the experiments where interference was maximised and the critical T1 item was systematically reported as the T2 item. The importation rate (the rate of guessing an item which was not shown in the RSVP stream) in both conditions (minimal and maximal interference) was identical, with no difference being found between the single and dual target trials.

#### *Discussion of Models of the AB*

There were four theoretical models of visual attention discussed in the introductory chapters of the thesis, all of which have been used to explain the AB phenomenon. They are (a) a two-stage model of attention, (b) an inhibitory model, (c) criterion shifting and, (d) the interference model of attention. Each of

these models will be considered in light of the results reported in this thesis. The final model discussed is the interference continuum model (a variant of Shapiro's interference model) presented as an alternative to explain the results of this thesis.

### *Two-stage Model of the AB*

Chun and Potter (1995) clearly articulated a two-stage model of attention based on the work of several prior researchers (Broadbent & Broadbent 1987; Gathercole & Broadbent, 1984; McLean et al., 1982). The first stage in Chun and Potter's model involves rapid detection with the relevant features analysed to the stage where identities are briefly associated with each item. This stage is very short lived, and the precepts must be consolidated in a second, more resource intensive stage of processing in order for report or response to occur. According to this model,

...when T2 appears before the second stage is free, it will be detected by Stage 1 processing, but Stage 2 processing will be delayed. The longer the delay, the greater the probability that T2 will have been lost, according to our previous assumption that Stage 1 representations are short-lived. (Chun & Potter, 1995, p. 122)

The results from the experiments reported above are difficult for this model to account for.

Much of the AB evidence has relied on a "detect the presence of the T2 item" (detect "X") paradigm. The AB is robust during this task. This suggests that, according to Chun & Potter (1995), the representations that are "short-lived"

include the realisation that the T2 key feature ("X" ness) has occurred. If this is true, the occurrence of a T2 item for which the key feature has been lost will have no special connotation for the processing system. This is not the case.

When interference is minimised, the most common intrusion observed is the T2 +1 item. This is in spite of the fact that, according to Chun and Potter (1995), the T2 key feature is lost awaiting Stage 2 processing. It could be argued that the T2 +1 item is the last item shown during the minimal blink procedure, so it is easily available for report. As evidence against this argument, during the experiments when interference is maximised there is no difference in T2 +1 report between the single target and dual target tasks. If it were the case that the T2 item was mis-identified as the T2+1 item because it is the last item in the stream, there would be an expected difference when the task is changed from dual to single target report. Additionally, it has been demonstrated (Isaak et al., 1999) that the predominance of T2 +1 errors occurs even when a full RSVP stream of letters is used. This means that immediately following the Stage 1 processing of the T2 key feature (which is lost if not quickly consolidated), an item is selected for report and consolidated through Stage 2 processing, even though the item selected (T2 +1 item) has occurred within the depths of the AB as well. In its present form, Chun and Potter's two-stage theory of processing is inadequate to account for the results of these experiments.

#### *Inhibition Model of the AB*

Raymond, Shapiro, and Arnell (1992) proposed an interference model of attention to account for the AB. According to this model, an inhibitory



mechanism is invoked in order to prevent too many items from entering VSTM and interfering with the T1 identification process. Because of the speed of presentation, the intended T1 item and the immediately following T1+1 item is allowed into the processing system before the inhibitory mechanism can be engaged. The same evidence presented to argue against the two-stage model of attention argues against the inhibitory model of attention.

If visual processing following the T1 item is inhibited, there can be no processing of the T2 key feature. As a result, the AB would be a ballistic process, lasting until the inhibitory mechanism is released and processing can resume (about 300 ms.). The results from the experiments in this thesis support other evidence which has accumulated (Isaak et al., 1999; Luck, Vogel, & Shapiro 1996; Shapiro et al., 1994; Shapiro, Driver, Ward, & Sorensen, 1997) suggesting that processing does occur during the 300 ms. following the presentation of the T1 item. Even though the T2+1 item occurred during the depths of the AB, it was the most commonly reported item when the T2 item was missed.

