The Persistence of Attentional Set and its Implications for Top-Down Control

Catherine Thompson, BSc. MSc.

Thesis submitted to the University of Nottingham

for the degree of Doctor of Philosophy

March 2009

Abstract

A top-down attentional set allows selective processing of the most informative aspects of a scene by biasing attention towards task-relevant stimuli and away from task-irrelevant stimuli on the basis of task demands. The work in this thesis explored the characteristics of the attentional set and top-down control by measuring the persistence of a set. That is, the *carry-over* of a set from a task in which it is appropriate to a subsequent task in which it is inappropriate. Twelve experiments were completed, employing three different methodologies in order to provide converging evidence for the persistence of attentional set. The first method was a rapid serial visual presentation task, the second was a change detection task that was preceded by a visual search task, and the third was a visual search of natural scenes following an unrelated search through letter strings. All three methodologies provided strong evidence for the carry-over effect, whereby the allocation of attention in a second task was influenced by the top-down settings from the first task. This shows that an attentional set is not established solely based on current task demands but is also influenced by previous experience. Carry-over appears to be contingent upon the level of control invested in the task; too much control over the initial top-down set will enhance carry-over, but a high level of control in the second task will attenuate carry-over. In addition, a lack of executive control over the set will also lead to carry-over when the set is highly practiced because task performance will not be monitored, and a change in task demands will not be accompanied by a change in attentional set. Carry-over provided evidence for three different types of attentional set; a location-based set, a feature-based set, and a feature-value-based set. It also indicated that the attentional orienting system can be configured at more than one level according to the task demands, implying that top-down control is more flexible than previously suggested. The work ultimately led to the development of a general model of attentional set (G-MAS) which attempts to explain the current results and account for pertinent findings from the literature.

Acknowledgements

Whilst completing my PhD I have been lucky enough to have support from several people. First I would especially like to thank my supervisor David Crundall, who has been a continuous source of knowledge, motivation, and kindness; and has made the last few years immensely enjoyable. I could not have asked for a better supervisor and I feel privileged to be his first PhD student.

I would also like to acknowledge Peter Chapman and Geoff Underwood for imparting their knowledge on a number of occasions, and members of the Psychology department who have done their utmost to keep my PhD running smoothly; from solving computer problems (Lee and Alexia) to sorting out finances (Angela and Deborah); grateful thanks to you all. I am also indebted to the many participants who gave up their time to complete my experiments.

I would like to thank all my family for providing me with continual love and encouragement throughout my life. Special thanks must however go to my Mum and Dad. Their unending love and support is the foundation for all my achievements. Finally, a special mention goes to my partner Naresh, for his love, affection, endless patience, and lovely smile.

This work is dedicated to my Father, Philip; with love.

Declaration

I declare that this thesis is my own original work and has not, whether in the same or different form, been submitted to this or any other University for any degree.

Signed,

Catherine Thompson

Table of Contents

Table of Figures

Table

Equation

"Those who give too much attention to trifling things become generally incapable of great things"

-La Rochefoucauld

Chapter One: General Introduction – The importance of top-down control in the allocation of visual attention

1.1 Overview of Chapter One

On 28th December 1978 a plane crashed in Oregon, USA after failing to make an emergency landing at a nearby airport. From the 189 people onboard, 10 were killed and 23 suffered serious injuries. The accident was attributed to faulty landing equipment resulting in the plane circling the area close to the airport until the captain had assessed the damage, and determined the suitability of making an emergency landing; while the plane was circling it ran out of fuel and subsequently crashed. Reports made after the crash stated that the captain should have been aware that the fuel was low and consequently tried to land sooner, yet it was presumed that his attention was directed to the landing gear rather than the fuel situation. A further possible contributing factor to the crash (identified in reports) was that the captain was also a flight simulator instructor. At the time it was unnecessary to monitor the fuel levels in a flight simulator and it is postulated that as the captain did not direct attention to the fuel gauge in a simulator, he then failed to direct attention to the fuel situation in the plane.[1]

The above example illustrates the intrusion of a habitual behaviour from a task in which it is suitable to a task in which it is unsuitable (Reason, 1984). The captain was accustomed to working in a simulator and not allocating attention to the fuel gauge. Confronted with flying a real plane, with a similar task and layout of information to that of a simulator, the habitual strategy was triggered. Reason (1984)

[1] http://www.airdisaster.com/investigations/ua173.shtml

states that under normal circumstances the habitual behaviour (if inappropriate) will be suppressed by focused attention, but if attention is devoted elsewhere (e.g., to the faulty landing equipment) the habitual behaviour may intrude. These habitual behaviours represent the *carry-over* of one task strategy to another task, and this will inevitably impact upon the allocation of attention in the second task. Is it also possible that a strategy which directly controls attention may carry-over from a task in which it is suitable to a task in which it is unsuitable, therefore influencing attention (and performance) in the second task?

The ‘strategy’ in question is referred to as an *attentional set*. The attentional set is adopted based on the task demands and it controls the allocation of attention in the visual field by biasing attention towards task-relevant information and away from task-irrelevant information. This ensures that the observer focuses on stimuli which are most beneficial to the task. When the task demands change the observer should alter (switch) their attentional set in accordance with these changes, similar to altering behaviour. A failure to do so will result in the original set being utilised; this will mean that attention will be directed towards stimuli that were previously relevant and away from stimuli that were previously irrelevant. This may cause the observer to miss information which is vital for the successful completion of the task at hand (as in the above example), or it may cause the observer to pay attention to information that is no longer relevant (distracting the observer and resulting in a detriment to task performance).

The carry-over, or persistence, of attentional set is the focus of the current thesis. In particular the author will investigate whether an attentional set can persist from one task to a second task, despite being irrelevant for the second task; and determine whether the carry-over of an attentional set can reveal anything about the mechanisms and the control of attention. To give an introduction to these issues this chapter will provide a detailed review of the relevant literature. To begin there will be an overview of selective visual attention (how an individual can successfully attend to relevant information whilst ignoring irrelevant information and distractions), and the different influences upon this selection will be outlined. Specifically the review will concentrate on the differences between top-down and bottom-up control and the evidence for each. Related to this, the top-down attentional set will be defined and explained, and the significance of cognitive control will be discussed.

To clarify the notion of the persistence of attentional set the author will provide a summary of research which is similar to attentional set switching, but instead represents the carry-over of a behavioural response (a task set) as opposed to an attentional set (therefore more akin to the opening example of the plane crash). The relevance of this research to the current thesis will be documented. Following this, the main aims and objectives of the thesis will be presented and there will be a short summary of the contents of each chapter.

1.2 Selective visual attention

1.2.1 The control of selective attention

Due to the level of clutter in the visual field it is impossible to attend to all areas and items at any one time. Therefore priority must be given to the most relevant areas or objects within a scene to ensure that only the most informative aspects are processed (Driver & Bayliss, 1989; Schneider & Shiffrin, 1977). The ‘biasing’ of attention and resources towards task-relevant information and away from task-irrelevant information is *selective visual attention* (Johnston & Dark, 1986; Theeuwes, 1993). Whilst there is agreement among researchers regarding the definition and role of selective attention (Lavie, 1995), there is no consensus as to the *control* of this selection. That is, ‘what controls the allocation of attention?’, and ‘what controls the shift of attention from one region of the visual field to another?’.

Attention can be goal-driven, in which case it is allocated on the basis of current task demands and expectations held by the observer. It can also be described as stimulus-driven, whereby attention is guided in relation to the properties of the stimuli in the visual field. In line with these two forms of attentional control Posner (1980) outlined two separate ‘orienting’ systems; endogenous orienting and exogenous orienting. Endogenous orienting is goal-driven (top-down); it is voluntary (it can be suppressed if necessary) and shifts of attention controlled in this manner are relatively slow. Exogenous orienting is stimulus-driven (bottom-up); it is automatic (exogenous shifts of attention cannot be suppressed by conscious control) and shifts of attention are relatively fast (Klein, Kingstone, & Pontefract, 1992). A shift of attention can be accompanied by an eye movement (overt attention), or attention can move without a corresponding saccade to the focus of attention (covert attention). This gives four distinct types of attentional shift (Klein et al., 1992; Sereno, 1992), see figure 1.1 on page 5[2].

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[2] There is a debate over whether attention and eye movements are always linked. For example, some studies provide evidence to show that eye movements will always follow attention (e.g., Shepherd, Findlay, & Hockey, 1986; Subramaniam & Hoffman, 1995), and others indicate that eye movements can operate independently from attention (e.g., Peterson, Kramer, & Irwin, 2004; Tse, Sheinberg, & Logothetis, 2002, 2003). This debate is not the focus of the present thesis, and therefore this research will not be discussed. The author acknowledges that studies have shown evidence for eye movements without attention, but is of the belief that the studies which have been completed for the current thesis all represent clear overt shifts of attention, with attention preceding a saccade (that is where spatial shifts of attention were required).

ORIENTING

CONTROL		OVERT	COVERT
	EXOGENOUS (bottom-up)	Involuntary saccade	Automatic attention
	ENDOGENOUS (top-down)	Voluntary saccade	Controlled attention

Figure 1.1: The four types of attentional shift, defined by Klein et al. (1992) and Sereno (1992). Controlled attention represents a voluntary shift and automatic attention represents an involuntary shift.

Evidence for endogenous and exogenous orienting comes from spatial cuing studies. A central cue (an arrowhead in the centre of the display for example) elicits a relatively slow shift of attention to a peripherally located target. Response times are faster to a validly cued target compared to a neutrally cued target, but there is no cost to an invalidly cued target. In addition, when participants are informed that the cue does not benefit performance they are able to ignore it (Müller & Rabbitt, 1989; Posner, 1980; Posner, Snyder, & Davidson, 1980). This shows that attention can be voluntarily disengaged from the cue if it does not provide correct information. In comparison, when participants are cued to a target location by the use of a peripheral cue (a peripheral flash for example) faster RTs to validly cued targets are also paired with costs to invalidly cued targets (slower RT compared to neutral cues). Moreover, when told that the cue does not predict target location participants are unable to ignore it (Jonides, 1981; Müller & Rabbitt, 1989; Posner, 1980; Posner et al., 1980). This indicates that attention is reflexively captured by the peripheral cue and cannot be disengaged from the cue (therefore exogenous orienting is not under voluntary control). In accordance with these findings Sereno (1992) has proposed two distinct neural pathways for exogenous and endogenous shifts of attention; while the superior colliculus may be important for exogenous shifts of attention, areas of the prefrontal cortex may be responsible for endogenous shifts of attention.[3]

Again, although the majority of researchers acknowledge both top-down and bottom-up influences upon the guidance of attention, there is a difference of opinion (motivated by empirical findings) concerning the relative influence and importance of each form of control. Specifically, some propose that attention can be controlled in a purely bottom-up fashion, while others hold the viewpoint that attentional capture can never be solely driven by bottom-up factors and there is always a top-down influence upon exogenous shifts of attention.

1.2.2 Evidence for the automatic capture of attention

Early theories of selective visual attention specified a two-stage process (e.g., Broadbent, 1958; Koch & Ullman, 1985; Neisser, 1967; Treisman & Gelade, 1980; Ullman, 1984). The first stage allows the scene to be broken down into perceptual units on the basis of a 'preattentive' analysis. Following this a second, limited-capacity stage leads to more detailed processing of certain stimuli or locations through 'focused attention' (Neisser, 1967). Koch and Ullman (1985) stated that the preattentive analysis of a scene is completed on the basis of bottom-up influences. They suggest that a saliency map is created from the analysis of visual features such as colour, orientation, and motion, in relation to the uniqueness of an item or location compared to neighbouring items or locations. Attention is then allocated to the most salient region (the region that differs most from its surroundings). Once this region has been selected and processed, the location is suppressed to avoid recapture of

[3] Given the aims of this thesis the author will not go into great detail about the neuroanatomy of attention. Any literature that is presented and has links to neuropsychology is included on the basis of its importance to the overall discussion and should not be viewed as a substantial review of this field of research. For a more extensive overview please see Parasuraman (1998).

attention by previously-searched items, and attention is shifted to the next most salient region. Similarly, Treisman and Gelade (1980) suggested that an initial analysis of basic features guides selective attention. Each feature (colour, motion, etc.) is represented in a different feature map and these individual maps are combined into a 'master map'. The master map then governs the selection of items and locations for focused attention, with attention guided to the most salient region first.

Treisman and Gelade define two different types of visual search which can portray the workings of preattentive and later processing; a simple search and a conjunction search. One of the key predictions of preattentive processing is that it operates in parallel across all regions of the visual field, and as such the size of the display (set size) should have no influence upon selection at this stage. Treisman and Gelade have shown that a simple search, for example a search for a blue circle among green circles is completed efficiently regardless of set size and the time taken to find the target does not increase linearly with an increase in set size. In comparison, the efficiency of a conjunction search, for example a search for a blue circle among green circles and blue squares, decreases (RT increases) with an increase in set size, indicating that participants are searching through the display serially.

Like Treisman and Gelade, Yantis and Jonides (1990) specify that for selective attention to be described as automatic (and not under the control of top-down influences) it must not be modulated by the processing demands of the task. They refer to this as the 'load-insensitivity criteria'. In 1984 Yantis and Jonides found evidence for the automatic capture of attention using abrupt onsets. Detection of onset targets was faster than detection of no-onset targets regardless of whether the display set size was three, five, or seven. This finding would fit with the notion of a saliency or feature map because an abrupt onset is a motion transient and would be the most salient item in the display, therefore capturing attention quicker than a no-onset target.

However, a second criteria which must also be met before attention can be defined as automatic is the ‘intentionality criteria’ (Yantis & Jonides, 1990). This specifies that automatic capture cannot be suppressed by voluntary (top-down) control. Therefore the most salient region in the visual field should capture attention regardless of the task-relevance of this region, and regardless of where participants are focusing their attention. Across a series of experiments Yantis and Jonides (1990) re-evaluated the capture of attention by abrupt onsets. In an initial experiment participants had to identify a target letter (E or H) which was validly or invalidly cued by a centrally located arrowhead. The target (and a single distracter) appeared in the location of one of four placeholders and depending on the properties of the placeholders the target could be an ‘onset’ or a ‘no-onset’ (see figure 1.2 on page 9). The cue was valid on 80% of trials but if the onset captured attention automatically the top-down knowledge of cue predictability should have had no influence. Findings showed that when the cue was invalid onset targets were detected faster than no-onset targets (as expected from automatic capture). However when the cue was valid the time taken to detect onset targets did not differ from the time taken to detect no-onset targets. The automatic capture of attention by the abrupt onset was therefore modulated by the cue predictability, violating the intentionality criteria.

By manipulating the cue to target stimulus onset asynchrony (SOA; experiment two) and the cue predictability (experiment three) Yantis and Jonides showed that focused attention will suppress automatic capture by the abrupt onset. This led them to suggest that when attention is focused priority is given to the cued location, however once the item at this location has been processed attention shifts to the next most salient item (in line with the model of Koch & Ullman, 1985). They therefore take the view that although abrupt onsets will capture attention automatically; this can be influenced by top-down control in the form of focused attention. Although this does not satisfy the intentionality criteria they propose that it does fit with a 'weaker' account of automaticity (Kahneman & Treisman, 1984).

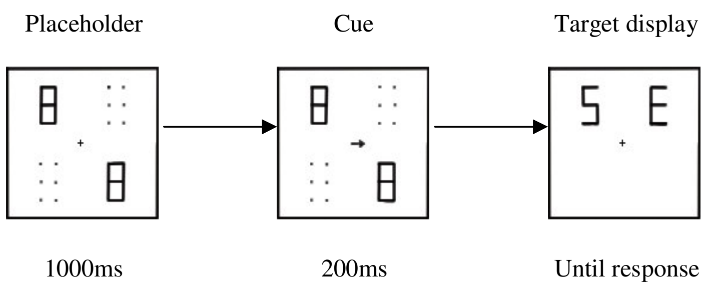

Figure 1.2: Trial layout in experiment one completed by Yantis and Jonides (1990). A target appearing in the location of the filled placeholder is a no-onset and a target appearing in the location of a broken placeholder is an onset. In this example the target (E) is an onset and is validly cued.

Studies by Jonides and Yantis (1988) showed that although abrupt onsets can capture attention automatically, the same cannot be said for a colour singleton among a display of homogenously coloured items. If onsets are the only items which can capture attention automatically this does limit the support for pure stimulus-driven capture. Using a visual search task Theeuwes (1990) investigated the possibility that other features (form and colour) could attract attention in the same way as an abrupt onset. Participants were asked to detect a slanted line segment among a series of upright or horizontal line segments. Each segment was situated inside a shape and these shapes were arranged in a circle around fixation. The display could also include either a unique shape, a uniquely coloured shape, or an abrupt onset; the target appeared inside the unique item or inside one of the non-unique items. Theeuwes found that in all conditions except the onset condition there was no difference in performance between detection of a target appearing in a unique shape, or one appearing in another shape, suggesting that participants were searching for the target serially and the unique item did not capture attention unless it was an abrupt onset. However, in later work Theeuwes found that an offset (1991a) and a colour singleton (1991b) could capture attention automatically in the same way that an abrupt onset can, providing more substantial evidence to support the notion that attention can be guided solely on the basis of stimulus properties.

1.2.3 Evidence for top-down control over automatic capture

Theeuwes concluded that his findings were consistent with the two-stage theories of attention; when an item is unique it will capture attention automatically because it will be the most salient item in the display and preattentive analysis will guide attention to this area. If the item is not salient enough (e.g., a unique shape) a serial search has to be completed. This is why a unique shape did not capture attention (1990) but an onset, an offset, and a colour singleton did capture attention (1991a, 1991b); a shape singleton is not salient enough to capture attention. However, given the relatively limited evidence for purely stimulus driven capture, and the findings that automatic capture by abrupt onsets is suppressed by focused attention (Yantis & Jonides, 1990), the two-stage models were updated. These newer models were different in that they specified a role for top-down control at the preattentive stage (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Treisman & Sato, 1990).

Bundesen suggested that based on the goals of a task (e.g., search for a red shape) a category is formed by which to select possible targets (in the case of the example this would be ‘red’). Attentional weights are then assigned to elements within this category (anything red) which are based on "pertinence values". The values represent the importance of selecting items in a certain category therefore the weight is higher when there is evidence that the item belongs to the target category. Elements which belong to the target category have higher pertinence values than distracters and their weights are increased relative to the other items in the display. Attention is then allocated to items with the highest weights, therefore ensuring that any items which do not belong to the target category are inhibited. This process allows for fast, efficient visual search. Attention is still guided based on the relative weights of each item or location in the display in comparison to neighbouring items (similar to the saliency map of Koch & Ullman, 1985) but weights are allocated in terms of task-relevance, not solely on the basis of stimulus properties.

Bundesen's theory can effectively account for findings which show that the time taken to complete a conjunction search (e.g., search for a blue circle among green circles and blue squares) does not necessarily increase with display size. For example Egeth, Virzi and Garbart (1984) and Kaptein, Theeuwes, and van der Heijden (1995) have found that participants are able to parse the display into a subset of *features* (e.g., blue and green) and then selectively search through the relevant *feature value* (blue) to find the target (circle). A serial search may be required at the second stage of processing, but at the initial stage the display is segmented into relevant and irrelevant items on the basis of top-down knowledge about the identity of the target.

The Guided Search model (Wolfe, 1994) also allows for an influence of top-down factors on preattentive analysis. Similar to the Feature Integration model (Treisman & Gelade, 1980) Wolfe and colleagues (Cave & Wolfe, 1990; Wolfe, 1994; Wolfe, Cave, & Frantzel, 1984) suggest that at the preattentive stage a series of feature maps are created for every basic feature. Locations in the maps are then activated and the maps are combined into a single activation map. Attention is then guided to the region with the highest activation. In contrast to the earlier theories however, Wolfe and colleagues specify that the activation of the feature maps is the product of both bottom-up and top-down factors. Bottom-up activation occurs when items are more unique in comparison to neighbouring items. Top-down activation is based on knowledge of the task, for example if the observer knows that all items are the same colour, colour will not be activated because it will not benefit target search.

Consistent with these models, Folk, Remington, and Johnston (1992) state that attentional orienting can never be purely bottom-up, and it is always influenced by top-down control. They predict that automatic capture of an irrelevant item will only occur if the item “shares a feature property that is critical to the performance of the task at hand” (pp.1032). This is the *contingent involuntary orienting hypothesis*; the capture of attention is contingent upon the task demands. Folk et al. suggest that the orienting system is “configured” to selectively attend to items that are relevant to the task, establishing an “attentional control setting”. Anything matching the attentional control setting will capture attention, anything which does not match will be ignored.

In their spatial cuing paradigm (see figure 1.3 on page 13) participants were presented with a display containing five boxes. One of the boxes was cued by the onset of four small circles surrounding the box, before a target appeared (either in the validly cued box or one of the invalidly cued boxes). There were two experimental conditions; onset and colour. In the onset condition the target (the letter X) appeared inside one of the boxes and the other boxes were left empty. In the colour condition all boxes contained a character but whilst the other characters were white the target (X) was always red. Participants were therefore searching for an onset or a colour singleton in the task. They were also told whether the cue would be 100% valid or 100% invalid. Folk et al. reasoned that as the cue was an onset it would only capture attention (and result in a cuing effect) in the onset condition when participants were searching for an onset, in the colour condition the cue would not elicit a shift in attention. This is exactly what they found; the cue only captured attention in the onset condition, with costs to response times for invalidly cued targets.

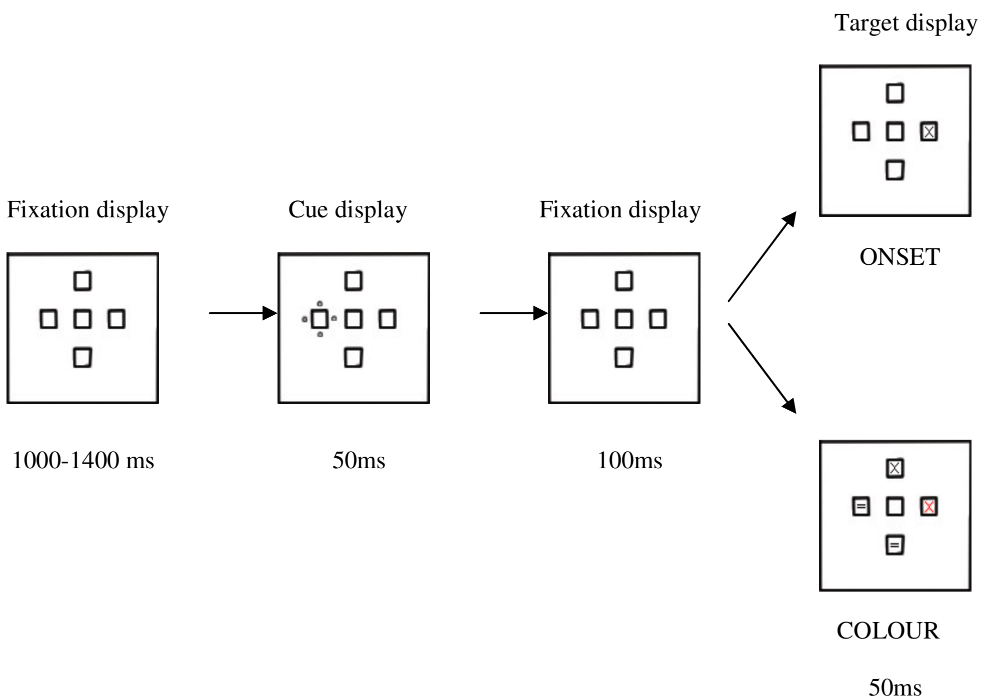

Figure 1.3: Trial layout in experiment one completed by Folk et al. (1992). The cue was always an onset but the target was either an onset or a colour target. In the 'colour' condition the target was red and the distracters were white (shown in black here). This example shows an invalid trial.

In a second experiment they tested the same effect with a colour cue rather than an onset cue. This time the cue only captured attention and resulted in faster responses to validly cued targets and slower responses to invalidly cued targets in the colour condition when participants were searching for a colour target. Additionally they also found (experiment four) that a different coloured cue (e.g., green) would capture attention when the target was red (for instance), suggesting that the orienting system was configured at a *feature* level (colour), and not configured for the specific *feature values* (red or green). Together their collection of four experiments showed that an abrupt onset and a colour singleton were capable of capturing attention exogenously, but only if they were relevant to the task demands. This presents something of a paradox; how can the capture of attention be exogenous when it is influenced by top-down control? Folk et al. (1992) maintain that such shifts of attention are still exogenous and involuntary because they are motivated by the stimulus properties. Yet the fact that these shifts are influenced by top-down control does imply that it is inaccurate to refer to them as 'automatic'.

Despite evidence for contingent capture from Folk et al. (1992) a subsequent paper by Theeuwes (1992) provided evidence for automatic capture which was not contingent upon top-down control settings. When participants had to search for an abrupt onset an irrelevant colour singleton captured attention, and when searching for a colour singleton an abrupt onset captured attention. According to the involuntary orienting hypothesis, if the orienting system was configured for one specific feature (colour or onset), an item not matching this feature should not capture attention. Theeuwes also found that when the colour singleton was less distinctive it failed to capture attention when participants were searching for an onset. He states that this shows the importance of salience in the control of attention; the most salient item will always be attended first due to the preattentive analysis which is entirely based on stimulus properties. His *data-driven selection* model allows for the possibility that focused attention can prevent automatic capture, but concludes that selection is governed by relative salience (Theeuwes, 1993).

Contrary to this argument Folk, Remington, and Wright (1994) extended their earlier findings by revealing contingent capture for motion in addition to colour and abrupt onsets. They found that a cue would only capture attention when participants were expecting a moving target if the cue was also defined by motion. The cue did not capture attention when it was defined by colour, or was an abrupt onset. How can these two opposing sets of findings be reconciled? Folk and colleagues (Folk et al., 1994; Folk & Remington, 2006) state that in the experiments completed by Theeuwes participants could complete the task by searching for the *unique* item in the display, rather than searching for a specific feature. As such the orienting system would be configured to any unique item and any unique item would capture attention. In essence the findings would therefore provide support for contingent capture; the irrelevant item captured attention because it matched the top-down control settings (search for the unique item). They support their argument using the two modes of search defined by Bacon and Egeth (1994) who stated that based on the task demands a visual search could be completed using a *singleton detection search mode* or a *feature detection search mode*. In the singleton detection mode observers would always search for the unique item (the odd one out of the display). In the feature search mode observers would search for an item which could be defined by a specific feature, for example colour or shape. Folk and colleagues argued that participants adopted a singleton detection mode in Theeuwes' studies which is why any irrelevant singleton captured attention.

Theeuwes and Burger (1998) attempted to investigate the validity of the involuntary orienting hypothesis using a series of experiments designed to measure automatic capture. In one experiment (experiment three) participants had to find a target letter (E or R) among a set of non-target letters. All letters were grey and

Theeuwes and Burger predicted that if top-down factors play a role at the preattentive stage ‘grey’ would be activated and search would be biased towards grey items. Despite this, an irrelevant colour singleton captured attention, indicating that automatic capture can override any top-down control settings, and leading Theeuwes and Burger to conclude that their findings contradict the Guided Search model (Wolfe, 1994). Yet, in this experiment searching for a grey item would have no benefit to the task (other than to prevent capture by the singleton) because the only item which was not grey was the singleton. If participants were searching on the basis of the target being grey they would have to complete a serial search through the display, reducing search efficiency. Wolfe (1994) clearly states that if a feature is not beneficial for search this feature will not be activated at the preattentive stage. Participants may therefore not be searching for grey because all items are grey and instead they may be searching for a unique item. In this case the singleton would capture attention because it was unique (and matches the top-down settings), not because it overrides the top-down settings.

In another experiment Theeuwes and Burger (1998) found that when the colour of the targets and the irrelevant singletons remained constant across all trials the singleton did not capture attention. It can be argued that participants may begin the task using a singleton detection mode (and all irrelevant singletons will capture attention) but over time were able to adopt a strategy which allowed them to selectively search among the items matching the target colour (with the knowledge that the colours were consistent over time) and inhibit the irrelevant singleton. Therefore, despite the claims of the authors, their evidence does not contradict the Guided Search model and it does not contradict the notion of contingent capture.

1.2.4 Recent evidence for the control of selective attention: The debate continues

Similar to the research conducted by Theeuwes and Burger (1998) recent work alleges to provide evidence for pure bottom-up capture, however, like the findings of Theeuwes and Burger there may be an alternative explanation for such evidence. In a visual search task Turatto and Galfano (2001) asked participants to search for a rotated T among rotated Ls and detect if the target was present or absent. Each letter was presented on one of several coloured discs arranged in a circle around fixation. A uniquely coloured disc (singleton) was also presented and RTs were recorded in relation to the distance of the target from the irrelevant singleton. They found that the singleton captured attention despite being task-irrelevant (RTs were longer to detect the target when it appeared closer to the irrelevant singleton, revealing that more inhibition had to be applied to the singleton, leaving fewer resources to detect the target) and concluded that participants were unable to prevent the automatic capture and that the search strategy could not override bottom-up salience. Turatto and Galfano state that they provide “direct behavioural proof that a task-irrelevant color singleton can elicit an automatic attentional capture in the absence of any set” (pp. 290). However, it is entirely possible that participants used a singleton detection search mode (Bacon & Egeth, 1994), in which case it would be no surprise that the irrelevant singleton captured attention. This argument is strengthened by their results which show that capture of attention by the irrelevant singleton reduced as the task went on (similar to the results of Theeuwes & Burger and possibly showing that participants modified their search strategy with experience to avoid automatic capture), and that the singleton failed to capture attention when participants were told that it did not predict where the target would appear. This clearly shows that automatic capture was reliant upon top-down knowledge about the task (despite the claims made by the authors).

The results from an experiment completed by Pratt, Sekuler, and McAuliffe (2001) are consistent with the above argument. Using Folk et al.'s 1992 spatial cuing paradigm they studied the ability of cues to capture attention when they did not match the target-defining features (and therefore did not match the top-down control settings). When the experiment was blocked so that participants knew the target search feature on each trial, only the matching cues captured attention and elicited a cuing effect. When the trials were randomised so that participants did not know whether the target would be an onset or a colour singleton, all cues resulted in a cuing effect. Therefore when participants were unable to use top-down control settings to complete the task an irrelevant item which did not match the target feature captured attention, but when they could exert top-down control this automatic capture was suppressed. This illustrates that the level at which the control settings can be configured has a significant impact upon the capture of attention by task-irrelevant stimuli.

There is still no consensus over the relative influence of top-down and bottom-up control on selective attention, and some researchers are now resorting to additional forms of evidence to provide support for their respective viewpoints. One popular method has been to measure the event related potential (ERP) associated with activity during target detection (the N2pc). Using a visual search task Hickey, McDonald, and Theeuwes (2006) found that when participants had to search for a target in the presence of a more salient distracter, the distracter elicited activity from the N2pc prior to the target, indicating that the most salient item will always capture attention regardless of the task demands. Conversely, using a spatial cuing paradigm, Eimer and Kiss (2008) and Lien, Ruthruff, Goodin, and Remington (2008) found that a cue only elicited strong N2pc activity when it matched the target-defining features (e.g., an onset cue only evoked an N2pc effect when the target was also an onset). In both spatial cuing experiments the onset was the most salient item yet automatic capture was contingent upon the experimental condition, indicating that top-down control suppressed any bottom-up influence of stimulus salience.

It is important to note that of the studies reported in the literature those claiming evidence for contingent capture often use a spatial cuing paradigm and those claiming to support stimulus-driven capture involve a visual search task. Theeuwes, Atchley, and Kramer (2000) claim that spatial cuing results in contingent capture (or rather the appearance of contingent capture) because disengagement of attention from a stimulus which matches the control settings takes longer than disengagement from a stimulus which does not match the control settings. This explanation is supported by evidence from Schreij, Owens, and Theeuwes (2008) which shows that presenting the cue at the same time as the target in a spatial cuing task eliminates the 'contingent capture' effect (because it eliminates the requirement to disengage from the cue), and all irrelevant singletons capture attention regardless of their task-relevance. The present author would argue that the task used by Theeuwes and colleagues (e.g., Schreij et al., 2008; Theeuwes, 1991b; Theeuwes & Burger, 1998) is equally problematic for their conclusions. It is predicted that Theeuwes et al. consistently fall prey to underestimating the level at which the orienting system can be configured. For instance, they state that an irrelevant unique item captures attention because it is the most salient item in the display, yet there is evidence to show that this capture is contingent upon the top-down control setting because participants are actually searching for a unique item (using a singleton detection mode; e.g., Bacon & Egeth, 1994). In addition to this, even when Theeuwes et al. presume that the task can be completed using a specific feature search mode (and find that an irrelevant singleton which does not match the target-defining feature captures attention), participants may instead be allocating attention to a different feature of the target. For example, in the study completed by Theeuwes and Burger (1998) participants were asked to search for the letters ‘E’ or ‘R’ and even when the irrelevant singleton did not share the same colour as the target letter it still captured attention. Theeuwes and Burger assumed that participants used colour to search for the target but it may be reasonable to suggest that they are actually searching for ‘form’ because all items were grey and a colour search would not facilitate target detection. As the singleton was also always the letter ‘E’ or ‘R’ it would match the top-down control settings, therefore the capture of attention was due to the task demands, not the salience of the stimulus. One aim of this thesis is to determine the levels at which the orienting system can be configured. This will help to clarify whether the design of the studies completed by Theeuwes et al. can really provide evidence for pure bottom-up capture.

1.2.5 Additional evidence for top-down control over stimulus-driven capture

The findings that have been reviewed thus far all account for the control of selective attention using low-level tasks. These tasks generally consist of a search for a single item among similar distracters, allowing the initial allocation of attention to the search display to be measured. Such tasks do not provide evidence for how attention is controlled in more natural environments and they are unable to show how attention moves through the visual field (beyond orienting towards the most relevant or the most salient regions). Experiments using more naturalistic scenes are able to bridge this gap, revealing how attention moves through the visual field on the basis of visual salience (bottom-up) and semantic information (top-down). These studies generally make use of pictures of natural scenes, or in some instances line drawings of natural scenes; participants are asked to search the scenes, and eye movements are measured. The critical issue is whether guidance of attention (and the eyes) is through low-level salience, or whether observers search on the basis of top-down knowledge about the scene[4].

Early studies by Yarbus (1967) provided support for a strong influence of top-down control, revealing that scan paths (sequences of fixations) in natural scenes varied in accordance with varying task demands; in his experiments participants were altering their search patterns to meet the requirements of the task. Several studies which monitor eye movements in everyday tasks have also found evidence for top-down guidance. For example Hayhoe, Land, & Shrivastava (1999) and Shinoda, Hayhoe, & Shrivastava (2001) have found that individuals have very stereotypical search patterns when completing certain (habitually repeated) tasks (e.g., driving). This is indicative of a search strategy which is based on previous experience with the task (i.e., top-down information). They also claim that these strategies provide a possible solution to the 'scheduling problem' (Hayhoe, 2000; also known as the 'initial access problem' [Ullman, 1984]). The scheduling problem is as follows: how does an observer know where to look in a scene when they do not know what the scene contains before looking? Shinoda et al. (2001) propose that an observer will use pre-existing knowledge of the scene to look towards the region most likely to contain task-relevant information (i.e., which region was most relevant on previous occasions?).

[4] Again, although there is an argument that the eyes can move independently from attention, there is good reason to believe that the following evidence represents overt shifts of attention. For example, in several cases there is evidence that attention moves before the eyes (e.g., Hayhoe, 2000; Land & Horwood, 1995) revealing that the eyes follow attention.

This fits well with the suggestion that attention is guided by 'spatial priors'. Spatial priors are knowledge about the location of relevant information in a scene due to previous experience of the scene. For instance, Tatler (2007) has found that observers have a 'central fixation bias' whereby they fixate to the centre of a scene initially before making an eye movement elsewhere. He posits that this may be due to the fact that the centre is an ideal place to begin a search, or that the centre is most informative, but suggests that it is independent of stimulus properties and task demands. Building on this account Einhäuser, Spain, and Perona (2008) hypothesise that spatial priors may be initially elicited by bottom-up influences (the first time one encounters a scene), but the subsequent application of spatial priors (on successive viewings) is completed top-down and is dependent upon the task demands.

The use of 'stereotypical' search patterns (e.g., Shinoda et al., 2001) is also consistent with the notion of 'contextual cuing' which shows that when observers see the same display on a number of occasions they learn the spatial configuration of the display, allowing them to search quicker in comparison to a novel display (Chun & Jiang, 1998). This means that individuals use previous knowledge about the spatial layout of the display to guide their attention (Chun, 2000) and this influences the pattern of visual search. Recently Brockmole and Henderson (2006) have found evidence for contextual cuing in natural scenes, reporting that participants locate a target letter in repeated scenes faster than in novel scenes, and revealing that pre-existing knowledge about the spatial configuration of the scene guides attention.

Land and Hayhoe (2001) have developed an 'orienting hypothesis' which accounts for the influence of previous knowledge over patterns of visual search. They suggest that when first viewing a scene an observer will create an initial analysis, allowing them to represent the gist of the scene. This representation will then guide attention and eye movements and can be updated over time as more information is derived from the scene. If, in the initial glimpse, the context is familiar, attention will be guided on the basis of previous experience. Castelhano and Henderson (2007) provide support for this hypothesis, showing that if participants are provided with a preview of a natural scene, prior to completing a search of the scene, they show a more efficient search (in comparison to when no preview is provided). This illustrates that observers learn something about the context of the scene from the preview, and this will facilitate subsequent search.

The importance of context in guiding attention and eye movements has also been demonstrated by Loftus and Mackworth (1978). They presented participants with line drawings of natural scenes and eye movements were recorded. An item was placed in each scene and this item could either be consistent with the scene (e.g., a tractor in a farmyard) or inconsistent with the scene (e.g., an octopus in a farmyard). They found that participants fixated inconsistent items earlier than consistent items, and suggested that observers will first take an initial analysis of the scene, after which attention is allocated to the inconsistent item because it does not fit with the semantic context of the scene. Further work in this area has yielded mixed results. For example in a similar study De Graef, Christiaens, and d'Ydewalle (1990) found no difference between fixations made to consistent and inconsistent items, and Hollingworth and Henderson (1998) found that participants fixated consistent items earlier than inconsistent items (experiment one). Henderson, Weeks, and Hollingworth (1999) subsequently developed a 'saliency map framework', proposing that covert attention will always initially be driven by salience, after which 'cognitive' factors take effect and the semantic context of the scene will guide attention.

In line with Henderson et al. (1999) other researchers also propose that attention is initially allocated on the basis of stimulus properties. Building on the model of attention developed by Koch and Ullman (1985), Itti and Koch (2000) have developed a saliency model which attempts to account for the control of selective attention in the visual field. Again they specify a 'saliency map' whereby the relative difference between regions in the visual field will be computed for several different features (they outline a total of 42 individual feature maps). Itti and Koch state that these 42 feature maps are then combined into three 'conspicuity maps' for intensity, orientation, and colour. Similar to the earlier model, a saliency map is created from these three conspicuity maps and attention is allocated to the most salient area of the scene. Once attention has shifted to this location, inhibition of return occurs (e.g., Posner, Cohen, & Rafal, 1982) to ensure that this area will not attract attention again, and attention moves to the next most salient region. Importantly, this model makes no account for top-down control over the initial guidance of attention, suggesting that in a natural scene visual search is initially based on the stimulus properties; the most salient items will always be fixated first. Evidence for saliency-driven search comes from a variety of sources (e.g., Baddeley & Tatler, 2006; Parkhurst & Niebur, 2003; Tatler, Baddeley, & Gilchrist, 2005). However this does not explain why other researchers have found that task demands modulate visual search patterns (e.g., Yarbus, 1967), and why the addition of 'spatial priors' in saliency maps provide a better prediction of fixation patterns than salience alone (e.g., Torralba, Oliva, Castelhano, & Henderson, 2006). As illustrated by this selection of literature, even in more applied research there is still no consensus regarding the control of selective attention.

1.3 Top-down attentional set

1.3.1 Characteristics of the attentional set

In order to provide further clarity regarding the relative influence of top-down and bottom-up control this author aims to investigate goal-driven selection. Specifically the work in this thesis will address how attention is allocated, at what level the orienting system is configured, and the influences upon top-down control. This will be achieved through the study of the attentional set.

Leber and Egeth (2006) define the top-down attentional set as "a preparatory state of the information processing system that prioritizes stimuli for selection based on simple visual features" (pp. 565). This means that based on the task demands the orienting system is 'set' to selectively attend to task-relevant stimuli and to inhibit task-irrelevant stimuli. The attentional set therefore determines which stimuli will be selected and attention will be biased towards items which match the set. The attentional set is what Folk et al. (1992) refer to as 'attentional control settings', and it is also what Bacon and Egeth (1994) refer to as singleton detection and feature search modes. It is the rules by which certain stimuli are selected for further processing at the expense of other stimuli.

The attentional set may be configured for a range of features (e.g., colour, orientation, motion) and these are consistent with those features thought to guide attention at the preattentive stage (Wolfe, 1996; Wolfe & Horowitz, 2004). This means that when searching for a red target among grey distracters participants may adopt an attentional set for "red", selectively attending to items which match the control setting and ignoring those items which do not match the settings. Folk et al. (1992) make the proposal that rather than configuring the orienting system to a specific feature value (e.g., red), the system is instead configured at a more general level of feature (e.g., colour). This would mean that observers search for a coloured item rather than a specifically coloured item and attention is directed to the uniquely coloured item. Results from their fourth experiment were consistent with this hypothesis, as when searching for a red target, a green cue also captured attention. This would be beneficial in instances where all distracters are the same colour, but it would not facilitate target detection if the distracters are different colours.

More recent work would suggest that the orienting system can be configured at a feature-value level. For example the studies completed by Egeth et al. (1984) and Kaptein et al. (1995) show that participants can selectively attend to a subset of features (e.g., selectively searching through all blue items and ignoring all green items). Rossi and Paradiso (1995) have also shown that when searching for a particular orientation at the centre of the visual field, peripheral distracters with the same orientation capture attention. Not only is this consistent with the explanation of the attentional set and its effects (the set will be based on the task demands and anything matching the set will capture attention), it also shows that attention can be 'set' to search for a specific *value* of orientation, not just the *feature* of orientation.

At the current time there is a solid understanding of the objectives and impacts of an attentional set; the system is set to selectively attend to relevant items, and this means that anything matching the target-defining features will capture attention. There is less research which focuses upon the way in which the orienting system is configured for a given task. This will be rectified by the present research, allowing an extension of the findings cited above.

1.3.2 Cognitive control and the attentional set

Goal-driven allocation of attention (the attentional set) is controlled by the cognitive system, and according to Luks, Simpson, Feiwell, and Miller (2002) this involves the use of 'self monitoring mechanisms' which ensure that goals are being achieved. This is important because if the task goals are not being satisfied a change in set may be required. Cognitive control is therefore essential to ensure that there is a balance between keeping control of the set (to complete the task and avoid distractions) and keeping the set flexible in order to switch set when the task goals are no longer being met. An emphasis on maintenance will lead to a more stable set, but it could also lead to perseverative behaviour whereby the set persists when the task demands change. An emphasis on flexibility will ensure that a switch can occur in conjunction with a change in task, but it could leave one more susceptible to distraction (Dreisbach & Goschke, 2004). An observer must therefore strike a balance between "stable maintenance" and "flexible switching" to ensure efficient performance on a task.

Luks et al. (2002) state that attentional control and attentional monitoring (which allow for stability and flexibility) appear to be related to two frontal brain areas; the dorsolateral prefrontal cortex (DLPFC) is responsible for the allocation of attention (and also associated with endogenous orienting [e.g., Sereno, 1992]), and the anterior cingulate cortex is responsible for monitoring and maintaining a set. Evidence for the importance of the frontal lobe in cognitive control comes from studies which indicate that patients with frontal lobe damage suffer impaired performance on tasks designed to measure cognitive control (e.g., the Wisconsin Card Sorting Task [WCST]; Nelson, 1976; Owen, Roberts, Hodges, Summers, Polkey, & Robbins, 1993). In the WCST participants are presented with a series of cards each containing a symbol. The symbols can be described on the basis of colour, shape, or number, and participants are usually asked to sort the cards using one of these features. After sorting the cards according to one feature, if participants are then asked to sort on the basis of another feature frontal lobe patients show increased perseverative errors compared to controls. This means that they often revert back to sorting the cards based on the previous feature. Damage to the DLPFC is directly related to perseverative errors in the WCST (Milner [1964], as cited by Robbins & Rogers [2000]), showing that the DLPFC is related to set switching and cognitive control.