#### *Task Switching and the AB*

Allport & Hsieh (2001) demonstrated that the shift in selection criterion (a task switch) between T1 and T2 produces a processing deficit. They suggested that a part of the AB deficit observed when a criterion shift is employed can be accounted for by task switching. Potter, Chun, Banks, & Muckenhoupt (1998), through their work on cross-modal processing, have arrived at the same conclusion. The definition of task switching is a change in perceptual set used to detect the item: a task switch is one in which the key feature of the two items is

different. A task switch could also be imagined in the report feature. If the report feature for a T1 item involved detecting the shape of an item and the T2 task was reporting the colour of a categorically defined item, there would be several perceptual sets used for selection: the shape of T1 as both the key and report features; the category of T2 as the key feature; and the colour of T2 as report feature.

In all of the experiments carried out in this thesis, a portion of the deficit must be attributed to task switching. Task switching is one of the reasons that the AB deficit does not disappear when the selection criteria are from different dimensions. Even though the resources needed to process the key features do not overlap, there is a task switch that is necessary to carry out the task; the T1 item is detected based on a predefined key feature (e.g. a red item) and the T2 item is identified (a task switch) based on a different key feature (another task switch). Allport & Hsieh (2001) report that there is no difference in the magnitude of the task switching deficit either within dimensions or between dimensions. This means that the task switching deficit is a constant across the various manipulations carried out in this thesis. Although task switching accounts for a portion of the overall observed AB deficit, the qualitative differences observed in the experiments reported above are from a different source.

Visser, Bischof, & Di Lollo (1999) found that task switching in the AB paradigm has an impact on the shape of the blink. In a meta-analysis of the AB research looking into the phenomena of "lag-1 sparing" (higher detection of the T1+1 item forming a "U" shaped AB function), they found that the T1 +1 item

can be readily identified if the task requirements do not include a significant task switch between the two targets. According to Visser et al., if the task switching requirements are uni-dimensional, lag-1 sparing occurred. In the experiments reported above, if the interference is minimised, the T1+1 item is rarely reported as the T2 item when the T2 item is missed: however, when the interference is maximised, the T1+1 item is regularly reported as the T2 item when the T2 item is missed. Although not empirically tested, there may be a relationship between lag-1 sparing and whether or not the T1+1 item is reported as the T2 item.

In order to explain the differences they found, Visser et al. (1999) concluded that the functional organisation of the brain is closer to an “aggregate of domain specific modules” operating in parallel rather than a single unitary central processor. This was concluded from evidence that demonstrated that the features of items selected for processing determined how the processing was carried out at higher levels of processing. One of the central tenets of this thesis supports the conclusions of Visser et al. The interference continuum model of processing suggests that the brain is composed of many different modules of processing that only become overloaded when more than one item is demanding the processing resources from an individual module.

#### *Interference Model of the AB*

If Shapiro's (Isaak et al., 1999; Shapiro, Raymond, & Arnell, 1994) interference theory is modified, it can adequately encompass the present findings. The interference theory suggests that all the critical items from an RSVP stream are processed to some extent, and are held in a storage buffer

called visual short-term memory (VSTM). Within VSTM, items compete for retrieval and subsequent report. According to this theory, items are selected for inclusion in VSTM according to their match to a selection template. The items most likely to be selected for inclusion in VSTM are the two target items (T1 and T2) as they exactly match the selection template and, due to the speed of presentation, the items immediately following the two targets (T1 +1 and T2 +1). The AB deficit is caused by the retrieval of the incorrect item from VSTM for report. Within the timeframe of the blink deficit, the T2 item does not enjoy enough activation within VSTM to be the obvious choice; hence, competing items are sometimes selected.

The problem with the interference model in its present form in accounting for the results of these experiments is the lack of T1 intrusions when interference is minimised. The AB deficit measured by the correct T2 report is slightly smaller than when interference is maximised, but is still present. Since the T1 item is a critical item and must be selected and present in VSTM for the successful completion of the T1 task in the maximised and minimised interference experiments, in order for the interference theory of attention to explain these results the T1 intrusions should be a common occurrence regardless of the interference manipulation: T1 intrusions occur only when the interference is maximised, not when it is minimised.

If in the theory, competition and the resultant interference is not restricted to VSTM (or entry into it), but is allowed to occur at different processing stages throughout the visual system, the results fit nicely into an interference

framework. This shift in the locus of interference is central to the interference continuum model proposed in the introduction and discussed below.

### *The Interference Continuum Model of the AB*

I will begin this section by outlining the model presented in the introduction, and then will demonstrate how the data fit the theory.

Broadbent and Broadbent (1986) proposed a model of mixed parallel and serial processing to explain some early AB findings. During some single target RSVP testing, they had observed a symmetrical pattern of intrusion errors (McLean, Broadbent, & Broadbent, 1982). To explain this, they proposed a mix of both parallel and serial processing within the visual system. They suggested that when selection is categorical (name the digit among letters), the processing is parallel, and intrusions occur both before and after the target item. However, if the target is fully specified (name the red letter), the processing is serial, and all the intrusion errors occur after the target item. A form of this model of mixed parallel and serial processing is elaborated upon and considered below in light of the results of the experiments reported above as a possible explanation for the findings.

The experiments reported in this thesis are examined in light of the model outlined in the introduction (the interference continuum model) which was the amalgamation of three theories of visual processing: Duncan's competitive integration model (1996), placed within the framework of Van Essen and DeYoe's (1995) concurrent processing model, with Johnston and Heinz's (1979) flexible selection mechanism.

The interference continuum model relies on Duncan's (1996) idea of competitive processing within modules. Where it differs from Duncan's approach is defining a module. Within Duncan's integrated competition framework, a module is described as a brain system. Duncan states that there are multiple brain systems activated by visual input. The different brain systems are internally competitive, while integration occurs between the systems as the processing coalesces around objects. A slight adaptation of how Duncan defines what a processing system is and does is needed to facilitate the building of the model. What a processing system is, for the purposes of the interference continuum model, must be more closely aligned with the work of Van Essen and DeYoe (1995) than Duncan.

Van Essen and DeYoe (1995) describe a system of processing wherein the visual processing streams converge and diverge at many different levels of processing within the brain. For the purposes of the proposed interference continuum model, a module (a processing sub-system) is defined as any process or set of processes that lead to a product. This could be as basic as neurones in area V1 defining an edge, or as complex as the complete representation of an object. In either case, within the hypothetical processing module, there has been a process that receives inputs and then produces a product.

The interference continuum model proposes that within every module, whether simple edge detection or whole object representation, the processing that occurs can be competitive, with a rise in activation for one feature (or object -- depending on where in the visual system the processing module is located) resulting in a corresponding decrease in activation for a competing feature (or

object). This is a direct reflection of how Duncan (1996) described processing within a system in his integrated competition system of processing. The modification introduced here is that Duncan's definition of a processing system has been expanded to include any set of processors, at any level, that receive inputs and provide a product. Based on the results of past research, it is important that at every level of processing, the system must be able to integrate the products of processing in order to accomplish the ultimate goal of whole object representation (e.g. Duncan, 1980; Kahneman, Treisman, & Gibbs, 1992).

In order to complete the interference continuum model, Johnston and Heinz's (1979) flexible selection mechanism needs to be introduced at this point. Within the interference continuum model, it is important that non-exclusionary selection is available for the products of most (if not all) of the visual processing modules. Non-exclusionary selection needs to be available within the processing system to account for the data that suggests the selection is made early in one case, but takes place later in the system in another case (see below when the results of the experiments are discussed). Selection for report **may** occur with the selection of the output of the edge detection module in V1, or it **may** occur with the output of the internal representation of the visual scene accomplished by the visual system. This means that the ultimate response of the organism could be triggered by the selection of the most basic physical feature, or by the selection of entire objects in specific orientations. The primary difference between the model being proposed here, and others that have been proposed in the past, is that the selection for either report or further processing may be non-

exclusionary: the process of selection does not preclude further processing of non-selected items from occurring.