This author is proposing that the notion of cognitive control can actually be separated into two distinct components; micro-control and macro-control. Micro-control is the control of attention; this would be the voluntary, top-down control over the allocation of resources to task-relevant stimuli and away from task-irrelevant stimuli. Capture of attention by task-irrelevant stimuli would represent a failure of top-down control. Macro-control would be the control over the internal task representation. This includes monitoring the situation to ensure that the task-goals are being met, ensuring that the set remains stable over the course of the task, and that the set switches when the task demands change (Dreisbach & Goschke, 2004). These two forms of control fit well with the definitions provided by Luks et al. (2002); cognitive control incorporates attentional control (micro-control) and attentional monitoring (macro-control). The introduction of these new terms does not imply that the original description (and use) of the term ‘cognitive control’ is now redundant or inaccurate. Instead, this author would argue that the notion of control requires further clarity, and to outline two separate components, within the overall idea of cognitive control, would be beneficial.

Importantly, micro-control can be situated on a 'continuum of automaticity', whereby over time an attentional set may become automatic and habitual because stimuli are consistently associated with the same responses. This means that the stimuli will evoke these responses automatically, without the need for top-down control. This suggestion follows that of Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) who make the distinction between controlled and automatic processing. Automatic processing is beneficial because it frees up resources to be used elsewhere. However, when a set is automatically triggered by stimuli associated with that set there is the potential that the set may be triggered (by the stimuli) when it is not relevant to the situation (see the example posed at the beginning of this chapter). This is where macro-control must be used to inhibit the habitual set and allow a more appropriate set to be configured (Posner & DiGirolamo, 1998). Macro-control is not defined as voluntary or automatic, and the 'stability' and 'flexibility' of a set does not denote variations in the levels of this type of control. Although both levels of control work together to achieve a stable yet flexible orienting system, it seems reasonable to suggest that when micro-control is reduced, macro-control must be increased, and when macro-control increases, there is less need for micro-control. Therefore both types of control can be equally described as automatic or voluntary, depending on the conditions surrounding a given task.

Throughout this thesis the author will attempt to make it clear when each type of control is being referred to. Specifically, "top-down control" and "attentional control" will relate to the micro-control over the allocation of attention, not the level of macro-control one has over the set, or the task. The terms macro- and micro-control will be re-visited in the General Discussion (Chapter Nine).

1.4 The carry-over of attentional set

1.4.1 The influence of experience

In light of the increasing interest surrounding top-down attentional control, researchers have attempted to study how an attentional set is established. Although the set is expected to be configured in line with current task demands (e.g., Folk et al., 1992) more recent work suggests that it may also be influenced by other factors. Using a rapid serial visual presentation task Leber and Egeth (2006) have demonstrated the impact of past experience on an attentional set. Participants were asked to attend to a stream of stimuli (letters) appearing sequentially at the centre of the screen and to search for a single target (a coloured letter) whilst ignoring any coloured peripheral distracters (a '#' symbol). For one group of participants all the letters were grey with the exception of the target letter which could be any colour. For a second group the letters were heterogeneously coloured (grey, blue, purple, and green) and participants had to search for a red target letter. Participants in the first group were told to complete the task using a singleton detection mode (search for the uniquely coloured target, whilst those in the second group were told to adopt a feature search mode (search for a red target). A training phase of trials showed that participants did indeed adopt the required 'sets' as participants in the singleton group were unable to ignore the peripheral distracters regardless of colour, whilst the performance of those in the feature group was only influenced by peripheral distracters which matched the specific target colour. In a second (test) phase of trials participants were all asked to search for a specific target colour among grey non-targets. Although the task could be completed using a singleton detection mode, this would mean that all peripheral distracters (unless grey) would capture attention, therefore a feature mode would be more beneficial to performance. Despite this, participants in the singleton group continued to use their original set and their performance suffered in comparison to the feature group.

Not only does this study provide evidence for the contingent capture hypothesis, it also shows that the implementation of any attentional set may not just be influenced by the task demands, it may also be influenced by previous experience. Like the findings from more real-world tasks (e.g., Hayhoe et al., 1999; Shinoda et al., 2001), Leber and Egeth have shown that past experience with a task will influence how one approaches the task on subsequent occasions. Although the task demands changed and participants were provided with more information about the identity of the target, they failed to alter the attentional set in line with these new demands, and instead the attentional set from the training phase *carried over* to the test phase. An attentional set is expected to facilitate performance as it biases attention towards task-relevant stimuli, yet if the attentional set that is suitable for one task persists to a second task in which it is no longer relevant, this facilitation will turn into a detriment. Attention will be prioritised on the basis of previous task demands therefore stimuli which are now irrelevant (but were previously relevant) will be attended.

Leber and Egeth are not the first to reveal an impact of past experience upon the allocation of attention, and several researchers have shown that attention is directed to items and locations that were previously relevant. Maljkovic and Nakayama (1994, 2000) found that when participants were asked to detect a uniquely coloured target among a display of homogenous distracters and make a decision about the form of the target responses were faster if the target was the same colour as the target in the previous trial. This effect has been replicated on several occasions and Müller and Krummenacher (2006) have referred to it as “intertrial facilitation”; the relevant feature in one trial guides attention in a subsequent trial. Jongen and Smulders (2007) found similar intertrial effects in a spatial cuing task; specifically, the costs of an invalid cue and the benefits of a valid cue increased when the target in the preceding trial had been validly cued. They suggested that if the cue is valid participants will pay more attention to the cue in a subsequent trial, on the basis that it has successfully predicted target location in the past. This resulted in faster responses to validly cued targets and slower responses to invalidly cued targets in comparison to trials in which the preceding trial involved a neutral or invalid cue.

These studies differ from those completed by Leber and Egeth (2006) because the duration of experience and the duration of carry-over is much smaller. In addition, several researchers suggest that intertrial facilitation is actually due to bottom-up priming of the target feature (e.g., Leonard & Egeth, 2008; Maljkovic & Nakayama, 1994; Theeuwes, Reimann, & Mortier, 2006). According to this explanation the saliency of the target increases on trials in which the target-defining feature remains constant because the priming effect gets stronger over time, resulting in pop-out of the target. This is in direct contrast to the carry-over revealed by Leber and Egeth (2006) in which the capture of attention was contingent upon the top-down control settings. The studies do however show that in addition to orienting attention in response to current task demands, the allocation of attention is also influenced by past experience.

1.4.2 A possible explanation for the carry-over effect

On the basis of a second experiment Leber and Egeth (2006) concluded that the carry-over of attentional set was due to a failure to change set according to the new task demands. This in turn was because the costs of switching set were greater than the benefits to performance that would have been afforded with a change of set (less contingent capture by the task-irrelevant peripheral distracters). In this second experiment participants were provided with fewer trials in the training phase of the task (40 as opposed to 320). Results showed that in this instance participants did alter their attentional set in accordance with changing task demands at the beginning of the test phase, and all adopted a feature search mode, regardless of the strategy they were using in the training phase. This led Leber and Egeth to hypothesise that greater experience with the task serves to consolidate the set, making it more costly to alter when necessary; these costs would outweigh any benefits of a new set. Less experience would mean fewer costs associated with a switch and as such the benefits to performance of adopting a new set would outweigh the costs of switching. Thus after 320 training trials participants maintained the original set, and after 40 training trials participants switched set.

1.5 The carry-over of a task set (i.e. *not* the carry-over of attentional set)

1.5.1 Attentional and intentional sets

With the exception of patient studies, and the experiments completed by Leber and Egeth (2006) there have been few attempts to study the persistence of an attentional set. This is not the case for the persistence of an *intentional set*. An intentional set (most commonly referred to as a task set) is similar to an attentional set in that it is established to satisfy the task demands. However whilst an attentional set ensures that attention will be allocated to the most relevant stimuli, an intentional set ensures that the correct behavioural response will be made to the relevant stimuli. Therefore whenever there is a change in the task demands there is the potential that a switch in attentional set and/or a switch in intentional set may be required. Rushworth, Passingham, and Nobre (2002) distinguish between these two different types of set switching by giving the following definition: “attentional set switching requires subjects to change the rules by which they select between sensory stimuli. Intentional set switching requires subjects to change the rules by which they select between motor responses” (pp. 84). Unlike attentional set switching, the components of task switching have been widely studied, following the initial work of Jersild (1927) who used task switching to investigate cognitive control of a task set.

1.5.2 Task switching

Task switching is most often studied with the use of experiments which require participants to complete a task involving selecting between two rules in order to respond to stimuli. For example, participants may be presented with a letter appearing in the centre of a screen, if the letter is blue they have to identify whether the letter is presented in upper or lower case, if the letter is red they have to identify whether the letter is a vowel or a consonant. Depending on the particular paradigm chosen by the investigator the number of trials that are completed before a task switch is required varies (i.e., the number of trials in which the letter is always blue before it is red). Switching may occur at random so that participants will not know when to expect a switch, or it could be predictable so that they can prepare to switch. The impact of a task switch on performance is measured by subtracting RT in the no-switch trials (e.g., blue to blue) from RT in the switch trials (e.g., blue to red).

In general task switching studies show that responses are slower on switch trials than on no-switch trials, however these ‘switch costs’ are reduced somewhat when participants can prepare for the switch (e.g., Meiran, 1996; Wylie & Allport, 2000). As the switch cost is reduced when participants are given time to prepare for the switch Rogers and Monsell (1995) attribute the costs to task set reconfiguration; the re-activation of the alternate set. Reconfiguration takes time therefore performance on the switch trials suffers. Preparation allows reconfiguration to begin earlier, and as a consequence the costs are reduced. However, even a long interval between the trials (to allow for reconfiguration) does not fully eliminate switch costs (e.g., Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995), indicating that there may be additional reasons for the effect. Rogers and Monsell (1995) suggest that the set cannot be reconfigured fully until the stimuli associated with the set are presented because they exogenously trigger the set. This means that one can prepare for the set switch, but the switch will not be completed until the stimuli have appeared (resulting in the switch cost). This is a bottom-up influence (the stimuli automatically trigger the set). Allport et al. (1994) attribute the switch costs (those not accounted for by set reconfiguration) to the interference from the old set. Their task set inertia hypothesis proposes that the old set will persist to the new trial and this must be inhibited (taking resources away from the task and impairing performance). Using this explanation the switch costs are due to a lack of top-down control over the current set, allowing the previous set to interfere. Important to both accounts is the finding that a more practised set is easier to reconfigure, yet a more practised set is also more difficult to inhibit. This is consistent with the findings of Leber and Egeth (2006), however they attribute the persistence of attentional set to a failure to switch set, not the difficulty of switching set.

Although task switching is different from attentional set switching, it can be argued that a task switch will involve some form of attentional switch. For instance in the example of a task switching study provided earlier (participants respond to a different feature of a letter depending upon the colour of the letter) participants must allocate attention to the form of the letter when it is blue (is it upper or lowercase?) but they must allocate attention to the identity of the letter when it is red (is it a vowel or a consonant?). It is therefore important to account for the similarities and differences between attentional and intentional set switching.

1.6 Aims and objectives of the current thesis

The initial aim of this thesis was to explore the carry-over of attentional set between two tasks. As the work progressed it became clear that the investigation of the carry-over effect also highlighted some important aspects of top-down attentional control. As such the aims were expanded to include an examination of some of the characteristics of top-down selection (as shown through the persistence of attentional set). Specifically the research was conducted to address the following issues:

- Will an attentional set persist from one task to a subsequent task despite being irrelevant for the second task?
- What is the underlying cause of this carry-over effect?
- What are the conditions under which carry-over is most likely to occur?
- Can the carry-over effect reveal anything about the top-down control of selective attention? Related to this:
    - What is the focus of selection?
    - At what level is attentional control configured?
    - Can control be configured at more than one level?

The research will be conducted using three different methodologies, with the objective of providing converging evidence for the issues under investigation.

Twelve experiments will be presented in this thesis. An initial exploration of the carry-over effect was completed using the Attentional Blink paradigm. This consisted of two pilot studies and three subsequent experiments, and these are discussed in Chapters Two to Four. To increase the differences between the two tasks (the one in which the set is initially established and the one the set persists to) a second methodology was adopted which employed a change detection flicker task paired with a visual search task. The experiments completed using this methodology are presented in Chapters Five to Seven, and again the investigation consisted of two pilot studies and three later experiments. Two final experiments using a third methodology were then completed in an attempt to apply the findings to more naturalistic situations. To achieve this the visual search given to pictures of natural scenes was measured in relation to the spatial layout of stimuli in a preceding visual search task. These experiments can be found in Chapter Eight. All the findings and their implications for persistence of attentional set and the top-down control of attention will then be discussed in Chapter Nine. The results of all statistical tests can be found in Appendix One, and Appendix Two contains the instructions given to participants in each experiment.

Chapter Two: The Attentional Blink Effect

2.1 Introduction to the attentional blink

2.1.1 A description of the effect

The first five experiments in this thesis investigate the carry-over of attentional set by using a method known as a rapid serial visual presentation (RSVP). This method was initially developed as a way of measuring the temporal parameters of visual attention. Participants are shown a stream of stimuli, usually to the same spatial location, from which they have to detect and identify one or more targets (e.g., Weichselgartner & Sperling, 1987). Each item in the RSVP replaces each previously presented item, and the stimuli are shown extremely quickly, usually at a rate of around 10 items per second, however presentation rates can vary from 6 to 20 items per second (Shapiro, 2001).

The RSVP paradigm was chosen as a suitable methodology for investigating carry-over because it involves a very simple design with simple stimuli, it can be manipulated easily, and crucially, the completion of the task requires a participant to establish an attentional set. For example, a common RSVP experiment includes a series of grey distracter letters, from which participants have to identify one or more coloured digits. According to Raymond, Shapiro, and Arnell (1992) participants are set to search for the target-defining feature (in this case colour) and identify the to-be-reported feature (the number which is coloured). The RSVP methodology therefore captures the essence of attentional control in real-world tasks; individuals must attend to the task-relevant information to go about their every-day lives, whilst ignoring any task-irrelevant information.

Studies show that despite the speed at which items are shown in a RSVP, participants are usually extremely capable of detecting and identifying one target from a stream of distracters (single task RSVP; e.g., Broadbent and Broadbent, 1987). Problems arise however in a dual or multiple task RSVP when participants must detect and identify more than one target from a stream of distracters. In a dual task RSVP participants are presented with two targets separated by a temporal ‘lag’. Results show that when a second target (T2) is presented within 500ms of an initial target (T1), identification of T2 is impaired. This effect is known as the *attentional blink* (AB; Raymond et al., 1992) and reveals limitations in the brain’s ability to process information presented successively. There are countless experiments which measure the AB, and the effect is very robust, with most studies finding that identification of T2 is best described using a bimodal function. Identification is high when T2 immediately follows T1 (referred to as lag-1 sparing), decreases between 150 and 300 milliseconds SOA, after which point T2 accuracy increases and there is a ‘recovery’ from the blink (e.g., Broadbent & Broadbent, 1987; Chun & Potter, 1995; Raymond et al., 1992; Seiffert & Di Lollo, 1997; Shapiro, Raymond, & Arnell, 1994; Weichselgartner & Sperling, 1987). The greatest detriment is generally seen between 180 and 270 ms SOA (Raymond et al., 1992) but the blink can last up to and beyond 500 ms SOA.

2.1.2 Initial attempts to explain the AB effect

When the AB effect was first found it was attributed to T1; the brain is busy processing this first target and therefore misses T2. However, Raymond et al. (1992) found that in a single target RSVP the processing of T1 (which requires linking the target-defining characteristic with the to-be-reported feature) takes around 100ms.

This in no way accounts for the lengthy detriment found in the identification of T2 in a dual target RSVP. They instead proposed an Inhibition Model to account for the AB effect, which posits that when T1 is detected as a target and enters the processing system, the mechanisms used to identify targets will temporarily shut down to prevent interference from any incoming stimuli. If T2 appears at lag 1 it will be combined within the same ‘attentional episode’ as T1, resulting in lag-1 sparing. If T2 is presented at a later lag (lags 2-5 for instance) a new attentional episode will need to be instigated. This process is time consuming because the system has been ‘locked’ to inhibit T1+1 items. As a result there is a post-target processing deficit and T2 will go unnoticed.

The inhibition model specifies a depletion of resources following the detection of T1; when T2 appears at early lags the model predicts that it will not enter the processing system which is why identification is impaired. The model would therefore predict that the magnitude of the blink would be modulated by task difficulty of T1, yet this is not the case (Shapiro et al., 1994). In addition, studies have shown that even when T2 cannot be identified it can still act as a semantic prime to a third target shown later in the RSVP (Shapiro, Driver, Ward, & Sorensen, 1997). This suggests that T2 does enter the processing system. In support of this behavioural evidence, several researchers have found that even when T2 cannot be reported it still elicits an ERP. Vogel, Luck and Shapiro (1998) measured the ERP at N400 (which is associated with meaning) and discovered that even when T2 could not be identified it still evoked a waveform from the N400 component.

Broadbent and Broadbent (1987) found that when participants were required to report the identity of T2 in a dual target RSVP they most often (incorrectly) reported the distracter item following T2 (T2+1). Chun and Potter (1995) took the predominance of these ‘post-target intrusion errors’ as evidence for a two-stage processing system; encompassing a low-level stage of processing, and a higher, limited-capacity stage of processing. Chun and Potter proposed that all items in a RSVP will enter the first stage and any items which match the target-defining features (determined by the attentional set) will be transferred to the second stage for further processing. As T1 appears first in the AB it will be transferred to the second stage first and the ‘attentional gate’ between the two stages will close to prevent interference from any incoming distracters. If T2 appears before T1 has been processed it must remain in the first stage where it is subject to interference and may be replaced by subsequent items which are then reported as T2 (resulting in the post-target intrusion error). Therefore at early lags T2 cannot be reported but it is still processed to a certain extent, effectively accounting for the findings of semantic priming by Shapiro et al. (1997). The high level of T2 accuracy at lag 1 (found in approximately half of the AB studies published [Visser, Bischof, & Di Lollo, 1999]) is attributed to a slow closure of the attentional gate between stages one and two, allowing T1+1 to enter the second stage along with T1. Like the inhibition model, the two-stage model highlights processing limitations in the system; however it postulates that the AB is due to a bottleneck in higher level processing rather than a depletion of resources.

2.1.3 A role for top-down control in the AB

Early theories of the AB were so motivated to find the cause of the detriment in T2 identification that they failed to address the issue of how targets were selected in a RSVP. Olivers and Watson (2006) criticise this, specifying that top-down control over the selection process may be a key factor in understanding the blink. By carefully manipulating the featural similarity between T1 and T2 in a RSVP they were able to show the importance of top-down processing in the AB. Participants were asked to search through a stream of distracter letters for a specifically coloured letter (T1) and a dot pattern (T2) and report the letter and the number of dots they saw. T2 was either the same colour as T1, the same colour as the distracters, or a unique colour. Findings showed that the AB was much larger when T2 was the same colour as the distracters compared to when it was the same colour as T1. This suggests that the presumed role of the attentional set is correct and attention is programmed to select targets and actively inhibit distracters.

Crucial to the current work is the fact that other researchers have used the RSVP methodology to show the influence of top-down processing in the control of attention. The findings of Olivers and Watson (2006) provide evidence for contingent capture (Folk et al., 1992); items matching the target-defining features will be selected; items which do not match will be inhibited. They utilize the contingent capture hypothesis to further understand the workings of the AB; however others have utilised the AB paradigm to gain further evidence for contingent capture. For example, Folk, Leber and Egeth (2002) presented participants with a RSVP containing one target and one peripheral distracter. The distracter was presented before the target and it was either congruent or incongruent with the attentional set. When the distracter was incongruent it did not capture attention and did not cause an AB on the target, however when it was congruent with the set it did cause an AB. Folk et al. (2002) associated the deficit with spatially shifting attention to the distracter (it was shown peripheral to the RSVP), yet Ghorashi, Zuvic, Visser, and Di Lollo (2003) questioned whether it was partly due to the processing of this distracter. They conducted a similar study but presented all items to the same spatial location. Again there was an AB when a distracter shared target-defining features with the subsequent target. The deficit found lasted up to 600ms SOA, therefore the temporal deficit due to contingent capture very closely follows the pattern of performance found in a dual target RSVP when T1 must be processed. This not only shows that the task-irrelevant distracter was being processed to some extent, it also shows similarities between the different findings of the AB and contingent capture, revealing how useful the RSVP methodology can be.

In conjunction with the recent interest into the top-down influence over attentional capture (outlined in Chapter One), current theories of the AB are now suggesting a larger impact of top-down control than was previously projected. One prominent model at the present time is the Temporary Loss of Control model (TLC; Di Lollo, Kawahara, Ghorashi, & Enns, 2005). Di Lollo and colleagues propose that instead of the AB resulting from resource depletion, or a limited capacity processing system, it occurs at an 'executive level' and arises because when T1 is being processed the system temporarily loses top-down control. The attentional set used to complete the RSVP configures the processing system as an input filter which allows items matching the target-defining features to pass through, but denies entry to distracters. This top-down filter requires constant feedback but when the central processor is engaged in processing T1 it can no longer continue to send feedback. The absence of any signals means that the filter may come under exogenous control. Di Lollo, Kawahara, Ghorashi, & Enns specify that the characteristics of the targets and distracters have a critical role at this point. If the T1+1 item matches the attentional control settings it will activate the original set and pass through the filter for further processing, resulting in lag-1 sparing. If the item does not match the original set it will trigger an exogenous set, causing an AB on the items at lags 2+ (even if these items match the original top-down set) until feedback can again be sent to the endogenous set and the top-down system can regain control. The theory therefore proposes that the AB is not due to the number of items to be processed, but the fact that the processing system can only assume one configuration at a time. The processing of T1 only takes 100ms (Raymond et al., 1992) but Di Lollo, Kawahara, Ghorashi, & Enns (2005) suggest that the lengthy deficit caused by this processing is due to the costs associated with switching set.

The TLC model can account for more recent findings of the AB than previous models. For example, Olivers, van der Stigchel, and Hulleman (2007) presented participants with a RSVP containing three targets displayed successively, therefore T2 appeared at lag 1 and T3 appeared at lag 2. According to earlier models an AB effect should be found with lag-1 sparing (T2 would be easily identifiable) followed by a deficit in performance at later lags (T3 would be difficult to identify). What they actually found was that performance was high for all three targets and there was no evidence of an AB. The TLC model posits that this finding occurs because the system does not lose control over the input as the item at lag 1 matches the attentional set and so does not trigger an exogenous set.