In addition to selection being available on the product of any module, the interference continuum model also proposes that selection can be triggered by a rise in activation within a processing module. With this kind of processing available, it would be easier to see how selection for response could be driven by task demands. If the task demands are to detect a luminance change, the appropriate response can be selected at the product stage of the module detecting luminance differences (as seen in Experiment 4). If the task involves the identity of a complex figure, the by necessity, response selection will take place at the product stage of the identification module – in both cases, selection takes place at the earliest possible place where that information becomes available. Under this proposed system, if selection depends on the detection of a coloured item from among non-coloured items, a rise in activation in the colour processing module can trigger the selection mechanism. The earliest possible location where selection can occur is the most likely place where selection will occur.

Once a response selection is made, the usual course of action for the visual system is to share the heightened activity for the object to which the selected feature (detect the white item) belongs to spread to other processing modules, integrating the entire system around the selected object (Duncan, 1996). However, if we accept the proposition that selection can be non-exclusionary, this may not be the necessary result, only the usual result. Within the interference continuum model, if selection is non-exclusionary, features from



other objects may still be competing for processing in other modules. If there is a secondary task (as in dual target RSVP) for which a selection flag is set (identify the red item), when red is detected by a colour processing module, the activity for the item associated with redness begins to spread to other modules in order to complete the required identification task.

Fitting the data from the experiments reported above to the interference continuum model will consider the two primary conditions that were found: minimal interference and maximum interference. In the minimal interference dual target RSVP task (e.g. detect white, identify red), the first target that is selected, due to the presence of a luminance change, ignites the process of integration around that item among other processing modules. This integration process leads to possible object ascendancy for the T1 item, and hence heightened activation in all the modules processing features of the T1 item. This heightened activation enjoyed by the first target must be overcome by the processing necessary for the features of the second target. The switch in processing from the first target features to the second target features is necessary for the identification of the second target, for which the key feature (red) has triggered a selection mechanism. The rise in activation for the second target is obstructed by the heightened activation enjoyed by the first target. As a result of the time involved in switching module processing from one item to another, the identity that systematically replaces the correct T2 item in VSTM is the identity of the item that immediately follows T2 in the RSVP stream.

This is in contrast to the condition wherein the two targets share a selection dimension (maximised interference) or are processed by the same

processing module. When the key features for both the targets is a chromatic change (e.g. detect green, identify red), the likelihood of interference between the targets increases. When the T1 item (detect green) is selected for processing, the selection trigger is not simply a rise in activation in the colour module (as was the case when the T1 is the only coloured item in the RSVP stream) but is the *product* of that processing module (a specific colour). Since both the T1 and T2 result in heightened activation within the colour module, selection cannot be made on the basis of heightened activation in that module alone. Selection of the identity of the T2 item is unavailable until the items are processed to the point where the colour of the item is conjoined to the identity. Since both target items have colour associated with them in VSTM, and the T2 task is to report the identity of a coloured item, the T1 identity is the most likely substitute when the identity of the T2 item (the report feature) is unavailable. In addition to the pattern of intrusion errors supporting this argument, because both targets require the same resources during the dual target RSVP trials, the T2 overall performance is significantly lower during the AB (see Figure 31).

The interference continuum model is proposed here as a possible account for the unusual set of intrusions or illusory conjunctions observed in the experiments reported above. Below, the model is considered in relation to other findings that have been reported in the literature to see if it can be used as a possible explanation for them as well.

*Other Findings and the Interference Continuum Model*

The interference continuum model proposed is supportive of the results reported by Broadbent and Broadbent (1986). When the key feature T2 item is categorically defined, the report feature for the T2 item is associated with a rise in activation within the module associated with that specific category. In the work of McLean, Broadbent, and Broadbent (1982), the report task was to name the colour of the categorically defined item. Since the intrusion errors for the colour reported as the T2 came from a symmetrical distribution around the T2 item, they concluded that there is a combination of both serial and parallel processes occurring, which depended largely on task demands. This is exactly what has been proposed in the interference continuum model presented here. When the processing of several items do not require the same resources (between dimensions), the processing proceeds in parallel. When the same resources (or processing modules) are required for two different items, the processing is carried out serially.

This is consistent with the case Broadbent and Broadbent (1986) made when items are fully specified. If identification is required as the processing key feature, the intrusion errors are limited almost exclusively to items following the targeted item. They suggested that this is the result of serial processing. Since identification requires the resources of a specific module, and selection is dependent on the output, the interference continuum model also predicts that the errors follow the target because processing must be carried out in serial.

The interference observed in the experiments reported here appears to be dependent on a combination of both the task demands and the physical

characteristics of the stimuli. This supports Duncan and Humphreys' (1989) similarity model of selection. Duncan and Humphreys suggest that interference in processing a target item is related to the similarity of the target items to the distractors, and the similarity of the distractors to each other (distractor homogeneity). The more similar the target is to the distractors, the more interference that will be observed. The more similar that the distractors are to each other (with the target being different), the easier the target is to select. However, if the distractors are heterogeneous, interference is observed during target selection. The interference due to similarity is dependent on the dimension of selection only. In other words, if all the items are the same shape, they are very similar along that dimension, but if the target feature is the colour red, among green distractors, target/distractor similarity along the shape dimension is irrelevant. This is what has been observed in the experiments reported in this thesis. The interference observed when the items are similar depends on the dimension along which the similarity is observed. If the similarity is along a dimension that is of critical importance to the task, interference is increased, while if the similarity is along a dimension which is not of critical importance to the task, interference is minimised.

The interference continuum model is supportive of the central processing bottleneck proposed by Jolicoeur et al. (2001) as an explanation for the AB deficit. Jolicoeur has demonstrated that the deficits observed during the AB are similar in nature to those observed during the psychological refractory period. The accounting for the processing deficits observed in this thesis are similar to those proposed by Jolicoeur. Jolicoeur's theoretical accounting involves a processing

bottleneck that occurs when two speeded tasks require the same processing resources. A processing deficit arising from tasks demanding the same resources is a central tenant of the Interference Continuum model. Some of the evidence presented by Jolicoeur will be reviewed in an attempt to illustrate how the Interference Continuum model supports Jolicoeur's conclusions.

In a speeded response variant of the AB paradigm, Jolicoeur et al. (2001) presented evidence that manipulations of the T1 task can effect the time it takes to respond to the T2 task. In three of the four examples cited by Jolicoeur, both T1 and T2 required the same processing resources. Both tasks required participants to deal with the identities of letters. In two of the examples, the participants were required to identify a T1 and then identify a T2 item, and in the third experiment, the task was to detect the presence of a particular letter as the T1 task and then identify the T2 letter. The fourth example involved a cross-modal AB, which is beyond the scope of this thesis. Jolicoeur was illustrating an effect he called a "carry-over" effect.

The carry-over effect discussed by Jolicoeur et al. (2001) is observed when the T1 item is more difficult, and the T2 deficit is more pronounced as a result. In the experiments reported, the tasks all demanded that the participants process letter identities. If the T1 task requires the same resources as the T2 task, and the T1 task is made more difficult, the T1 item will take longer to process. This extended processing time will be reflected in a later freeing up of the shared resources to process the T2 item, and as a result a more pronounced AB will be observed.

Jolicoeur (2001) also presented evidence of a correlation between the time it takes to respond to the T1 item and the time it takes to respond to the T2 item in an AB task. Jolicoeur suggests that this correlation is due to the resources being freed for a T2 task as a result of the T1 task processing occurring faster. This means that the overall time taken to process the T2 item will appear shorter, not because the processing of the T2 item takes less time, but because the resources tied up in processing the T1 item are made available sooner.