2.1.4 Intention and aims of the current work

The goal of the present research is not to provide a detailed review of the AB literature, nor is it to determine which theory of the AB can best account for the many findings; instead it is to use the AB paradigm to measure possible carry-over of attentional set from one task to a second task. The literature cited thus far has therefore been limited to the most influential theories, and those most relevant to the present investigation of the influence of top-down control. Given the recent attempts to explain the AB in terms of attentional control, there is good reason to use the RSVP methodology. It also means that any data found may be able to add to the current debate on how and why the AB occurs, despite this not being the primary aim.

The objective of the AB experiments contained in this thesis is to investigate the carry-over of attentional set by comparing T2 performance in a single target RSVP, based on previous experience with a dual target RSVP. In one condition participants will complete a dual target RSVP block followed by a single target RSVP block. In a second condition participants will complete two single target RSVP blocks. Each block will be identical with the only exception being that in the dual target block both T1 and T2 require a response, and in the single target block T1 is task-irrelevant, does not require a response and should therefore be ignored. In the dual target block an AB is expected when T2 is presented between 200 and 500 ms after the onset of T1. It is also predicted that in this dual target block participants will establish an attentional set to search for T1 and T2. When the task changes to a single target RSVP and T1 becomes irrelevant they will fail to alter the attentional set in line with the new task demands. This means that T1 will still capture attention because it matches the target-defining features as specified by the attentional set, and it will therefore cause an AB on T2 despite the fact that it does not require a response. When participants complete two single target RSVP blocks and have no prior experience with a relevant T1 they will not suffer from an AB in the second block completed. These predictions are based on the previous findings of Leber and Egeth (2006) who found carry-over of attentional set in a RSVP. They determined that if participants had completed an initial block of trials using a singleton detection mode (Bacon & Egeth, 1994), they would continue to use this mode (set) in a second block of trials. This was despite the fact that the set resulted in an impairment to performance because task-irrelevant distracters were more likely to capture attention, and that a feature search mode was more appropriate in the second block of trials.

This author has completed a total of five experiments using the RSVP paradigm. Experiments One and Two can be found in this chapter, Experiments Three and Four are presented in Chapter Three, and Chapter Four consists of the final experiment and a detailed discussion of all the findings and what they can reveal about the persistence of attentional set, the AB effect, and the top-down control of attention.

2.1.5 Methodological constraints

Before embarking on the design of the AB experiments there are several key things to take into account. First, the many experiments showing contingent capture in a RSVP leading to an AB (e.g., Folk et al., 2002; Ghorashi et al., 2003; Olivers & Watson, 2006), means that the stimuli chosen for the studies must not be able to elicit an AB in a single target RSVP when participants are only asked to respond to T2. The single target RSVP is being used as a control condition (when it is not completed after a dual target block) and T2 identification should be high regardless of the temporal lag between the task-irrelevant T1 and the task-relevant T2, and the characteristics of the stimuli. It is essential that performance in the single target RSVP is not influenced by the design of the experiment, or the stimuli involved; any change in performance across temporal lag in a single target RSVP will mean that the AB effect and the carry-over of attentional set from a dual target RSVP to a single target RSVP will be difficult to measure accurately.

A second consideration is that the AB effect appears to be contingent upon the backwards masking of T1 and the backwards masking of T2. Raymond et al. (1992)

found that the AB effect disappeared when a blank was inserted after T1, therefore removing the backwards masking of this initial target. Kawahara, Zuvic, Enns, and Di Lollo (2003) state that backwards masking of T2 is essential for the AB because when processing of T2 is delayed, it must suffer interference by a mask in order to degrade performance. They did complete a study in which an AB was found without backwards masking of T2, however in this study T1 and T2 were highly dissimilar. Participants were told to search the RSVP for a letter (T1) and also determine if the diagonal lines in the following circular array (T2) were in the same orientation. T2 was the last item in the RSVP therefore was not masked by a distracter, yet an AB was found. Kawahara et al. state that the AB effect they found is due to a task switch. Identifying T1 and T2 involved very different tasks; therefore a task switch would be necessary to complete both. A task switch involves reconfiguration of the system from the initial task set to the new task set and this takes time (e.g., Rogers & Monsell, 1995). They believe that the time taken to reconfigure the system is akin to the time taken to process T1 in a standard AB experiment, therefore causing an AB with no mask following T2. Martin and Shapiro (2008) have recently found that the lag-1 sparing effect is also attenuated by a mask between T1 and T2, showing that the mask is a significant factor in the detriment ascribed to the AB. The design used for the present experiments must therefore ensure that T2 is never the final item in the RSVP and T1 and T2 are always masked by a distracter (or T1 is masked by T2 in the case of a lag 1 trial). Of course the design of the experiments could follow that of Kawahara et al. (2003), but introducing a further task switch between T1 and T2 could have consequences upon the carry-over of attentional set from a dual target RSVP block to a single target RSVP block.

One final consideration is the findings of a second experiment presented by Leber and Egeth (2006). Whilst they found evidence of carry-over of the attentional set from the training phase (containing 320 trials) to the testing phase in their first experiment, a second study which only involved 40 training trials found no evidence of carry-over. It is important to make certain that participants have sufficient experience with the attentional set to allow for carry-over. Leber and Egeth state that substantial experience with a set results in consolidation of this set; a change in task demands should be paired with a change in set, but if the benefits to performance of a change in set do not outweigh the costs associated with switching set (reconfiguring the processing system to the new task demands), the original set will persist. Increased experience with a set will mean that more resources have been invested, as such there will be a greater cost associated with switching set.

2.2 Experiment One: Piloting the single target RSVP

2.2.1 Rationale and aims of Experiment One

The intention of the AB studies in this thesis is to investigate carry-over of attentional set by comparing a single target RSVP block that has been completed after a dual target block with a single target RSVP block that has been completed after an identical single target block. The prediction made is that an AB will be found in the second block from the first condition (dual target block followed by single target block) but not in the second block from the second condition (two single target blocks). This comparison can only be made successfully if an AB cannot be found in a single target block under normal circumstances when T1 is not, and has never been task-relevant. If T1 captures attention in a standard single target block, any carry-over from a dual target block could not be measured effectively. For this reason the first pilot study was conducted to investigate the conditions under which an irrelevant target might capture attention and therefore influence responses to T2.

Although the AB is a very robust effect, the pattern of T2 performance is not constant across all experiments. In particular there is one key difference; approximately half the experiments cited in the literature find the lag-1 sparing effect, and the other half do not (Visser, Bischof, & Di Lollo, 1999). Findings show that when T1 and T2 are presented in different spatial locations the lag-1 sparing effect disappears (Kristjánsson & Nakayama, 2002; Visser, Zuvic, Bischof, & Di Lollo, 1999). In addition to this, lag-1 sparing will not occur when T1 and T2 are sufficiently different that a task switch is required (Enns, Visser, Kawahara, & Di Lollo, 2001; Seiffert & Di Lollo, 1997). One way to assess the impact of an irrelevant T1 on T2 detection is therefore to present it in a different spatial location to T2. It is predicted that if an irrelevant T1 captures attention T2 identification accuracy will differ across temporal lag, with accuracy high at lag 1, decreasing between lags 2 and 3, and then increasing again. If the irrelevant T1 appears in a different spatial location to T2 and captures attention T2 identification will still suffer but there will be no lag-1 sparing.

A further aim of the pilot experiment was to assess the impact of different RSVP speeds on the detection and identification of T2. If participants have difficulty identifying T2 without having to also respond to T1 problems may arise in a dual target block. For example, as T2 accuracy is subtracted from T1 accuracy to obtain a measure of AB magnitude, low T1 accuracy will reduce the number of possible trials that can be analysed. A difference in T2 accuracy is expected in relation to RSVP speed, with a higher speed resulting in lower identification accuracy.

The first pilot study will therefore explore the potential that an irrelevant T1 can cause an AB on T2 in a single target RSVP by varying the temporal lag between T1 and T2 and measuring T2 performance, and by manipulating the spatial location of T1. This will show whether the stimuli chosen will induce contingent capture (Folk et al., 1992) and whether they are suitable for investigating the AB and the carry-over effect. It will also identify the most appropriate RSVP speed to use (with the chosen stimuli) to ensure high accuracy in a single target block.

2.2.2 Method

2.2.2.1 Participants:

Ten participants (1 male and 9 females) took part in the experiment. All were aged between 21 and 27, with a mean age of 23 and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

2.2.2.2 Design:

The experiment had a within-participants design, with three variables. The first was *demand* of the foveal task, which was altered by changing the presentation speed of stimuli in the RSVP. This variable had two levels, high demand (each item in the RSVP was shown for 50ms) and low demand (each item in the RSVP was shown for 150ms). The second variable was the *location of T1* which also had two levels; centre (T1 was shown within the RSVP) and periphery (T1 was shown to the left or right of the RSVP). The third variable was the *lag* between T1 and T2 which had five levels; lag 1, lag 2, lag 3, lag 4, and catch trials. In a catch trial no T2 was shown. For the high demand condition the SOA from T1 to T2 was 50ms, 100ms, 150ms, and

200ms, and in the low demand condition the SOA was 150ms, 300ms, 450ms, and 600ms, for lags 1, 2, 3, and 4 respectively. The dependent measure was T2 accuracy.

2.2.2.3 Apparatus and Stimuli:

The experiment was designed and run using E-Studio on a Viglen Contender P3 computer with a 17" monitor[5]. Participants were seated 60cm from the screen and head movements were minimised with the use of a chin rest[6]. T1 was a white diamond with a black outline, and a visual angle of 4.6º. T1 was shown either in the centre of the screen, or to the right or left of the RSVP. When shown in the periphery the centre of the diamond was always 10.9º from the centre of the screen. All twenty six letters of the alphabet were also used, with 5 T2s (vowels) and 21 distracters (consonants). All letters were presented uppercase, at the centre of the screen, in black on a white background, in Verdana typeface size 30, measuring 1.4º by a maximum of 1.2º.

2.2.2.4 Procedure:

The experiment was divided into two blocks based on rotation speed of the RSVP. One block presented each stimulus for 50ms and took eight minutes to complete; the second presented each stimulus for 150ms and took twenty minutes to complete. The order of these blocks was counterbalanced across participants. In each block participants completed 100 trials (after an initial 10 practice trials), consisting of 20 trials for each lag, ten trials with T1 appearing at the centre and 10 with T1 appearing in the periphery. For each of these lags each vowel appeared four times (twice following T1 at the centre, once following T1 to the right and once following T1 to the left), with the exception of catch trials which did not have a T2. Each trial

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[5] Every experiment reported in this thesis was designed and run using E-Studio and the same computer was used for all experiments completed.
[6] This was also standard for all experiments completed.

began by showing a black fixation cross to the centre of the screen for 500ms, then a series of between 10 and 40 distracters were shown followed by the appearance of T1 either in the centre of the screen or to the right or left of the RSVP. A distracter always appeared when T1 was shown; therefore when it was shown to the centre of the screen a letter appeared inside the diamond. T2 would then be shown unless the trial was a catch trial. T2 was presented immediately after T1 in a lag 1 trial, or after 1, 2, or 3 distracters following T1 for lags 2, 3, and 4 respectively. Then between 10 and 15 distracters were shown before the trial ended. See figure 2.1 on page 53 for an example of a trial sequence.

Distracters, T2, and location of T1 were selected at random by the computer. Participants were instructed to attend to the series of letters appearing at the centre of the screen and look for a vowel appearing. They were told that on some trials a vowel may not be shown, and a maximum of one vowel would be shown in each trial. Participants were also told that a diamond shape would appear in each trial but that this was for the purpose of a different experiment and the diamond was irrelevant to their task. At the end of each trial participants were asked whether they saw a vowel (yes or no) and if so which vowel they saw (A, E, I, O, or U). They responded by pressing marked keys on the keyboard and were given on-screen feedback following their response to the second question.

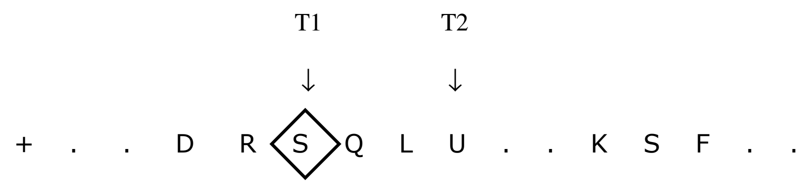

Figure 2.1: The timeline of events in Experiment One, all stimuli are shown sequentially at fixation (with the exception of a peripheral T1). This example shows T1 presented centrally and T2 appearing at lag 3. When T1 appears in the centre it encompasses the distracter, when it appears peripheral to the RSVP stream it is presented to the left or right of the distracter.

2.2.3 Results

Analysis consisted of a 2 (*demand*) x 2 (*location of T1*) x 4 (*lag*) within-participants ANOVA. This was conducted on trials in which participants had correctly detected the presence of a vowel, and had correctly identified this vowel. Any incorrect responses were removed. Two participants were removed from the analysis due to performing below 80% on catch trials. The ANOVA showed a main effect of *demand* ($F(1,7) = 12.120$, $MSE = 1489.586$, $p<0.01$) with higher accuracy in the low demand (150ms RSVP speed) block. There was also a main effect of *lag* ($F(1,7) = 14.409$, $MSE = 287.649$, $p<0.001$) with accuracy to T2 higher at lags 1 ($\bar{x} = 65\%$) and 2 ($\bar{x} = 64\%$) than 3 ($\bar{x} = 45\%$) and 4 ($\bar{x} = 44\%$). However given that T2 was presented at different SOAs for each lag across both blocks in the experiment this effect is difficult to assess without taking into account the interaction between *lag* and *demand*, which was also significant ($F(1,7) = 9.333$, $MSE = 175.00$, $p<0.001$). This showed that in the low demand condition (150ms) accuracy was high at lags 1 and 2 (with means of 86% and 78% respectively) but decreased to a mean of 49% and 53% for lags 3 and 4. In the high demand condition (50ms) accuracy did not vary greatly across the four lags (see figure 2.2 on page 54).

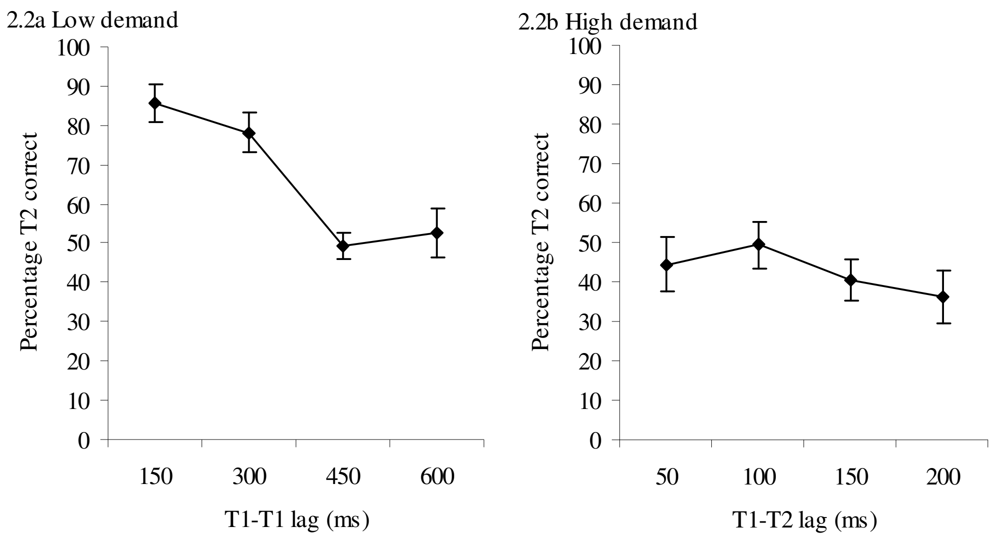

Figure 2.2: The interaction between *demand* and *lag*. Accuracy in the low demand block (a) is high at lags 1 and 2 but decreases to a level similar to the low demand block (b) at lags 3 and 4.

It is important to note that due to the difference in RSVP speeds, the high demand condition only covers the time limit of 0-200ms. Therefore performance shown across all lags in this condition is only comparable to performance from lags 1 and 2 in the low demand block. Figure 2.2 shows that the pattern of performance between 100 and 200ms in the high demand condition (lags 2-4) is very similar to the pattern of performance between 150 and 300ms in the low demand block (lags 1-2). Despite significantly lower accuracy in the high demand block than the low demand block, participants were showing a similar pattern of performance.

2.2.4 Discussion

The aim of the first experiment was to investigate whether T1 would capture attention and cause an AB when it was task-irrelevant and did not require a response. Additionally the study was completed in an effort to pilot some sample stimuli and timings for later experiments. With regard to the timings used, it appears that an

RSVP speed of 50ms is much too quick to allow a high level of accuracy to T2 when T1 is irrelevant. On a more positive note, there was no evidence of a blink caused by T1 at this speed.

Participants were much more able to complete the task of detecting T2 when the RSVP speed decreased to 150ms, however the pattern of performance in the low demand block closely follows that expected of an AB, with high accuracy immediately following T1, but a decrease in accuracy at later lags. This appears to provide evidence that the task-irrelevant T1 is actually capturing attention, and impairing identification of T2. Whilst there is a wide range of evidence to show that a task-irrelevant item can capture attention despite sharing no defining features with the target (e.g., Theeuwes, 1991a, 1991b; Yantis & Jonides, 1990), there are several reasons why the result found here does not support this view. First, AB experiments show that the detriment caused by T1 in a dual target block is most notable between 180ms to 270 ms SOA but in the present study the detriment was greatest after 300ms SOA, and there appeared to be no recovery from the 'blink', even at 600ms SOA. Moreover, studies which provide evidence of lag-1 sparing only find high accuracy at lag 1, whereas in the low demand condition there appears to be lag-1 and lag-2 sparing (Martin & Shapiro [2008] have reported lag-2 sparing but attribute this to the variable inter stimulus interval between T1 and T2 in their experiment). In addition to this if T1 was capturing attention and having a negative impact upon the processing of T2, there would have been an interaction with the position of T1. When T1 was shown to the periphery there should be no lag-1 sparing effect (as determined by Kristjánsson & Nakayama, 2002, and Visser, Zuvic, Bischof, & Di Lollo, 1999), however no effect of position was found.

It is therefore suggested that this finding is due to participants using T1 as a cue to the appearance of T2. Participants quickly learn that T2 always appears shortly after T1, therefore they use T1 to alert them to the presentation of T2, causing a heightening of awareness and increasing accuracy to T2 at lags 1 and 2. When T2 appears at later lags the effect of this cue has worn off, and performance drops to a level similar to that found in the high demand block. It may be the case that this 'cue' cannot be utilised in the high demand block due to processing demands associated with presenting each item for a shorter amount of time.

In conclusion, there is little evidence that a task-irrelevant T1 can capture attention and impair identification of T2 at early lags. Consequently there is no risk of contingent capture in a single target RSVP using the present set of stimuli. However, there are some concerns regarding the design of the experiment. Specifically that participants may use T1 as a cue in a single target block. If this is the case the current methodology may change the perceived size of the blink if a single target block was used as a comparison to a dual target block. There is also a problem with the low level of accuracy in the experiment. This was found across both blocks regardless of RSVP speed when the beneficial cuing effects of T1 are removed.

2.3 Experiment Two: Establishing the blink

2.3.1 Improvements to the RSVP design

The results from Experiment One show that a task-irrelevant T1 will not necessarily impair processing of T2. However the design of the experiment led to problems interpreting the data, as there was evidence to suggest that attention was allocated to the task-irrelevant T1 and this influenced identification of T2. Accuracy to T2 was high in the low demand condition at lags 1 and 2 and then decreased at lags 3 and 4. Whilst this effect could be taken as evidence for T1 causing a detriment on later processing of T2 (when it appears at lags 3 and 4), the findings instead show that allocating attention to T1 provides a benefit to the early processing of T2. This proposed advantage is supported by high accuracy at both lags 1 and 2 (AB studies showing lag-1 sparing have not found the effect to persist beyond lag 1) and by the finding that when T1 appeared in a different spatial location to T2 the high accuracy at lags 1 and 2 did not disappear (as usually happens when T1 and T2 are presented to different areas of space [Kristjánsson & Nakayama, 2002; Visser, Zuvic, Bischof, & Di Lollo, 1999]).

The second pilot experiment attempted to overcome the problems found in Experiment One, and was the first step towards finding the AB effect and measuring the persistence of this effect due to a carry-over of attentional set. To improve upon the previous design the temporal lags between T1 and T2 were increased to cover lags 1, 3, 5, and 7. As the blink is most prominent before 300ms SOA but can last over 500ms (e.g., Raymond et al., 1992) it is essential to have enough time between T1 and T2 to check for recovery from the blink. This would help to determine whether any blink found was actually a drop in performance following a benefit from using T1 as a cue. If there is no recovery from the blink this would be a warning sign that any lag-1 sparing was actually heightened performance, and the blink represented ‘normal’ performance on the task. In addition, to increase accuracy on the RSVP task an ISI was added to the experiment. One possible reason for the low level of accuracy in Experiment One was that each item immediately replaced its predecessor. Utilising an ISI (common practice in RSVP studies) will allow a small amount of time for consolidation of each item before it is masked by the following item. The speed of the RSVP was also changed. Accuracy in the high demand condition of Experiment One was too low, yet in the low demand condition participants were able to use T1 as a cue to T2. An SOA of 100ms was chosen for the current experiment to increase accuracy but prevent cuing from T1.

The objective of the second pilot experiment was to successfully find the AB effect in a dual target block and to measure carry-over of the attentional set to a subsequent single target block. In order to maximise the amount of data for each effect, and as a way of investigating the time limits of the carry-over effect, two groups of participants were used but all took part in each experimental condition. Participants in Group 1 completed a single target block followed by a dual target block, followed by a second single target block. Participants in Group 2 completed a dual target block followed by two single target blocks. The chosen design would provide a large amount of data for the AB effect (both groups complete the dual target block), and a large amount of data for the carry-over effect (both groups complete a single target block immediately after a dual target block). Any influence of an irrelevant T1 (without experience of this target being relevant) can be assessed using the first single target block completed by Group 1. The time limits of any carry-over found can be assessed using the second single target block completed by Group 2. Although this is quite a complex design it is an economical way of testing a number of hypotheses that will allow more targeted studies to follow.

2.3.2 Predictions regarding the AB effect and potential carry-over

As both T1 and T2 require a response in the dual target block, a clear AB is expected for this block. When a single target block is completed prior to any other block (Group 1) no AB is expected. However when a single target block is completed immediately following a dual target block an AB is predicted. This is because participants will establish an attentional set to respond to both T1 and T2 in the dual target block, the set will persist to the following single target block, and T1 will continue to capture attention. Whilst an AB is predicted for the first single target block completed by Group 2, T1 will only continue to influence T2 identification in the second single target block if the set continues to persist to a third block. A lack of any AB in this block (paired with an AB in the previous single target block) would indicate that participants have re-assessed their attentional set, allowing them to recover from the carry-over.

2.3.3 Method

2.3.3.1 Participants

Thirty participants took part in the experiment, 4 males and 26 females, all were aged between 18 and 32, with a mean age of 24.13. All reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

2.3.3.2 Design:

The experiment used a mixed design, with two within-participant variables (*lag* and *block*) and one between-participants variable (*group*). *Lag* had five levels; lags 1, 3, 5, 7, and catch trials. *Block* had two levels; in a single target block (S) participants were told to respond to T2 and ignore T1 and in a dual target block (D) participants were told to respond to both T1 and T2. Participants were randomly assigned to one of two groups, the first group completed a single target block followed by a dual target block, and then a further single target block (SDS). The second group completed a dual target block followed by two single target blocks (DSS). This gave the between-participants variable of *group*. Measures taken were identification accuracy of T1 and T2 in a dual target block and identification accuracy of T2 in a single target block.

2.3.3.3 Apparatus and Stimuli:

This was identical to Experiment One, except that T1 was one of four shapes, a diamond, a triangle, a square or a hexagon. All shapes were white with a black outline, measuring a maximum of 4.4º.

2.3.3.4 Procedure:

The experiment was separated into three blocks. The dual target block took 15 minutes to complete and the single target block took 12 minutes to complete. In each block participants completed 100 trials (after an initial 10 practice trials) consisting of 20 trials for each lag. This allowed every T2 (vowel) to be shown once with every T1 (shape) in each lag. Every trial began by showing a black fixation cross in the centre of the screen for 500ms. Then a series of between 10 and 40 distracters were shown followed by T1. T2 would then be shown immediately after T1 in a lag 1 trial, or after 2, 4, or 6 distracters following T1 for lags 3, 5, and 7 respectively. After T2 a further 10-15 distracters were shown before the trial ended. In a catch trial no T2 was presented. Distracters, T1, T2 and lag were selected randomly by the computer. All stimuli were shown for 30ms with an ISI of 70ms. This yielded an SOA of 100ms, and a RSVP speed of 10 items/s. Participants were instructed to attend to the letters appearing in the centre of the screen. In the single target blocks they were told to look for a vowel appearing, but to ignore any shapes that appeared. In the dual target block they were told to look for a shape and a vowel in each trial. Participants were informed that a maximum of one vowel would be shown in every trial, but on some trials a vowel may not appear. At the end of each trial in a single target block participants were asked if they had seen a vowel (yes or no), and if so what this vowel was (A, E, I, O, or U). At the end of each trial in a dual target block participants were asked which shape they had seen (diamond, triangle, square, or hexagon) and were then asked about the vowel. Participants responded verbally and the experimenter recorded all responses. On-screen feedback was given but the experimenter was unaware of accuracy.

2.3.4 Results

Analysis was conducted on T2 performance, however only trials in which participants had correctly identified T1 (in a dual target block), and had correctly detected and identified T2 (in all blocks) were analysed. To directly test each of the predictions made, the analysis took the form of four 2 (*block/group*) x 4 (*lag*) ANOVAs. The first tested the AB effect, this compared block one between groups (S1 from SDS and D from DSS). The second and third ANOVAs were within-groups comparisons of the dual target block and the following single target block (D and S2 from SDS, and D and S1 from DSS), which specifically tested the notion of carry-over of the attentional set. The fourth ANOVA was a between-participants comparison of the last block, completed to discover the time limits of any carry-over found. Where sphericity was an issue the degrees of freedom were adjusted using the

Greenouse-Geisser, however, unless this altered the level of significance of the effect, the uncorrected degrees of freedom are reported[7].

For the variable of *lag* planned contrasts were used which compared the mean at each lag to the overall mean. AB experiments often measure the blink by subtracting performance in a dual target block from performance in a single target block. In the present set of experiments the author has made explicit predictions based on the pattern of performance in a dual target block, a standard single target block, and a single target block which succeeds a dual target block, therefore it was desirable to analyse each block individually. To do this the performance at each lag was compared to the average level of performance across each block in each specific analysis. This provides a measure of the extent to which performance at each lag in each block deviates from the mean (in the given block). Following AB experiments in the literature the measures used in the analysis were the proportion of trials in which T2 was correctly identified (based on the total number of trials completed in a single target block, and based on the total number of trials in which T1 was identified correctly in a dual target block).

2.3.4.1 The attentional blink effect:

To compare the dual target block from DSS with the first single target block from SDS a 2 (*group*) x 4 (*lag*) mixed ANOVA was completed. This showed no main effects of *group* or *lag*, however the planned contrasts showed a significant interaction between *group* and *lag* at lag 3 compared to the mean ($F(1,28) = 10.171$, $MSE = 142.547$, $p<0.005$). This reflects a drop in T2 identification at lag 3 compared to general performance across all lags. Whilst accuracy in the dual target block fell at lag

[7] This is standard practice for all subsequent experiments using the RSVP methodology.

3 ($\bar{x}$ = 25.87%) compared to a mean of 32.35%, accuracy in the single target block was high at lag 3 ($\bar{x}$ = 61%), see figure 2.3a, on page 65.

2.3.4.2 Carry-over of attentional set:

A comparison of the dual target block with the following single target block in DSS was completed using a 2 (*block*) x 4 (*lag*) within-participants ANOVA. This showed a main effect of *block* ($F(1,14) = 50.942$, $MSE = 275.993$, $p<0.001$) with significantly higher accuracy in the single target block compared to the dual target block. There was also an interaction between *block* and *lag* ($F(3,42) = 3.649$, $MSE = 128.161$, $p<0.05$). This was at lag 3 compared to the mean across all lags ($F(1,14) = 9.658$, $MSE = 85.340$, $p<0.01$), which showed that whilst accuracy in the dual target block dropped at lag 3, accuracy in the single target block did not vary greatly across all four lags (see figure 2.3b, page 65). This lends support to the AB effect found in the dual target block. However the findings do not support the idea of carry-over of attentional set which would predict a similar drop-off in performance at lag 3 for the single target block.

When comparing the same blocks for the SDS group (D and S2) there was a main effect of *block* ($F(1,14) = 30.101$, $MSE = 147.958$, $p<0.001$), with accuracy much higher in the single target block compared to the dual target block. There was an effect of *lag*, however after accepting the Greenhouse-Geisser this effect was non-significant ($F(1.36,19.044) = 3.302$, $MSE = 970.644$, $p=0.074$). Planned contrasts showed that performance at lag 3 ($\bar{x}$ = 48.33%) was significantly lower than the mean ($\bar{x}$ =52.91%; $F(1,14) = 5.524$, $MSE = 113.862$, $p<0.05$), as was performance at lag 5

($\bar{x}$ = 47.21%; $F(1,14) = 6.613$, $MSE = 147.118$, $p<.05$). There was also an interaction between *block* and *lag* ($F(3,42) = 4.050$, $MSE = 113.646$, $p<0.05$). As before this was at lag 3 compared to the mean ($F(1,14) = 7.528$, $MSE = 33.799$, $p<0.05$); whilst the mean at lag 3 in the single target block (57.33%) did not differ from the overall mean (59%), accuracy at lag 3 in the dual target block (39%) was significantly lower than the overall mean (46.82%). Again, this shows the AB as expected in the dual target block, but no carry-over to the single target block, see figure 2.3c, page 65.

2.3.4.3 Comparison of the final two blocks between groups:

A comparison of the third block between groups using a 2 (*group*) x 4 (*lag*) mixed ANOVA revealed a main effect of *lag* ($F(3,84) = 8.279$, $MSE = 360.648$, $p=0.001$). Performance at lag 1 ($\bar{x}$ = 72.5%) was significantly higher than the mean (59.67%; $F(1,28) = 9.599$, $MSE = 514.717$, $p<0.005$), and performance at lag 3 was significantly lower than the mean ($\bar{x}$ = 51%; $F(1,28) = 17.467$, $MSE = 129.003$, $p<0.001$). See figure 2.3d, page 65. Similar to the findings of Experiment One, accuracy was high at early lags and then decreased at later lags, despite the fact that only T2 was relevant. Based on the findings so far, this effect does not signal lag-1 sparing, but instead shows that participants were again using T1 as a cue to the appearance of T2, improving performance at early lags.

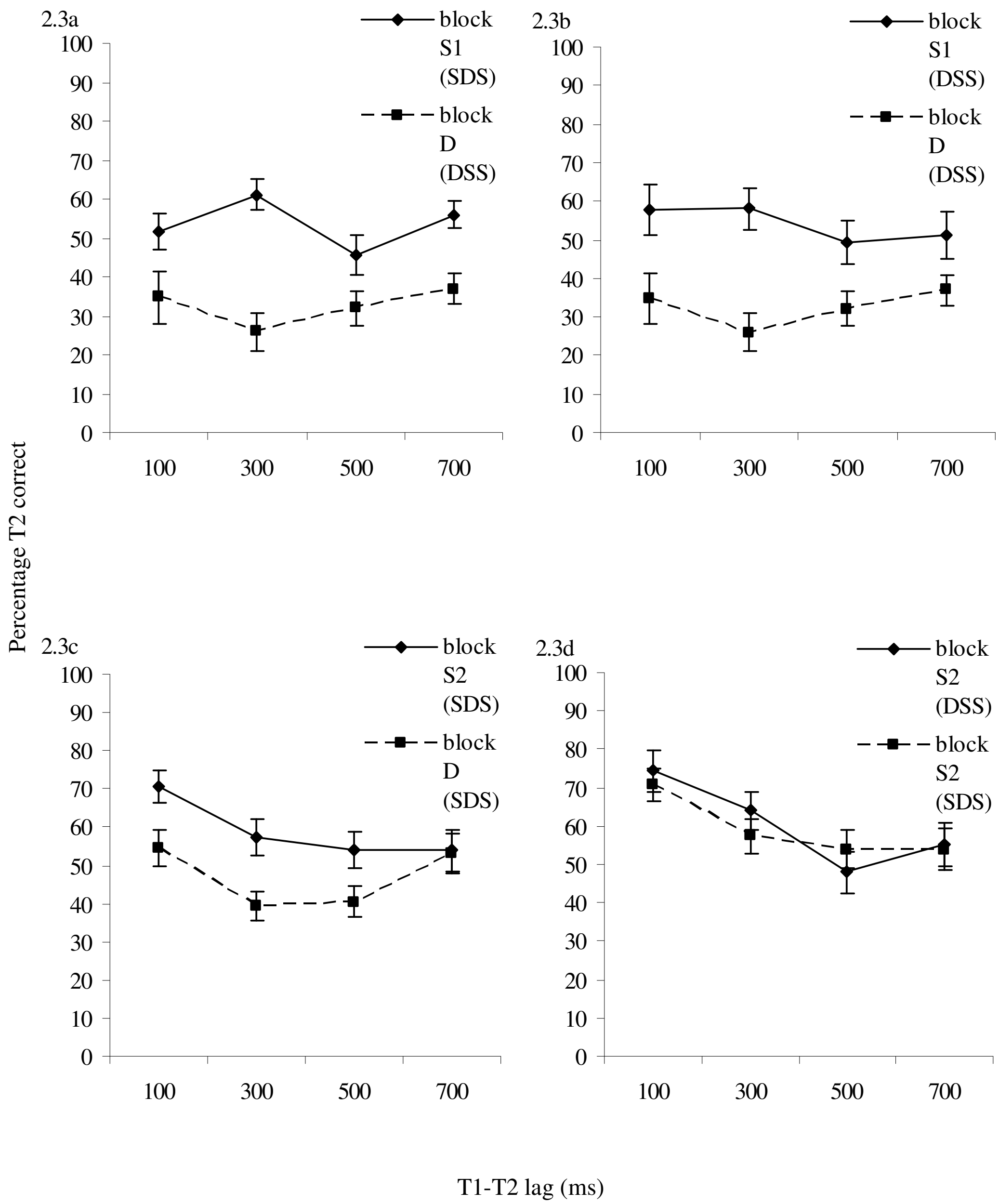

Figure 2.3: Graphs to show the comparison of blocks between and within groups. Figure 2.3a shows the AB effect by comparing the first blocks between groups (D from DSS and S1 from SDS). Figures 2.3b and 2.3c show the AB effect in the dual target block with no carry-over of attentional set to the single target block in D and S1 in DSS and D and S2 in SDS respectively. Figure 2.3d shows the proposed cuing effect from a task-irrelevant T1 in the final two blocks of the experiment (S2 from DSS and SDS).

The lack of any interaction between accuracy at lag 1 and position of T1 in Experiment One argues against lag-1 sparing in the single target block. In addition to this, mean T2 accuracy in S2 from DSS (60%) was higher than mean T2 accuracy in S1 from SDS (53.58%). This shows that participants were improving across the course of the experiment. With more experience of the procedure participants would learn that T1 always preceded T2, allowing them to use this irrelevant target in a single target block to cue them to the appearance of T2. This increased accuracy at lag 1 does not occur in the first single target block completed by SDS due to less experience with the procedure, and therefore a reluctance to use T1 as a cue.

2.3.5 Discussion

The second experiment was successful in finding the AB effect when T1 and T2 were both task-relevant. This fits with the host of other experiments that have also found the effect (e.g., Chun & Potter, 1995; Raymond et al., 1992; Visser, Zuvic, Bischof, & Di Lollo, 1999). In the dual target blocks performance to T2 followed the standard U-shaped function, with lag-1 sparing, a decrease in identification, followed by a recovery from the blink. The main detriment in performance came at 300ms SOA, which is slightly later than that suggested by Raymond et al. (1992), but still within the limits of the maximum detriment found. One issue however was the overall low level of accuracy to T2. Despite the fact that a detriment was expected, previous studies have found higher accuracy at lag 1 when participants do not appear to suffer from the blink (e.g., Visser, Zuvic, Bischof, & Di Lollo [1999] found that in a dual target block accuracy at lag 1 was over 75%, and Chun & Potter [1995] record accuracy at lag 1 at over 80%). In the present experiment mean T2 accuracy at lag 1 in a dual target block is 44.47%. Even in the final single target block when participants have the benefit of practice and show improved performance mean T2 accuracy at lag 1 is only 72.5%.

The fact that participants are again showing improved performance across the three blocks implies that they are learning that T2 will always follow T1, and therefore they can use T1 as a cue to the appearance of T2. This is still a definite concern, even though no other AB study reports such an effect (to the best of this author's knowledge). Although this may be an artefact of the current study, it is worth noting that such a cuing effect may have influenced previously reported AB studies. This is particularly the case when using a control block, as any comparison with the dual target block will exaggerate the size of the blink. For future experiments, the cuing effect needs to be removed, or the magnitude of the AB needs to be increased to overcome this apparent enhancement of performance.

The cuing effect may also be partly to blame for the low level of accuracy found at lag 1 in a dual target block, compared to previous studies reported in the literature. It may be the case that participants were more focused on using T1 as a cue rather than detecting the appearance of T2, in which case they may allocate additional attention and processing resources to this target. According to the inhibition model (Raymond et al., 1992), this would leave even fewer resources to process T2, reducing any lag 1-sparing. This prediction also fits with the two-stage model of Chun and Potter (1995) if one assumes that the higher stage of processing has a limited capacity. The model states that under normal circumstances when T2 appears at lag 1 it will be transferred to the second stage before the attentional gate between the stages has closed (representing an error on the part of the processing system, despite resulting in increased accuracy of T2). If an individual has to allocate more resources to T1 it may cause the attentional gate to close sooner, so T2 remains in stage 1 despite being at lag

1, or it may mean that T2 has to remain in stage 1 regardless of whether the gate is open, because there is not enough room available in the second stage.

Similar to Experiment One, there is no evidence of contingent capture (Folk, et al., 1992) in a single target block. This is not unexpected due to the findings of Experiment One, and due to the nature of the two targets; T1 and T2 are sufficiently different so that in a single target block T1 should not match the target-defining features associated with T2. Unfortunately however, there was little evidence for the carry-over of attentional set from a dual target block to a subsequent single target block. An AB was expected for both blocks, but this was only found in the dual target block. This could mean that the attentional set does not persist across blocks and participants are able to re-evaluate the attentional set in conjunction with a change in task demands (contrary to the findings of Leber & Egeth, 2006). However, due to the number of extraneous variables which had an influence on the results (e.g., the cuing effect), it is difficult to draw firm conclusions at this stage.

2.4 Discussion of the two pilot experiments

2.4.1 Effectiveness of the experimental design

At this point in the research the design used has successfully shown an AB effect in a standard dual target RSVP, and no evidence of contingent capture resulting in an AB in a single target RSVP. However there are problems with the present set of stimuli as participants seem to be using T1 as a cue to the appearance of T2. Both pilot experiments show evidence of cuing, resulting in higher accuracy at early lags which then influences the perceived AB, and any carry-over.

An additional concern with the stimuli is the possibility that detecting T1 and T2 may present a task switch which will add to the AB effect. Kawahara et al. (2003) have found that when T2 is not followed by a mask an AB can still occur providing T1 and T2 are sufficiently different to elicit a task switch. This means that although there are no succeeding distracters to interfere with T2 processing, it was still disrupted by the time taken to reconfigure the task set once a task switch has taken place. This is similar to suggestions made by Ferlazzo, Lucido, Di Nocera, Fagioli, and Sdoia (2007) who believe that in some studies, part of the AB may be attributed to goal switching. In their RSVP experiment, when participants had to report T1 and T2 there was a large AB but when participants had to report a combination of T1 and T2 the AB was reduced. They propose that this is because in the second scenario participants only have one goal to complete and therefore no goal switch is required, despite the fact that they still have to detect both targets. Ferlazzo et al. cite Polson, Lewis, Rieman, and Wharton (1992) who claim that the first goal activated may shut down or inhibit the goal associated with the second task.

This is another example of how top-down control contributes to the AB, and may in part be influencing the current results. The aim of keeping T1 and T2 different was to avoid contingent capture, but based on these findings it may be the case that this actually resulted in a task switch. This additional factor could be another reason why the experiments show such a low level of accuracy in comparison to previous AB studies. An important point to note however is that Visser, Bischof, and Di Lollo (1999) show that lag-1 sparing only occurs when there is no attentional switching between T1 and T2; when a switch is required the lag-1 sparing effect disappears. They suggest that the attentional gate between high- and low-level processing closes 150-200 ms after T1 has entered; this would allow T2 to be processed if it appears at lag 1 (providing the RSVP speed presents at least one item between 0 and 200 ms SOA). However, if T2 is substantially different from T1 an attentional switch will be required and a new attentional filter must be configured for this second target. This takes time and the attentional gate will close before T2 can be processed, resulting in no lag-1 sparing. In the dual target blocks completed in Experiment Two of the present research participants show a clear lag-1 sparing effect, suggesting that no set switch is required between the two targets.

2.4.2 Improvements to be made for future experiments

Both pilot experiments revealed a substantial effect of the task-irrelevant T1 in a single target block. This did not result in a detriment to T2 performance, as found in contingent capture experiments (Folk, et al., 2002; Ghorashi et al., 2003), but was instead highlighted by an increase in performance when T2 appeared shortly after T1. This has been attributed to a cuing effect. Participants quickly learn that T2 is always presented after T1 and so they use T1 to alert them to the appearance of T2. By comparing a dual target block to this single target block there arises an issue of whether any AB effect found is artificially enhanced by the cuing effect. The relatively low level of accuracy in a dual target block suggests that cuing does not occur in a dual target RSVP. Note however that in Experiment Two the detection and identification of T1 is not a difficult task. Given the rest of the stimuli in the experiment (letters), a shape (particularly one which is larger than the other items in the RSVP) is relatively easy to detect. In which case, the low level of processing required may allow for a possible cuing effect on T2. In Experiment Two participants were detecting T1 in 89.43% of dual target trials therefore the potential cuing effect is not occurring at the expense of T1 processing. This also means that the low level of accuracy cannot be attributed to a large number of trials being removed due to poor T1 performance.

One way to remove the cuing effect would be to vary the presentation order of T1 and T2. This is not standard practice in AB experiments, and usually T2 always follows T1. One problem with this is that the trials in which T2 appears before T1 will need to be removed from the analysis and will not contribute to the findings. However, given the level of cuing reported here this is regarded as a worthwhile measure to take. Another way to avoid the influence of the cuing effect is to increase the magnitude of the AB effect in order to overcome any concerns regarding the size of the AB in a dual target block when compared to a single target block. This can be achieved by maximizing the similarity between the targets and the distracters. Olivers and Watson (2006) show that when T2 shares features with the distracters, the blink observed is larger than when they are substantially different. They attribute this finding to the attentional set established to complete the RSVP; the set will actively select any item matching the target-defining features, but will inhibit anything else. If T2 is similar to the distracters there is an increased chance that it will be inhibited.

An alternative explanation to the target-distracter similarity effect is that instead of targets being incorrectly inhibited, distracters are incorrectly selected. In their stimulus similarity theory of visual search Duncan and Humphreys (1989) propose that items in visual short term memory (VSTM) are weighted based on their similarity to the target template (as defined by the attentional set). If these items are not transferred to the report stage the weights decay. Items most similar to the target template will have a higher weighting and therefore take longer to decay. As a consequence they will remain in VSTM for longer and cause greater interference to the processing of any targets. This means that if distracters are similar to targets they will have a higher weighting and so cause more interference. Although this theory fits with models of the AB which suggest different stages of processing (e.g., Chun & Potter, 1995) it does propose that the similarity between targets and distracters influences processing because of the attentional set, showing the importance of top-down processing.

Increasing the similarity between the targets will also make T1 more difficult to detect and identify. This will mean that in a dual target block there is little chance of using T1 as a cue because all resources will be required to detect the target. In this case it will be essential to check accuracy to both T1 and T2 to make sure that the high level of similarity between the RSVP items does not impair performance and mask the AB effect, or any potential carry-over. Increasing the similarity between T1 and T2 will also remove any concerns regarding an attentional switch between the two targets, despite the fact that studies which require a switch do not report lag-1 sparing and the present studies do.