Jolicoeur et al's. (2001) discussion of the manipulation of T2 difficulty relies heavily on reaction time data to support the bottleneck theory of interference. The result is that when the T2 task difficulty is manipulated, the reaction times to the T2 conditions at short SOAs do not differ, whereas at long SOAs, the more difficult T2 tasks take longer than the easier T2 tasks. Jolicoeur argues that this is the result of some of the T2 processing taking place during the T1 processing time. If the T1 and T2 tasks require the same resources for processing, it is difficult to see how the T2 item can be processed while the T1 item is being processed. In the thesis above, when the T1 and T2 tasks require the same resources, the T1 item is reported when the T2 item is missed; the size of the AB is not effected.

It might be argued that our manipulation was more akin to the manipulation carried out by Jolicoeur et al. (2001) to test the lengthening of the processing bottleneck for the T2 item. In order to lengthen the bottleneck, the resources required for the T2 processing would have to be the same as the resources required for the T1 processing. That is exactly the condition used in

this thesis to maximise interference. In this case, our results are in complete harmony with Jolicoeur's.

Overall, the results reported here are in complete agreement with those of Jolicoeur et al's. (2001). Jolicoeur argues that at least some of the processing bottleneck occurs at the same stage as the PRP bottleneck (centrally) and this is supported by the arguments put forward here. This thesis argues that the location of the processing bottleneck is wherever the competing stimuli require the same processing resources, which may be centrally, as in the PRP case, or the processing bottleneck may occur more peripherally.

Increased interference during a divided attention task when the processes occur along the same dimension was first observed by Treisman (1969), with supporting empirical work by Allport (1971; and see Wing & Allport, 1972) closely following. When judgements were necessary that involved the same dimensions (orientation), interference was observed, whereas when the judgements were made across dimensions (orientation and spatial frequency), there was no interference. These results were problematic as the displays used when the judgements were made along the same dimension may have been interpreted as consisting of separate objects, whereas the experiments across dimensions appeared to involve different objects, confounding dimensions and objects. Was the interference the result of processing features from two separate objects, or was it the result of within dimensional interference.

Duncan (1993) addressed the problem directly with more sophisticated displays and found a different result. According to Duncan, interference can be accounted for by the number of objects present and there is no effect of

processing dimension. In other words, it makes no difference whether the judgements are along the same or different dimensions, the only factor which affects performance is the number of different objects to be processed.

Duncan (1993) argued that given four different conditions, the question of whether the interference is due to objects or dimensions could be answered. He presented four conditions for the reporting of two features from two different items, along with predictions based on different possible results. If two letters varying in size and shape are presented, the participants' dual report possibilities are the following four conditions: (a) size and shape of a single letter (one object, different dimensions), (b) the same attribute (size or shape) of both letters (two objects, one dimension), (c) the shape of one letter and the size of the other (two objects, two dimensions), (d) the size and shape of both items (two objects, two dimensions). He suggested that if the number of objects is the basis of interference, performance would be highest in Condition 1 and lower in the other three conditions. If processing along dimensions is a cause for interference, then Conditions 1 and 3 should enjoy higher performance than Conditions 2 and 4. He found that Condition 1 had the highest performance, while the other three conditions had similar performance. From this, Duncan concluded that the only factor effecting performance was the number of objects that needed processing.

Duncan's (1993) argument is valid only if the visual system is capable of keeping tasks separate for different objects being processed simultaneously. Kanwisher, Driver, and Machado (1995) found that when the task demands are different for two separate objects, the visual system is forced to perform both



tasks on both objects. If the task is to identify the shape of an object on the right, and the size of the object on the left, the visual system will automatically process the shape (for identification) and the size for both the objects present. This means that Duncan's (1993) experiments would have produced within dimension processing interference in all three of the conditions involving more than one object. When presented with two objects and a different dimensional task for each object, the visual system processes both of the required dimensions for both of the objects. This is supported by the robust effect that has been reported in which all of the features for an object are selected when any one feature of that object is selected (cf. Duncan, 1984). Because of the specific interference reported by Kanwisher et al. (1995), which arises when processing different dimensions for different objects, between dimensional processing effects will always be masked by object effects (for which there is an abundance of evidence, cf. Duncan, 1979) in displays using simultaneously presented objects.