Chapter Three: Individual differences in attentional control revealed using the RSVP methodology

3.1 Overview of Chapter Three

In this chapter two experiments are presented which were both completed with the aim of investigating the proposed carry-over effect from a dual target RSVP block to a single target RSVP block. Taking account of the findings from the two pilot studies Experiment Three had a more refined design and was the first definitive attempt to investigate the persistence of attentional set using the AB paradigm. Before the experiment is presented the key alterations that were made to the design will be explained and justified. The results of the third experiment did indicate that a carry-over effect may exist, however there were individual variations in performance which appeared to influence this. These individual differences will be discussed in terms of cognitive control and following this Experiment Four will be presented. The fourth experiment was completed to address the issue of cognitive control and its influence upon the AB and the predicted carry-over effect. The findings of this experiment will be discussed, and implications will be outlined.

3.2 Designing Experiment Three

3.2.1 The current design

At this point in the research the studies have shown that an AB effect can be successfully found in a dual target RSVP with the chosen stimuli (distracters are consonants, T2 is one of five vowels, and T1 is one of four shapes), and the speed of presentation (10 items/second). Moreover, this design shows no evidence of contingent capture by T1 impairing identification of T2 in a single target RSVP. Experiments One and Two did however raise a critical issue concerning the design, which was the possible cuing of T2 using T1. T1 appears before T2 in every trial, therefore participants soon realise that when they do not have to respond to T1 they can use it to cue them to the appearance of T2. This leads to an increase in T2 accuracy at early lags. This is a problem for a number of reasons. First, the increase in accuracy in a single target block artificially enhances the relative size of the blink in a dual target block, as the detriment in this block is compared to performance in the control block. In addition, although the cuing effect may only occur in a single target block, there is the possibility that participants were also using T1 as a cue in the dual target block. This would improve T2 performance, underestimating the true extent of the AB. A final concern is that the strategy of using T1 as a cue may overshadow any carry-over of attentional set from a dual target block to a single target block.

3.2.2 Changes to the design

As a result of the cuing effect two main changes were implemented to the experimental design prior to running Experiment Three. The first was introducing a 'negative' lag, where T2 would appear before T1. Taking into account the standard time deficit of the AB (around 500ms SOA) and the fact that cuing had the greatest impact on early lags, T1 could never be presented within 1000ms SOA of T2 in a negative lag trial. Therefore when T2 was presented first it could not be used as a cue to T1 and it would not cause an AB on T1. Past AB experiments do not use a negative lag, and it comes with its own drawbacks; namely that these trials will be removed from the analysis as they do not help to show evidence for the AB effect, they only serve to eliminate extraneous variables. An alternative option would have been to create a trial type in which no T1 is presented. Whilst this would possibly remove the cuing effect as T2 is not always preceded by T1 it would not remove the temporal link between T1 and T2 in trials when T1 is presented. To ensure that participants understand that there is no benefit to using T1 as a signal for the presentation of T2 the link between T1 and T2 must be broken. As such a negative lag was used.

Ensuring an equal number of trials in which T1 appears before, and after T2, would encourage participants not to use T1 as a cue because there is no benefit to performance. However, this did mean that the overall number of trials had to be increased to allow for sufficient data for the AB and carry-over effects whilst removing the cuing effect. As a result the catch trials were removed. In addition to this, because increasing the number of trials increased the duration of each block the experiment was reduced to a two block design. One group of participants completed a dual target block followed by a single target block, and a second group completed two single target blocks. Adopting a between-participants design did mean that there was a reduction in the amount of data which could support the AB effect (and carry-over), however the between-participants analysis completed in Experiment Two shows that the AB can be reliably found with fifteen participants in each group. Reducing the number of blocks from three to two also meant that the time-limit of any carry-over effect could not be assessed, but then equally this issue cannot be explored unless the carry-over effect is found.

The introduction of a negative lag would hopefully ensure that participants did not use T1 as a cue to T2; however a further alteration to the design was made to ensure that any cuing effect which still existed would have a minimal effect. This was to raise the similarity between the items in the RSVP. The distracters were kept as consonants and T2 was still one of five vowels, however T1 was changed and became one of five digits. By presenting all RSVP items in the same font and the same size it was expected that the task would become more difficult. In a dual target block this would mean that more attention has to be allocated to the processing of T1 therefore removing the possibility of using this target as a cue. In addition to this, increasing the similarity between the items may increase the size of the blink. When the RSVP items are more similar the processing system has to work harder to inhibit the irrelevant items, this leaves fewer resources to process T2, increasing the time course and magnitude of the AB (Visser, Bischof, & Di Lollo, 2004).

It is worth noting at this point that the reason for selecting shapes as T1 and vowels as T2 in the pilot experiments was to ensure that the targets were different enough to prevent contingent capture in a single target block. The prospect of contingent capture was investigated in Experiment One and the results showed no evidence that a task-irrelevant T1 captured attention. Increasing the similarity between T1 and T2 would therefore be expected to increase the chances that contingent capture would occur in a single target block. However, Di Lollo, Kawahara, Ghorashi, & Enns (2005) state that digits are sufficiently different to letters and there can be no ambiguity in the set chosen, particularly when the distracters are also very similar. As the similarity between RSVP items increases the top-down set has to be more specific to effectively select the targets and inhibit the distracters. As such contingent capture should not occur. This would suggest that increasing target-distracter similarity would not increase blink magnitude, however several researchers have found that high similarity between RSVP items will increase the blink (e.g., Isaak, Shapiro, & Martin, 1999; Olivers and Watson, 2006). Bundesen’s (1990) theory of attention can effectively explain this increase in T2 impairment. If the similarity between items is low there is less need for pertinence values to be allocated to distracters to prevent attentional capture by these irrelevant targets; focus can be given to the targets. However, if the targets and distracters are very similar both types should be assigned weights to increase the relative differences between the items and reduce intrusion errors (the incorrect selection of distracters). If this is the case, increasing the similarity of items in the display should increase the AB because more resources have to be given to each item, potentially increasing the effects of T1. In the present set of experiments the precise blink magnitude is not critical, as long as participants do suffer from a blink in the dual target block. The proposed cuing effect is problematic however and as such taking steps to increase the similarity of RSVP items was deemed worthwhile.

Increasing the similarity between the targets will also remove any possibility that part of the AB found can be attributed to a task or goal switch due to differences in the stimuli presented, as suggested by Ferlazzo et al. (2007). One further consideration to make however is that if the similarity between the RSVP items makes the task more difficult, identification of targets may suffer. The pilot experiments have already raised concerns about the low level of accuracy (both to T1 and T2) and to lower performance further would be unwise as it would leave fewer trials in the analysis. To avoid this each item in the RSVP was shown for a longer period of time.

3.2.3 Rationale of Experiment Three

The third experiment was designed to measure the carry-over of attentional set from a dual target RSVP block to a single target RSVP block. The intention was to improve upon the design of the previous experiments by removing the cuing effect, simplifying the procedure, and therefore allowing carry-over to be identified. The critical changes to the design will also allow the study to expand current findings in the literature regarding the allocation of attention to task-relevant stimuli presented amongst highly similar task-irrelevant stimuli. It was predicted that participants would show an AB in a dual target block but not in a single target block. However, if the single target block follows a dual target block participants will suffer from a blink due to the persistence of attentional set from the preceding block.

3.3 Experiment Three: Carry-over of attentional set using the AB paradigm

3.3.1 Method

3.3.1.1 Participants:

Thirty participants (11 male and 19 female) took part in the experiment for a payment of £5; all were aged between 18 and 34, with a mean age of 23.3. All reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

3.3.1.2 Design:

A mixed design was used with two within-participant factors (*lag* and *block*) and one between-participants' factor (*set priming*). Lag had five levels corresponding to four different SOAs between T1 and T2, and a negative lag in which T2 was presented before T1. The factor of *set priming* referred to the experience that participants were given with a task-relevant T1. This was an attempt to 'prime' half the participants to develop an attentional set to respond to T1 and T2 in the first block.

In block 1, fifteen participants completed a dual target block in which they had to respond to T1 and T2; this was the “set-priming group”. The other fifteen participants completed a single target block that only required them to respond to T2 and ignore T1; this was the “no-set-priming” group. Following this first block all participants then completed a single target block. The measures taken were accuracy to T1 and T2 in dual target blocks and accuracy to T2 in single target blocks.

3.3.1.3 Apparatus and Stimuli:

This was identical to the previous two experiments except that T1 was one of five numbers (2, 3, 4, 5, and 6). Like the distracters and T2 all the numbers were presented to the centre of the screen in black on a white background, in Verdana typeface, size 30.

3.3.1.4 Procedure:

The experiment was divided into two blocks. Each block took twenty five minutes to complete and there was a five minute break between the two. For each block participants completed 200 trials (after an initial 10 practice trials), consisting of 100 negative lag trials and 25 trials for each other lag.[8] In the case of the positive lag trials this allowed every vowel (T2) to be shown once with every number (T1) at each lag; for the negative lag trials every vowel was shown five times with every number. Each trial began by showing a black fixation cross in the centre of the screen for 500ms, and then a series of between 10 and 20 distracters were shown followed by T1. T2 would then be shown immediately after T1 in a lag 1 trial, or after 2, 4, or 6

[8] This is a large number of trials, however in addition to requiring a sufficient number of data points for the analysis of the AB and any carry-over, there had to be an equal number of negative lag trials to prevent participants using T1 as a cue to the appearance of T2. Equal probability of T1 appearing before and after T2 would ensure that there was no perceived benefit to using T1 as a cue.

distracters following T1 for lags 3, 5, and 7 respectively. After T2 a further 10-15 distracters were shown before the trial ended. In a negative lag trial T2 was presented after 10-15 distracters, followed by a further 10-15 distracters before T1 appeared, and 10-15 more distracters before the end of the trial. Distracters, T1, T2 and lag were selected randomly by the computer (please refer to figure 3.1 on page 81 for an example of a positive and negative lag trial).

All stimuli were shown for 50ms with an ISI of 50ms (a rate of 10 items/second). The rate of presentation follows previous studies however the ISI in this experiment is fairly short in comparison. The reasoning behind this was that the task was quite difficult with participants having to detect and discriminate targets from very similar distracters. Showing each item for longer would make the task easier; therefore any AB found would be particularly robust[9]. Participants were instructed to attend to the series of letters in the centre of the screen and look for a vowel appearing. They were told that at least one vowel would be shown in every trial; if they did not see a vowel they were asked to make a guess as there was no option to state that they had not seen one. They were told that there could be more than one vowel in each trial, and if they saw more than one they should report the last vowel they had seen (although only one vowel was shown in each trial). This was a further technique employed to ensure participants would not try to use T1 in a single target block to alert them to T2 if T2 had not already appeared. By expecting more than one vowel they would hopefully assume that using T1 as a cue would not be beneficial. Participants were also told that a number would be shown in each trial, but they were only asked to respond to this in the dual target blocks and ignore it in the single target blocks (separate instructions were given at the beginning of each block

[9] The single target block was piloted on two participants prior to testing the 30 participants described above. Both showed a high level of identification accuracy for T2 (an average of 82.8% across all lags).

and participants were given no information about the second block until they had completed the first block).

Negative lag trial –

T2 ↓ … T1 ↓

+ . . . S Q X L P Y E . . . W N B T R . . . 5 V M C Z F . . .

10-15 distracters preceded T2, followed by a further 10-15 distracters before T1 appeared. 10-15 more distracters were then shown before the trial ended.

Positive lag trial (example using lag 3) –

T1 ↓ … T2 ↓

+ . . . R V L Y Q 3 D H A W Z F J P . . .

10-20 distracters preceded T1, followed by 2 distracters before T2 appeared at 300ms SOA. 10-20 distracters then followed T2. The number of distracters between T1 and T2 differed depending on the lag.

Figure 3.1: Sequences of stimuli presented serially at fixation. The number of distracters presented before the first target and after the second target differs between the positive and negative lags. This was because there had to be at least 1000ms between T2 and T1 in a negative lag trial to avoid an AB on T1, therefore to ensure these trials were not noticeably longer than the positive lag trials the number of distracters presented before T2 and after T1 was reduced.

At the end of each trial in the single target block participants were asked which vowel they had seen (A, E, I, O, or U). At the end of each trial in the dual target block they were asked which number they had seen (2, 3, 4, 5, or 6) and then asked which vowel they had seen. Participants responded verbally and the experimenter recorded all responses. On-screen feedback was given, but the experimenter was unaware of accuracy.

3.3.2 Results

Participants in the set-priming group took part in one dual target block (respond to T1 and T2) followed by a single target block (respond to T2), and those in the no-set-priming group took part in two single target blocks (respond to T2, T1 is task-irrelevant). The design allowed the first block to be compared between groups to determine if there was an AB effect in the set-priming group. Due to practice with the procedure and the stimuli participants may improve across the course of the experiment, but a comparison of the second block between groups would eliminate any effect of practice, whilst showing any evidence of carry-over from the set-priming group. For each comparison analysis consisted of one 2 (*set priming*) x 4 (*lag*) ANOVA followed by planned contrasts which compared the actual performance means across participants at each lag, to the overall mean for that block. Results calculated were accuracy levels to T2. Any trials in which T1 was incorrect were filtered out and not entered into the analysis.

An alternative way to analyse the data would be to compare the relative difference between the two blocks completed by each group (the dual target and single target blocks from the set-priming group, and the two single target blocks from the no-set-priming group). This would involve expressing performance in the second block as a proportion reduction in relation to performance in the first block, and then comparing these values between groups. This would show any difference that arose across the two blocks (i.e., whether set-priming participants switched set between the two blocks and therefore suffered from the AB in the dual target block but not in the single target block) whilst also controlling for any practice effects. The drawback to this method of analysis is that the author would be searching for a null effect. Based on the theoretical assumptions of carry-over there should be no difference between performance in block one (dual) and block two (single) for the set-priming group because participants would not switch set and would therefore still suffer from the blink in the second block. Equally, no difference would be expected between blocks for the no-set-priming group because participants perform the same task in both blocks. As a result, when comparing the relative difference for each group, no difference would be predicted. Therefore the initial method of analysis (comparing each block between groups) was selected.

Prior to carrying out the analyses on the positive lags in each condition a 1x4 ANOVA was conducted to check T2 performance in the negative lags across the four blocks completed. Crucially if T1 was still being used as a cue to T2, identification of T2 in the no-set-priming group would suffer. This is because participants would always search the RSVP for T1 before searching for T2 (expecting T1 to appear first), therefore T2 would be unexpected and may go unnoticed. Results showed no significant differences between blocks ($F(3,56) = 1.426$, $MSE = 248.295$, $p = 0.245$), showing that the experimental condition did not affect accuracy in a negative lag. This suggests that the presentation order of T1 and T2 in the negative lag trials had the required outcome of removing the cuing effect. It also shows that T2 did not cause an AB on T1 in negative lag trials. No further analysis was carried out on the negative lag trials as they were present in the experiment purely for the purpose of removing any facilitation effects.

3.3.2.1 Comparison of the first block between groups:

When comparing the positive lags between the first block completed by the two groups the results showed a main effect of *lag* ($F(3,84) = 5.803$, $MSE = 134.137$, $p<0.001$). Planned contrasts revealed that this effect was found at lag 3 compared to the overall mean performance across all lags ($F(1, 28) = 7.587$, *MSE* = 124.322, $p<0.01$). There was also a *lag* by *set priming* interaction ($F(3,84) = 3.530$, *MSE* = 134.137, $p<0.05$). In the no-set-priming group there was no significant effect of lag as mean performance at each lag fell between 65.07% and 70%, however mean performance in the set-priming group varied from 46.62% at lag 3 to 68.24% at lag 7. Planned interaction contrasts supported this, showing that the interaction was only present at lag 3 ($F(1,28) = 6.883$, *MSE* = 124.322, $p<0.01$), see figure 3.2a, page 85.

3.3.2.2 Comparison of the final block between groups:

Carry-over of attentional set from a dual target block to a single target block completed by the set-priming group was assessed by comparing the final two blocks between groups. In this case those in the no-set-priming group would have no experience of a relevant T1 but would have the same amount of exposure to the stimuli involved. The analysis showed an almost significant effect of *lag* ($F(3,84) = 2.592$, *MSE* = 89.771, $p = 0.058$), but no interaction between *set priming* and *lag*. Despite the lack of significant results planned contrasts were still conducted as they do not require the omnibus F to reach significance. When comparing accuracy at each lag with the mean accuracy across all lags a significant effect was found at both lag 3 ($F(1,28) = 4.591$, *MSE* = 68.310, $p<0.05$) and lag 5 ($F(1,28) = 6.456$, *MSE* = 59.110, $p<0.05$). In the set-priming group participants were scoring below the group mean score of 65.93% at lag 3 ($\bar{x}$ =60%) but mean accuracy increased at lag 5 to 70%, see figure 3.2b. The data trend from this group does support the sort of U-shaped function found in standard AB experiments, but the interaction suggested in figure 3.2b failed to reach statistical significance.

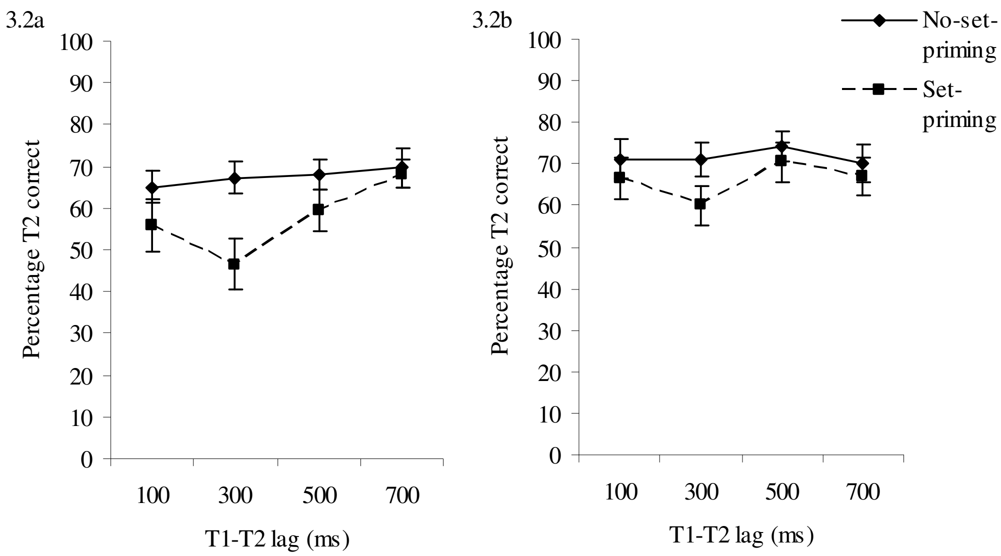

Figure 3.2: Identification of T2 in block one (a) and block two (b) for the set-priming group and the no-set-priming group.

3.3.2.3 Additional Findings:

Taken as a whole, the data suggests that whilst the set-priming group shows an AB in block one in comparison to the no-set-priming group, this effect does not persist to block two when T1 becomes task-irrelevant. There is a significant drop in performance at lag 3 in block two, as shown through the planned contrasts, but this effect is not strong enough to fully support the hypothesis made. It therefore seems that the attentional set from block one is not carrying over to block two. However, it may be the case that although set-priming participants fail to switch set between the two blocks (and therefore suffer from the AB in the single target block), they may switch set mid-way through the second block (therefore the initial carry-over effect is diluted and does not reach significance). This was tested by comparing the first ten trials for each lag between groups, and the last ten trials for each lag between groups, in the final block completed. If participants in the set-priming group had maintained the set from the dual target block but then switched set partway through the second block there would be a significant interaction between lag and block for the first ten trials, but not the last ten trials. The analysis did not support this prediction, showing a non-significant interaction for both analyses, indicating that participants were not switching set in the middle of the block. This hypothesis can therefore not explain the weak AB effect in the final block completed by the set-priming group.

An alternative explanation for the non-significant interaction in the final block (paired with a pattern of performance which follows that of an AB) is that whilst some participants were switching set others were maintaining the original set. When this data is merged the carry-over effect will subsequently appear to be weak. When looking at individual performance rather than group performance, it appears that whilst approximately half the participants in the set-priming group show a pattern similar to an AB in the second block, the other half identify T2 equally well across all lags in this block (see figure 3.3b, page 87). Crucially, the participants who do not show a U-shaped pattern of performance in the second block also show a less convincing AB in the first block when T1 is task-relevant (figure 3.3a, page 87). This is important because it is impossible to look at carry-over to the second block, in the form of an AB in the second block, if participants have not established a set which results in an AB in the first block.

This is not the first study to report individual differences in the AB effect, and a number of experiments have been conducted to investigate these differences (e.g., Martens, Munneke, Smid, & Johnson, 2006). Such studies separate participants into two groups; those who show a clear AB effect in a dual target RSVP (blinkers) and those who show little or no AB in a dual target RSVP (nonblinkers). The AB magnitude can be computed using a formula which measures the difference between T1 and T2 performance across the most pertinent lags. In the case of most research this would be lags 2 and 3, however in the present work this is lags 3 and 5. In order to determine the variation in performance across the set-priming group the AB magnitude for all participants in this group was computed. The magnitude was calculated on the proportion of correct responses using Equation 3.1 (page 88) which was adapted from Martens et al. (2006).

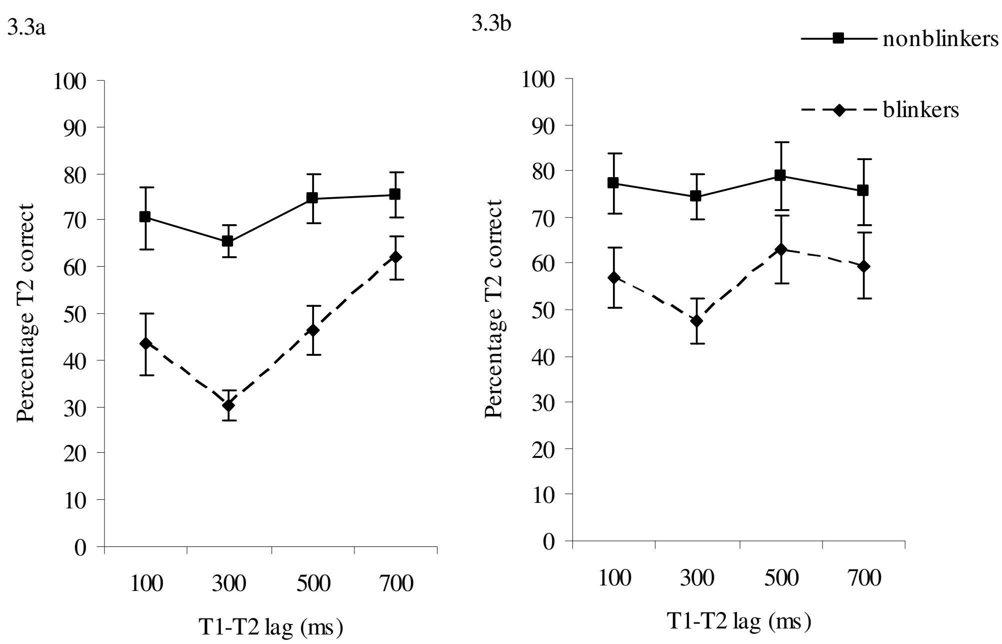

Figure 3.3: Identification accuracy of T2 from the set-priming group in the dual target block (a) and the single target block (b), with participants separated into two groups based on the magnitude of their AB in the dual target block, using Equation 3.1. Those with a large AB ($\bar{x}$ = 55.56%) are "blinkers" (broken line), those with a smaller AB ($\bar{x}$ = 25.63%) are "nonblinkers" (solid line).

Blink magnitude in the dual target block completed by the set-priming group ranged from 4.37% to 65.38%, with a mean of 41.59%. In the study completed by Martens et al. all participants who had a magnitude of less than 10% were classed as nonblinkers, however in the present experiment only one participant had a magnitude of less than 10%. Removing this participant from the analysis made no difference to the AB effect in the dual target block or the carry-over effect in the single target block when the set-priming group was again compared to the no-set-priming group. Removing this data from the analysis would mean that any carry-over effect in the final block cannot be overshadowed by participants who do not show the AB in a previous dual target block. The fact that this had no impact on the difference between the set-priming group and the no-set-priming group implies that there is no carry-over effect occurring in this experiment.

$$\left\{ \left(\frac{(\text{T1 acc at lag 3} - \text{T2/T1 acc at lag 3})}{\text{T1 acc at lag 3}} + \frac{(\text{T1 acc at lag 5} - \text{T2/T1 acc at lag 5})}{\text{T1 acc at lag 5}} \right) /2 \right\} \text{ x } 100$$

Equation 3.1: Blink magnitude is calculated using the proportion of lag 3 and lag 5 trials in which T1 and T2 are correctly identified. Magnitude is expressed as a percentage, with the highest blink being 100% (this would occur if participants correctly identified T1 on 100% of lag 3 and lag 5 trials but incorrectly identified T2 on 100% of lag 3 and lag 5 trials). This means that a higher magnitude represents a larger blink. Magnitude can also be negative; in which case the proportion of trials in which T2 is correctly identified would be higher than the proportion of trials in which T1 was correctly identified.

3.3.3 Discussion

The aim of Experiment Three was to find evidence of a carry-over of attentional set from a dual target block to a single target block, whilst eliminating the substantial cuing effect of T1 found in the two previous studies. Analysis showed that the negative lag successfully removed the cuing effect, and there was no evidence to show that performance at lag 1 was artificially increased due to participants using T1 as a cue. Performance in the negative lag was not influenced by the variables under investigation, proving it to be a worthwhile addition to the design. To the best of this author's knowledge this is the first reported AB study to use a negative lag, it may be the case that the stimuli used in Experiments One and Two prompted the cuing effect, but other researchers should be aware that it can happen, and it can affect the perceived magnitude of the AB. As such, measures should be taken to avoid the effect, and a negative lag offers a solution.

There is a potential problem with using the negative lag as it could induce participants to adopt a 'weaker' attentional set. For instance, if T1 always precedes T2 participants can adopt a controlled set to use for the task because the layout of every trial is identical. If the order of the targets differs across trials participants may not be able to use such a controlled set because there are two possible layouts for each trial. This could lead to an overall decrease in performance (and possible decrease in blink magnitude if participants place less emphasis on target detection), and it could also mean that the set is less likely to persist to a second block of trials (the set is less controlled and therefore the costs of switching set are reduced). In the current experiments overall accuracy for T1 and T2 is relatively high; however the fact that the carry-over effect is not statistically significant may in part be caused by the introduction of the negative lag. Given that there appears to be individual differences in carry-over it is predicted that the lack of an AB in the second block completed by the set-priming group is due a dilution of the effect, rather than any influence of the negative lag in this instance. Moreover, the success of the negative lag in removing the cuing effect would outweigh any problems caused by this lag. In conclusion, despite the fact that the negative lag does remove the cuing effect, researchers must consider its global influence on the AB and any carry-over effect in relation to its benefits before opting to use it.

Statistical analysis provided clear evidence of an AB effect in a standard dual target block completed by the set-priming group compared to the first single target block completed by the no-set-priming group. This shows that the new T1s were able to elicit the well known AB effect, but did not cause contingent capture when T1 was irrelevant. Although T1 was more similar to T2 than in Experiments One and Two, it did not share any similarities with T2 above that which the distracters in the RSVP also shared. Ensuring that all stimuli involved were very similar meant that the attentional set had to be more specific and contingent capture would not occur. T1 accuracy was high in the dual target block, with a mean of 90%, confirming the findings of Di Lollo, Kawahara, Ghorashi, & Enns (2005) that participants had no difficulty establishing an attentional set to complete the task, despite increased similarity between T1 and the distracters. However, the differences in T2 identification between Experiments Two and Three suggest that increasing the similarity between RSVP items did influence performance. In Experiment Two (when T1 was substantially different from the distracters and T2) performance in a dual target block varied from 25.87% at lag 3 to 36.92% at lag 7. This is a mean detriment in performance of 11.05%. In Experiment Three performance in the dual target block varied from 46.62% at lag 3 to 68.24% at lag 7, a total mean difference of 21.62%. The increase in accuracy overall between the two experiments shows that participants were able to complete the task in the current experiment, however the increase in blink magnitude reveals that the processing system had to work harder to effectively select targets from highly similar distracters, increasing the size of the blink (e.g., Bundesen, 1990; Duncan & Humphreys, 1989; Visser et al., 2004). This finding also supports previous AB studies reporting larger blinks when stimuli are highly similar (e.g., Isaak et al., 1999; Olivers and Watson, 2006).

Unfortunately there was little statistical evidence to show that the attentional set from block one carried over to block two, causing an AB in a single target block for the set-priming group. All participants improved across the two blocks, but there was no AB found in the second block completed by the set-priming group. This does not fit with the predictions made. However, although no carry-over effect was found when taking all participants data together, a closer look at individual performance revealed that some participants did seem to be showing a pattern of performance in the second block which closely resembled an AB. At first this suggested individual differences between the carry-over of top-down attentional set; some participants may have changed set between blocks whilst others maintained their original set and their performance was still affected by the now irrelevant but previously relevant T1. Yet when performance in the dual target block was separated on an individual basis those who showed signs of an AB in the single target block also showed a more convincing AB in the preceding dual target block.

Unless there is a clear pattern of performance which arises from the attentional set established for the first block, the persistence of this set cannot be assessed. It was therefore hypothesised that carry-over did occur, but this effect could not be revealed because some set-priming participants were not suffering from the blink in the dual target block, and therefore not showing the U-shaped function associated with the AB. This would serve to dilute the 'AB' in the single target block and reduce the carry-over effect. Removal of data from the analysis based on AB magnitude in the dual target block did little to support this prediction; however the individual trends within the data do indicate that some set-priming participants were suffering from carry-over, providing evidence for the effect.

3.4 Individual differences in cognitive control

3.4.1 Cognitive control in the AB

As previously mentioned, this is not the first example of an RSVP experiment to find differences between participants regarding the AB effect. Martens et al. (2006) recorded electroencephalographic (EEG) activity from 11 blinkers and 11 nonblinkers who performed a dual target RSVP, and found that when T1 was successfully identified nonblinkers showed more activity in the ventrolateral prefrontal cortex. This is an area linked to early target selection processes and they propose that if there is not enough activity in this area participants will have problems selecting relevant information from irrelevant information, resulting in interference in T2 processing. They postulate that the AB arises because participants fail to consolidate the relevant information fast enough; more activity is consistent with the early processing of T1, allowing T2 to be processed and therefore resulting in a smaller blink. This implies that individuals may differ in their ability to attend to task-relevant information and inhibit task-irrelevant information, potentially due to cortical activity (Martens & Valchev, 2009).

It is therefore equally plausible to suggest that the differences found may be due to differing levels of cognitive control; with some people having more difficulty controlling the allocation of attention than others. This notion fits with findings showing that the AB increases in magnitude and duration for people with attention-deficit hyperactivity disorder (Hollingsworth, McAuliffe, & Knowlton, 2001), people with moderate to severe dysphoria (Rokke, Arnell, Koch, & Andrews, 2002), children with specific language impairment (Lum, Conti-Ramsden, & Lindell, 2007), and older adults (Lahar, Isaak, & McArthur, 2001).

Taatgen, Juvina, Herd, Jilk, and Martens (2007) have associated these findings with differences in cognitive control. It is generally accepted that the more control an individual has in a specific task, the better they will perform. However when that task is a dual target RSVP this is not always the case and too much control causes a detriment in performance, which is revealed through an increase in the AB. Taatgen et al. have found that the magnitude of the AB is correlated with performance on other tasks designed to measure cognitive control, for example, the abstract decision making task (Joslyn & Hunt, 1998, as cited by Taatgen et al.) in which participants must sort objects into bins once they have obtained enough information regarding the properties of the objects. They find that participants who show a larger blink also show greater levels of cognitive control in other tasks. An increase in cognitive control causes problems with tasks like the RSVP because it reduces cognitive flexibility. In a dual target RSVP participants must flexibly respond to both T1 and T2, a reduction in flexibility means that the detection of a second target is more difficult because the individual is so focused on the first target. Olivers and Nieuwenhuis (2006) suggest that when participants are less focused on one source of information they can flexibly attend to multiple stimuli and therefore the AB is reduced. Experimental evidence to support this shows that the AB diminishes when participants share their attentional resources between the RSVP and another task, such as listening to music (Olivers & Nieuwenhuis, 2005) or when they are encouraged to adopt a more distributed state of attention (Olivers & Nieuwenhuis, 2006).

Olivers et al. (2007) have suggested that the AB is caused by an "overzealous application of control over the input" (pp. 137) and they account for the AB using the 'overinvestment hypothesis'. Completing the RSVP task requires a balance between allowing for the detection of targets and inhibiting the selection of distracters; too much emphasis on selecting targets means that some distracters may be processed, too much emphasis on inhibiting distracters may lead to some targets being missed. When T1 is detected the attentional set loosens and T1+1 may enter processing, if T1+1 is a distracter the set needs to tighten and correct itself, meaning that if T2 is presented at early lags following lag 1 it will be missed as more emphasis is placed on inhibition. Following from this it may be proposed that the more flexible, and less controlled the set is initially, the less likely this problem will occur; the individual will strike a more appropriate balance between selection and inhibition, and the control system will not need to continually readjust, so allowing better performance and a smaller AB. The finding that T1 accuracy is also better for nonblinkers supports this.

Although Olivers and colleagues do not support the TLC model (Di Lollo, Kawahara, Ghorashi, & Enns, 2005) and instead propose that their work is an extension of the early limited-capacity theories, their hypothesis does suggest that the AB is caused by limitations in top-down processing and control. Indeed the majority of recent studies reporting evidence of individual differences suggest a role for top-down control, but Olivers et al. (2007) state that their findings provide support for resource depletion accounts of the AB, and they deny that the AB is purely due to issues with the top-down attentional set. Can individual differences in AB magnitude also be explained by the TLC model? The model states that the top-down attentional set requires constant feedback to keep it active. When T1 is being processed feedback signals can no longer be sent and the top-down system loses control. If T1+1 is a distracter it will trigger an exogenous attentional set, and the endogenous set will have to be reconfigured to regain control. This reconfiguration causes switch costs which result in the AB. It may be suggested that when more cognitive control is exerted the set will be less flexible because more emphasis will be placed on stabilising the set to prevent exogenous capture. Reconfiguring the top-down set once the exogenous system has gained control will therefore lead to greater switch costs and a larger AB. At this stage it is difficult to do more than postulate on the possible impact of control over the AB, but the individual differences in performance found in the current work, and previous reports in the literature do imply that the cognitive control of attention does have an impact upon performance in a RSVP.

3.4.2 The influence of cognitive control on carry-over of attentional set

Experiment Three does not provide strong statistical evidence that the top-down attentional set from a dual target RSVP will persist to a single target RSVP, however trends found within the data do suggest that carry-over may be occurring. In addition, the individual differences found in the experiment may have had an impact upon the findings of carry-over. First, the amount of control given to the task may not actually influence the possibility of a participant using the same attentional set in two different blocks, but it may influence the perceived carry-over. The rationale for using the RSVP methodology is that in a dual target block performance follows a U-shaped function (the AB). If the set adopted to complete the dual target block is not abandoned when the block ends it will also elicit the same pattern in a subsequent single target block. If an individual does not show an AB in the dual target block there is no way of determining whether the attentional set used to complete the task has persisted to the single target block, because performance will be no different to the no-set-priming group. As a result the evidence for persistence of attentional set will appear to be weak.

In addition to this the control of the top-down attentional set may also have a more direct influence over the persistence of this set. It has been predicted that an increase in cognitive control results in a larger AB because it reduces cognitive flexibility. Regardless of which theory one chooses to support, most researchers state that increased control leads to a larger AB (Martens et al., 2006; Olivers & Nieuwenhuis, 2005; 2006; Olivers et al., 2007; Taatgen et al., 2007). If the set becomes less flexible and more resources are allocated to the task the costs associated with switching set will be greater. If the costs of switching set outweigh the benefits there will be the less motivation to change set when the task demands change (Leber & Egeth, 2006). It is therefore hypothesised that individuals who have greater control will be more likely to suffer from the persistence of attentional set.

It is important to clarify which level of cognitive control (micro or macro) the author is referring to at this point. Recall that macro-control is defined as the overall control over the goal representation, and the set established to complete the goal, whereas micro-control is defined as direct control over the task. Although macro-control is essential for the balance between flexibility and stability it is postulated that the above work is more related to the definition of micro-control; how much control (or effort) one puts into the task and the cognitive set. A high level of control (leading to a larger AB) will consolidate the set and a low level of control (smaller AB) will allow the set to be more passive and flexible. This means that increased micro-control will increase the chance that the set will carry-over.

3.4.3 Implications for previous findings

It is worth noting that the findings from Experiment Two may also have been influenced by individual differences in AB magnitude. In Experiment Two the comparison of the first block completed by each group only revealed an AB in the dual target block in the planned contrasts, not in the main effects (see page 62).

Additionally, participants showed a mean detriment in performance in a dual target block of 11.05%. When comparing this to the detriment found in the dual target block completed in Experiment Three (21.62%) it is clear to see a big difference in the size of the blink. Obviously the experiments differ in terms of the stimuli used, the design implemented, overall RSVP performance, and the cuing effect found in Experiment Two, yet this is still an important difference. It suggests that the participants in Experiment Two were clustered towards the nonblinker end of the scale, therefore reducing the size of the AB in a dual target block, and any carry-over in the following single target block.

3.5 Experiment Four: Individual differences in the control of attentional set

3.5.1 Cognitive control as measured through Field Dependence

The aim of the fourth experiment was to investigate individual differences in the AB and the carry-over of attentional set. The experiment was identical to Experiment Three, except that more participants were tested in the set-priming condition, and this group was separated into two based on cognitive control. It was predicted that those set-priming participants who have greater cognitive control (micro-control in this case) would show a more substantial AB in the first block and would also show carry-over of attentional set to the second block.

There are many different ways to describe and account for cognitive control, and differences in this control. One of the most widely known cognitive styles is Field Dependence. This was first outlined by Witkin, Lewis, Hertzman, Machover, Meissner, and Wapner (1954) who stated that people could be described as Field

Dependent (FD) or Field Independent (FI) based on the way in which they perceive the environment, and themselves in relation to the environment. FDs tend to rely on information from the outside world, they approach any task from the broadest perspective and often have problems determining which information is relevant in the early stages of a task (Pask, 1976). FIs rely more on internal cues, their focus is very narrow and they are thought to be very intolerant of task-irrelevant information because it is an extra, unnecessary burden (Pask, 1976).

The ability to inhibit task-irrelevant items has been found to be related to Field Dependence. Peterson and Carson (2000) measured the latent inhibition of participants in relation to their ‘openness to experience’. Latent inhibition is the ‘retarded’ learning of a previously irrelevant stimulus that is now relevant, and openness to experience is thought to be a trait more often found in FDs. Participants were asked to use a stimulus to work out a rule for target presentation and this stimulus could be pre-exposed to participants prior to the trial. When the stimulus was pre-exposed it was described as irrelevant to the task, therefore when trying to subsequently associate a rule with this stimulus participants must learn that it is now relevant. Participants who scored low on openness were not able to learn to process the now relevant but previously irrelevant stimulus and performed poorly on the task, however participants who were regarded as high in openness performed well, indicating that they were able to learn and process the now relevant stimulus. This suggests that FDs (high in openness) were either less able to inhibit the task-irrelevant stimulus initially, meaning that it was easier to process it later, or were more able to switch set and alter their responses to a previously irrelevant but now relevant item.

This shows that FDs have a more flexible attentional set and this will lead to effective set switching when necessary. In comparison, FIs will have a more stable set; effectively inhibiting all irrelevant information, but potentially leading to carry-over due to a lack of flexibility. As cognitive control is thought to be related to AB magnitude it is predicted that FIs will show a larger AB than FDs and they will also be more likely to show carry-over than FDs. In Experiment Four this will be tested using the RSVP methodology from Experiment Three, to assess AB magnitude and carry-over; and the Embedded Figures Test (Witkin, 1969) to determine levels of Field Dependence.

3.5.2 Method

3.5.2.1 Participants:

Thirty participants (25 females and 5 males) took part in the experiment for a payment of £8. All were aged between 19 and 31, with a mean age of 22.2, and all reported normal or corrected-to-normal vision. To act as a control group with which to compare performance from these thirty participants, the results from the fifteen participants in the no-set-priming group from Experiment Three were also used. Of these fifteen participants ten were female and five were male, all were aged between 18 and 29 with a mean age of 20.9. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

3.5.2.2 Design:

The experiment used a mixed design with two within-participants factors (*lag* and *block*) and one between-participant factor (*group*). The variables of *lag* and *block* were identical to those in Experiment Three. All thirty participants completed a dual target block followed by a single target block and were therefore in the set-priming condition; however they were separated into two equal sized groups, using a median split, based on performance on the EFT; Field Dependents (FDs) and Field Independents (FIs). Each group was then compared to the no-set-priming group from Experiment Three. Measures taken were accuracy to T1 and T2 in dual target blocks, accuracy to T2 in single target blocks, and RT in the EFT.

3.5.2.3 Apparatus and Stimuli:

The stimuli for the RSVP experiment remained the same as Experiment Three. The only additional apparatus used was the Embedded Figures Test (Witkin, 1969) and a stop watch to record RT. The EFT consists of 8 simple figures, 24 complex figures, and a practice pair of one simple and one complex figure. Each figure is shown on a rectangular shaped card. The simple figures are simple shapes with a black outline, and are not filled with colour. The complex figures are made up of a series of shapes and the majority are coloured. Each complex figure has one of the simple figures embedded within it. The EFT manual (Witkin, Oltman, Raskin, & Karp, 1971) suggests that only 12 of the 24 pairs of figures should be used in the test to shorten administration time without reducing the validity or reliability of the test. Complex figures 1-12 were used in the present experiment, as advised by the manual.

3.5.2.4 Procedure:

The procedure of the RSVP experiment was identical to Experiment Three. Participants were also asked to complete the EFT. They were first shown a complex figure for 15 seconds, and following this the corresponding simple figure was placed over the top of the complex figure. After 10 seconds the experimenter turned the simple figure face down and participants had 3 minutes to find the simple figure within the complex figure. They indicated they had found the figure by tracing the outline of it within the complex figure. Participants could view the simple figure as many times as necessary but could not view both figures at the same time. If they asked to see the simple figure again the clock was stopped, the simple figure was placed over the complex figure and they were given 10 seconds to view the figure, after which time it was again turned face down and the clock was restarted. The time taken to find each figure was recorded in seconds and if participants had not found the figure within three minutes a time of 180 seconds was recorded and the experimenter moved on to the next item. This procedure was the same for all 12 pairs of items, after an initial practice with the practice items. The order of the EFT and the RSVP experiment was counterbalanced across participants.

3.5.3 Results

To separate the set-priming participants based on Field Dependence the mean RT to find all simple figures within the 12 complex figures was taken for all thirty participants and a median split was performed. The median score was 24.09 seconds and mean RTs ranged from 6.58 seconds to 71.58 seconds. The overall mean was 25.49 seconds, which is substantially faster than the norm obtained from 102 college students by Witkin et al. (1954) of 56.2 seconds. However similar to Witkin et al. who found a gender difference, with males faster than females (45.5 seconds vs. 66.9 seconds) this study also showed that males had a faster mean RT (17.72 seconds) than females (27.05 seconds). The fifteen participants with a mean RT faster than the median of 24.09 seconds were classed as Field Independents (FI; $\bar{x}$ =13.28 seconds) and the fifteen with a mean RT slower than the median were classed as Field Dependents (FD; $\bar{x}$ =37.69 seconds).

Following this, the analysis consisted of two 3 x 4 ANOVAs to compare performance in each block across each *lag* for each of the three *groups*; FIs, FDs, and the no-set-priming group from Experiment Three. Planned contrasts were conducted to compare the mean at each lag with the overall mean across all lags, and to compare FDs and FIs with the no-set-priming group. Analysis of the negative lags (consisting of two one-way ANOVAs followed by post hoc tests using the Bonferroni correction) showed that accuracy to T2 when it was presented before T1 did not differ with regard to which experimental condition participants were assigned to in the first block ($F_{(2,42)} = 1.854$, *MSE* = 413.558, $p=0.169$). However in the second block completed there was a difference between the three groups ($F_{(2,42)} = 3.253$, *MSE* = 379.400, $p<0.05$). The post-hoc comparisons showed no difference between accuracy in the set-priming group ($\bar{x}$ = 74.2%) and the FI ($\bar{x}$ = 81.6%) or FD groups ($\bar{x}$ = 72%), however the difference in accuracy between FDs and FIs was approaching significance ($p=0.058$).