One of the central features of an interference continuum model is that selection for processing is not exclusionary; if an item is selected for processing, this does not mean that processing is limited to that object only. Lavie (2000) has proposed a model wherein the information processed, once an item has been selected, depends on the perceptual difficulty of the processing task. If the perceptual load is low, resulting in spare processing capacity, irrelevant stimuli will be processed (non-exclusionary selection). However, she has found that when the perceptual load is high and requires all the processing capacity available in order to complete the processing task, irrelevant information is not processed because of a lack of processing resources.

The evidence presented in this thesis supports the perceptual load model presented by Lavie (2001). In the experiments presented above perceptual load was manipulated; high perceptual load occurred when the items to be processed demanded the same processing resources (maximal interference) while low perceptual load occurred when the items were processed using different processing resources (minimal interference). This manipulation also found that when the perceptual load was maximised, there were more distracter intrusions, while when the perceptual load was minimised, the distracter intrusions were predictable, arising almost exclusively from the T2+1 item.

The interference continuum model of selection supports the Feature Gate model of visual selection proposed by Cave (1999). He observed that during the course of visual processing, when non-target or irrelevant items in the visual field share features with the intended target, there is some processing of the non-target item. This processing of non-target items that share features with the target results in interference being observed. In the interference continuum model, this is predicted because the features that are shared between the items will require the resources of the same processing module. This division of resources between the two items will result in neither item receiving a full measure of processing, and interference will be observed.

Using the RSVP paradigm, and examining the errors made during the AB, it has been demonstrated here that there is a qualitative difference in the types of errors made, depending on the kind of processing that is demanded. When interference is minimised, the error type suggests that the pattern of intrusion errors observed in the dual target task are similar to those observed in the single

target RSVP research (Botella, Garcia, & Barriopedro, 1992; Broadbent & Broadbent, 1986; Lawrence, 1971; McLean, Broadbent, & Broadbent, 1982). This earlier research has shown that the most frequent intrusion error observed in single target RSVP tasks when the target is specified (defined by shape) is a post-target intrusion error, or the reporting of the item immediately following the targeted item (the +1 item).

In the experiments reported in this thesis, the rates of T2+1 intrusions were much higher during the dual target tasks with minimal interference than those observed during single target identification with minimal interference. This purely quantitative difference in intrusion rates suggests that the underlying processing is similar in the single and dual target processing, but that the processing deficiency observed in the single target case is exaggerated in the dual target case. In other words, whatever underlies the inability to report the correct target in the single target case is more of a problem during the dual target trials.

When interference is maximised by using the same dimensions of processing to identify the two targets, there is no difference between the single and dual target the immediate post-target intrusion errors (T2 +1 intrusions). Rather, there is a systematic shift to pre-target intrusions. Not only are the intrusions from an item preceding the target; they also arise from an item that preceded the targeted item by up to several hundred ms, and with an intervening item. The experiment was designed to observe interference resulting from tasks requiring processing of two objects along the same dimension.

Possible experiments that would test this model would both maximise and minimise interference along the entire continuum of processing. This could include experiments designed to see if interference from a physical property could interfere with an internally generated representation. Using a Stroop variation of an RSVP task, I predict that a colour word would interfere with a task wherein the target report feature was a physical colour. Although the Stroop colour task demonstrates interference in processing, there has never been a suggestion that the physical colour has been displaced within the processing system by an internally generated representation of colour.

Experiments designed to test the degree of interference will provide insight into how internal brain processes are organised. Minimal interference suggests processing carried out by different brain systems, while maximal interference suggests that the processes rely on the same processing modules.

The proposed interference continuum model needs further work and clarification. If it can withstand the rigors of testing, the model will be useful in understanding many of the specific aspects of brain processing. The basic tenants of the interference continuum model support many of the models of visual attention that are current in the literature, with the empirical work underlying the model providing additional direct evidence for some of the models.

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