3.5.3.1 Block one compared between groups:

In the first block FDs and FIs had to respond to T1 and T2 and the no-set-priming group only responded to T2, therefore an AB was expected for the FD and FI groups but not for the no-set-priming group. Analysis showed a main effect of *lag* ($F_{(3,126)} = 24.028$, *MSE* = 137.550, $p<0.001$). The planned contrasts showed that mean performance at lag 3 was significantly lower than the mean across all lags (51.8% vs. 63.8%; $F_{(1,42)} = 50.497$, *MSE* = 128.456, $p<0.001$). There was no main effect of *group*, however the planned contrasts showed that T2 accuracy for FDs ($\bar{x}$ = 58.5%) was significantly worse than T2 accuracy for the no-set-priming group ($\bar{x}$ = 67.5%). There was also a *lag* by *group* interaction ($F_{(6,126)} = 5.649$, *MSE* =

137.550, $p<0.001$). As expected T2 accuracy dropped at lag 3 for FDs and FIs but not for the no-set-priming group ($F(2,42) = 12.088$, $MSE = 128.456$, $p<0.001$), see figure 3.4.

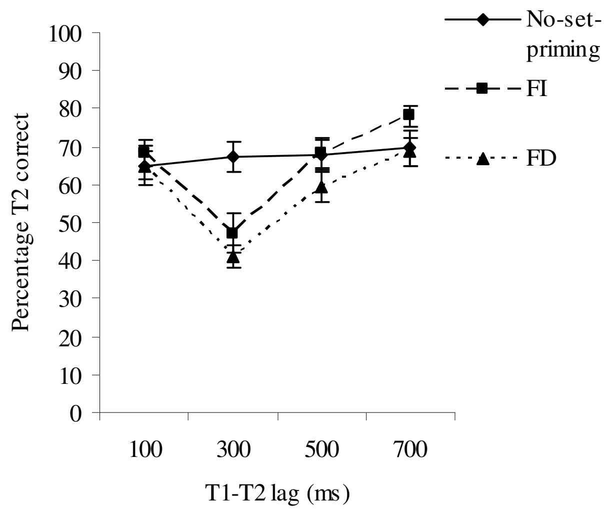

Figure 3.4: Accuracy in identifying T2 in block one for the two set-priming groups (dual target) and the no-set-priming group (single target)

3.5.3.2 Block two compared between groups:

In the second block all participants were told to identify T2 but ignore T1, however an AB was still expected for the FI group. This is because they will invest more resources into creating a stable attentional set, decreasing the flexibility of the set and increasing the cost of switching set between the two blocks. FDs have greater flexibility and will therefore switch set at the end of the first block, allowing them to inhibit T1 in the single target block. The analysis showed a main effect of *lag* ($F(3,126) = 5.573$, $MSE = 79.890$, $p=0.001$). T2 accuracy was lower at lag 3 ($\bar{x} = 68.8\%$) compared to the mean ($\bar{x} = 73.4\%$; $F(1,42) = 14.975$, $MSE = 64.819$, $p<0.001$). There was also a main effect of *group* ($F(2,42) = 3.574$, $MSE = 136.184$, p<0.05). The planned contrasts showed no significant difference between the no-set-priming group ($\bar{x}$ = 71.7%) and FDs ($\bar{x}$ = 68.8%; p=0.495), but there was a marginally significant difference between the no-set-priming group and FIs ($\bar{x}$ = 79.8%; p=0.065). There was however no interaction between *lag* and *group*, and the planned interaction contrast at lag 3 was only approaching significance (F (2,42) = 2.946, *MSE* = 64.819, p=0.063). See figure 3.5 for these effects.

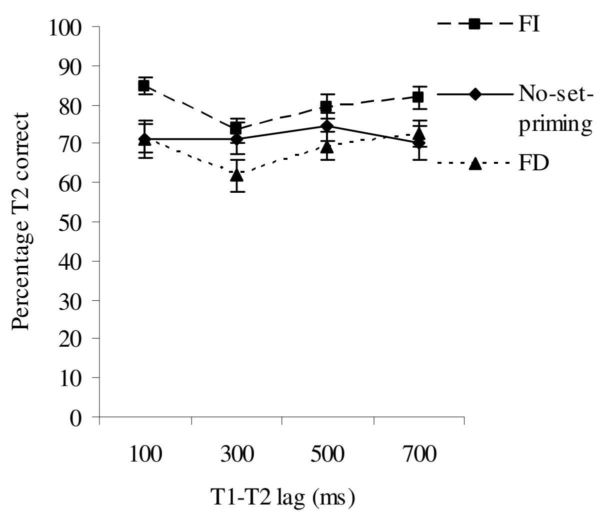

Figure 3.5: Accuracy of T2 identification for all three groups in the second block when only T2 was task-relevant.

3.5.3.3 Magnitude of the AB in block one:

It was predicted that participants who place less emphasis on target detection and take longer to complete the EFT (FDs) would show a smaller AB in a dual target block. This prediction was not met, and both FDs and FIs showed a significant AB in this first block when compared to the no-set-priming group (although FIs had a mean level of accuracy similar to the no-set-priming group). The mean blink magnitude for each group was compared using Equation 3.1 on page 88 followed by an independent t-test. This showed that although FDs did suffer from the AB to a greater extent ($\bar{x}$ = 42.53%) than FIs ($\bar{x}$ = 36.48%), there was no significant difference between the two groups (t (28) = 0.954, p=0.076). It therefore seems that cognitive control, as measured through Field Dependence does not influence the AB effect. However, because the sample was not fully representative of the FD-FI continuum (and all participants performed relatively well on the EFT) this author cannot conclude that Field Dependence does not predict AB magnitude.

To check for further individual differences in AB magnitude (regardless of Field Dependence) a second 3 x 4 ANOVA was conducted on T2 accuracy in block one across the four positive lags. This compared the no-set-priming group with two new groups of set-priming participants; blinkers and nonblinkers. According to Martens et al. (2006), only participants who show an AB of less than 10% can be classed as a ‘nonblinker’, yet in the current study although AB magnitude ranged from -6.25% to 67.4%, with a mean of 39.5%, only 2 of the 30 set-priming participants had a magnitude of less than 10%. Therefore, rather than separating participants using this limit, participants were separated into blinkers and nonblinkers by taking the 15 with the highest magnitude ($\bar{x}$ = 53.13%), and the 15 with the lowest magnitude ($\bar{x}$ = 25.88%).

The analysis showed a main effect of *lag* (F (3,126) = 25.811, *MSE* = 128.048, p<0.001), and a *lag* by *group* interaction (F (6,126) = 7.626, *MSE* = 128.048, p<0.001). The effect of *lag* was due to performance falling at lag 3 compared to the mean across all lags (F (1,42) = 52.339, *MSE* = 123.935, p<0.001). This drop in T2 accuracy only occurred for the blinkers and nonblinkers, and not for the no-set-priming group (F (2,42) = 13.295, *MSE* = 123.935, p<0.001). In addition there was an almost significant *lag* by *group* interaction at lag 5 ($F(2,42) = 3.155$, $MSE = 66.872$, $p=0.053$) which showed that whilst accuracy in the no-set-priming group remained the same across lags, it decreased at lag 5 for blinkers and increased at lag 5 for the nonblinkers, see figure 3.6. This suggests that the nonblinkers recovered from the blink sooner than the blinkers. The analysis also showed a main effect of *group* ($F(2,42) = 10.561$, $MSE = 108.481$, $p<0.001$). Both blinkers and nonblinkers showed significantly different performance to the no-set-priming group ($p<0.001$ and $p = 0.001$ respectively) meaning that both set-priming groups showed a significant AB. However, mean accuracy for the blinkers (53.83%) was lower than that of the no-set-priming group (67.47%), and mean accuracy for the nonblinkers was higher (70%). Although both groups who completed the dual target block showed an AB, accuracy was much higher for the nonblinkers.

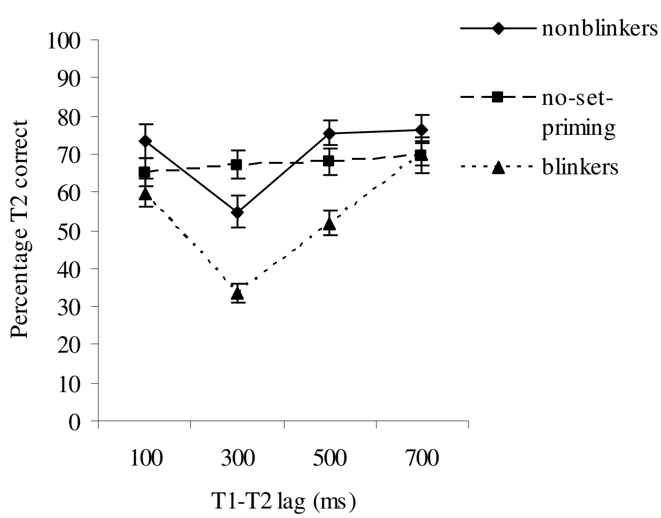

Figure 3.6: Performance in block one with participants from the set-priming group separated into two groups on the basis of AB magnitude.

3.5.3.4 Carry-over for blinkers and nonblinkers:

Performance in block two was also compared based on AB magnitude in block one. There was again a main effect of *lag* ($F(3,126) = 5.604$, $MSE = 79.458$, $p=0.001$), with a drop in accuracy at lag 3 overall ($F(1,42) = 15.458$, $MSE = 62.795$, $p<0.001$). The interaction between *lag* and *group* was also nearing significance ($F(6,126) = 2.048$, $MSE = 79.458$, $p=0.064$). The planned contrasts showed a significant interaction at lag 3 ($F(2,42) = 3.718$, $MSE = 62.795$, $p<0.05$), with accuracy falling at lag 3 in the blinker group ($\bar{x} = 61.07\%$) compared to the overall mean of 69.5%, but not at lag 3 in the nonblinker group ($\bar{x} = 74.13\%$) or the no-set-priming group ($\bar{x} = 71.2\%$). This suggests that blinkers were suffering from an AB in this single target block. Moreover, if participants in the set-priming group had suffered from the blink in the single target block their performance should differ from the no-set-priming group. Performance for the nonblinker group did not differ ($p = 0.604$), yet performance in the blinker group was significantly different ($p<0.05$), see figure 3.7 on page 108.

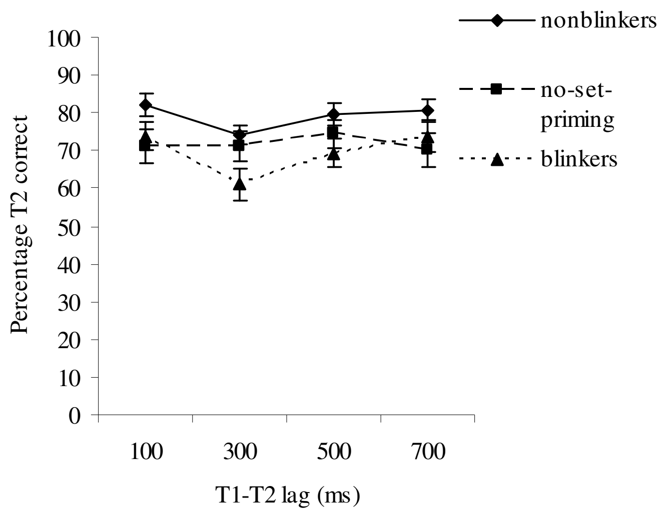

Figure 3.7: Performance in the second block (single target) for the no-set-priming group, participants who showed a large AB in the first block (blinkers), and participants who showed a small AB in the first block (nonblinkers).

3.5.4 Discussion

Experiment Four allowed two groups of set-priming participants to be compared with the no-set-priming group from Experiment Three on the basis of cognitive style. The aim of this was to determine if cognitive control (micro-control in this instance) had an influence on the magnitude of the AB, and the persistence of attentional set. The thirty participants were separated into FDs and FIs based on performance in the EFT and it was predicted that FIs were more likely to show carry-over of attentional set from a dual target block to a subsequent single target block. This was because FIs are thought to put greater effort into target detection and distracter inhibition, consolidating the attentional set and making it more resistant to change. It was also predicted that FIs would show a larger AB in the first block.

The hypothesis that FIs would suffer from a larger blink in the dual target block was not supported and all set-priming participants showed a clear AB in this first block, regardless of performance on the EFT. The only difference between FIs and FDs was that FIs were showing higher accuracy in the RSVP task, even though they were equally as susceptible to the blink as FDs. This difference in RSVP performance fits with previous studies which show that FI individuals are more able to inhibit task-irrelevant information and focus their attention on task-relevant stimuli (Pask, 1976). As a result of this, although they have a less flexible attentional set, they perform better on the RSVP as a whole because they can concentrate solely on the targets and effectively ignore the distracters. Due to their more flexible attentional set FDs are more distracted by task-irrelevant information. This is shown through low accuracy in the RSVP experiment.

As cognitive control (measured using the EFT) could not predict the size of the AB in a dual target block, the present findings appear to be inconsistent with those of Olivers and Nieuwenhuis (2005, 2006) and Taatgen et al. (2007) who found that more cognitive control resulted in a larger blink. There is the possibility however that Field Dependence is a poor measure of cognitive control. It is not widely used in more modern psychological theory, and the majority of research into the area was conducted a number of years ago. As such, the EFT may be a less suitable tool for measuring cognitive control in today’s climate, than when it was first introduced over 40 years ago. Indeed there was a large difference between the average score obtained in the present study and the norms obtained by Witkin et al. (1954). Yet it is important to keep in mind that all participants scored reasonably high on the EFT, meaning that they were clustered towards the FI end of the FD-FI continuum. It is therefore predicted that if more participants had been tested, the difference in AB magnitude for FDs and FIs would have been substantial, providing stronger evidence for the influence of control over performance in a dual target RSVP.

Despite performance on the EFT being an unsuitable predictor for blink magnitude there were individual differences in the size of the AB in the dual target block. Whilst nearly all set-priming participants showed some form of detriment in T2 identification, the magnitude of this blink varied across participants. Separating the group into two based on blink magnitude showed that participants who suffered from a larger blink also performed worse in the RSVP task as a whole. This fits with the findings of Martens et al. (2006) that nonblinkers are better able to select task-relevant information and inhibit task-irrelevant information.

There was no evidence to suggest that participants in the FI group showed an AB in the single target block, therefore indicating that they were not suffering from carry-over. In addition there was no difference in the pattern of performance of FDs and FIs in this final block other than FDs performing worse on the task. This provides little support for the carry-over effect and little support for the hypothesis that cognitive control would influence carry-over. After analysing the data a second time using blink magnitude as a factor rather than EFT performance the results showed that participants who had suffered from a larger blink in the dual target block were also suffering from a blink in the subsequent single target block (albeit of a smaller magnitude). Those in the nonblinker group were not showing an AB in the single target block.

Despite being labelled ‘nonblinkers’, of the fifteen participants in the nonblinker group only two failed to show an AB in the dual target block. As this group did not show an AB in the single target block it may be assumed that these participants were able to switch attentional set between groups. This is in comparison to the blinkers group who did suffer from an AB in the single target block and therefore did not change their attentional set in line with the new task demands. This provides support for the carry-over effect and also shows that there are individual differences in the ability to switch set.

3.6 Conclusion of Experiments Three and Four

Experiments Three and Four were completed with the aim of finding a clear AB effect and investigating the carry-over effect. The experimental design was altered from Experiment Two by introducing a negative lag and increasing the similarity between T1 and T2. These changes had the desired outcome of removing the cuing effect of T1 that had been found previously, whilst improving overall accuracy in the RSVP task. Increasing the similarity between the RSVP items did not result in contingent capture in a single target block, showing that when all stimuli are highly similar attention can be specifically set to allow capture by task-relevant items and inhibit capture by irrelevant items (Di Lollo, Kawahara, Ghorashi, & Enns, 2005). Yet the increase in similarity did increase the magnitude of the blink. This is consistent with previous findings (e.g., Isaak et al., 1999; Olivers & Watson, 2006) and fits with claims that high target-distracter similarity increases processing demands (Visser et al., 2004).

The improvements made to the design allowed a clear AB effect to be established, however there was relatively limited evidence for the carry-over effect. In Experiment Three individual differences in blink magnitude in a dual target block implied that any carry-over effect was being overshadowed by the set-priming participants who were not suffering from the blink in this first block. As the AB is defined by a specific pattern of performance, this same pattern in a single target block would indicate carry-over; if the U-shaped pattern is not present in the dual target block it is impossible to ascertain carry-over to the single target block. Given the recent interest in individual differences in AB magnitude (e.g., Hollingsworth et al., 2001; Rokke et al., 2002) and the influence of cognitive control over this magnitude (e.g., Olivers & Nieuwenhuis, 2005; 2006; Taatgen et al., 2007) Experiment Four attempted to find the carry-over effect by accounting for these individual differences. Variations in blink magnitude were again found but cognitive control (measured using the EFT) appeared to have a more general effect on overall RSVP performance, rather than influencing identification of specific targets within the RSVP. A carry-over effect was found in this fourth experiment, but only after substantial post-hoc analysis had been conducted.

Despite the fact that cognitive control appeared to have little influence upon AB performance and carry-over there is a concern over the chosen measure of cognitive control in Experiment Four. Performance on the EFT was very different from the norms found by Witkin et al. (1954), suggesting that either the EFT is outdated, or the sample was not fully representative of the full FI-FD continuum. Based on this conclusion, and the findings that blink magnitude was related to the persistence of attentional set it is hypothesised that cognitive control does have a role to play in the present findings. Researchers suggest that individuals who suffer from a large blink will have more cognitive control than nonblinkers (Taatgen et al., 2007). Greater cognitive control and reduced cognitive flexibility increases the chance that an individual will show perserverative behaviour (Dreisbach & Goschke, 2004) as they are unable to flexibly alter their cognitive set when necessary. This is supported by the current findings; blinkers suffered from the AB to a greater extent than nonblinkers, they also performed worse on the RSVP task than nonblinkers, and crucially, they failed to alter their attentional set when task demands changed.

Again, note that the level of control the author is currently referring to is micro-control; that is the direct amount of control one has over the top-down allocation of attention. More control consolidates the set because participants are investing more resources into target detection and distracter inhibition. This makes the set less flexible and more likely to persist to a second task because the costs of switching set are greater than the benefits of switching set (Leber & Egeth, 2006).

Chapter Four: Carry-over of attentional set produces an attentional blink with task-irrelevant T1s

4.1 Overview of Chapter Four

In this chapter the final AB experiment will be presented. This will include the rationale for the study, how the study differs from the previous AB experiments in this thesis, and a description of the results found. The findings will then be compared to the results obtained in Experiments Three and Four. Following this there will be an overview of the AB experiments and a review of the main findings. These findings will be discussed with regard to the carry-over of attentional set, the influence of cognitive control, and theories of the AB.

4.2 Experiment Five: Persistence of attentional set in a RSVP task

4.2.1 Rationale and aims of the final AB experiment

After completing two pilot studies and two experiments using the RSVP methodology the present research has provided some evidence for the persistence of attentional set. This evidence is limited however due to participant differences in AB magnitude and carry-over. The objective of the final AB experiment in this thesis was to find more robust evidence for the effect.

The results of Experiment Four show that participants who suffer from a large AB also fail to switch set between a dual target block and a single target block, therefore showing a U-shaped pattern of performance in both blocks. Participants who suffer from a smaller AB appear to change set between the two blocks and therefore do not allocate attention to the previously relevant but now irrelevant T1. Based on this it has been concluded that *blinkers* (large AB and carry-over) exert a higher level of *micro-control* over the task. They put too much effort into processing targets and inhibiting distracters, reducing their capacity to flexibly attend to both T1 and T2 in a dual target block (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers et al., 2007). This means that the set becomes stronger and more resistant to change, and participants subsequently suffer from persistence of the set. One way to maximize carry-over would therefore be to increase the emphasis on consolidating the top-down set in the RSVP.

Leber and Egeth (2006) found that an attentional set will persist to a second task and influence the allocation of attention in this task, given sufficient experience with the set. This is because increased experience consolidates the set making it more stable over time. It may therefore be predicted that if set-priming participants are given more experience with a dual target block the set established to complete this block will become more stable. This is because more resources will be invested into the set, making the set less flexible and increasing the chance that participants will fail to change set when the task demands change (i.e. when the single target block begins and T1 becomes task-irrelevant).

Based on this prediction Experiment Five was completed with the aim of determining a clear carry-over effect by enhancing cognitive control through practice with the RSVP task. The design of the experiment remained the same as Experiments Three and Four; however the set-priming participants were given greater experience with the dual target block prior to completing the single target block. This was in order to encourage them to put more effort into consolidating the set for the dual target block, making it less flexible and more susceptible to carry-over. All participants completed four experimental blocks. The no-set-priming group completed four single target blocks and the set-priming group completed three dual target blocks followed by one single target block. It was expected that participants in the set-priming group would show a strong AB in the first three blocks compared to the no-set-priming group. Furthermore, these participants would also show an AB in the fourth block, as the attentional set from the dual target RSVP will persist to the single target RSVP and T1 will continue to capture attention.

4.2.2 Method

The method followed that of Experiment Three except where indicated.

4.2.2.1 Participants:

Thirty participants (18 females and 12 males) completed the experiment for a payment of £8. All were aged between 18 and 28, with an average age of 20.17, and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

4.2.2.2 Design:

Participants were randomly allocated to the set-priming or the no-set-priming group, and both groups completed four blocks of trials. The set-priming group completed three dual target blocks followed by one single target block, and the no-set-priming group completed four single target blocks. Testing took place across two sessions separated by 24 hours, and each participant completed two blocks in each session. Olivers and Nieuwenhuis (2006) have found that boredom decreases the AB, therefore the experiment was separated into two sessions in an attempt to reduce boredom, and any influence it may have on the size of the AB.

4.2.3 Results

Analysis consisted of four 2 (*set priming*) x 4 (*lag*) ANOVAs, one for each block completed. Prior to this, the negative lags, that were completed across the four blocks were analysed using two one-way ANOVAs (one for the set-priming group and one for the no-set-priming group). There was no difference in performance for the no-set-priming group (F (3,56) = 2.062, *MSE* = 134.898, $p=0.116$), but for the set-priming group there was a significant difference between blocks (F (3,56) = 5.395, *MSE* = 98.580, $p<0.01$), see table 4.1 on page 118. Post hoc comparisons using the Bonferroni correction showed that T2 accuracy in the negative lags in block one was significantly lower than in block three ($p=0.003$). T1 performance in the set-priming group showed a similar pattern of performance, with a significant difference between the three dual target blocks (F (2,28) = 8.654, *MSE* = 57.384, $p=0.001$). Accuracy was similar for blocks one and two, but increased in block 3 (see table 4.1 on page 118). This indicates a slight improvement across the course of the experiment.

	T2 accuracy in the negative lags		T1 accuracy
	No-set-priming	Set-priming	Set-priming
Block One	73.6%	69.7%	88.5%
Block Two	79.2%	74.8%	89.69%
Block Three	83.07%	83.2%	93.4%
Block Four	82.33%	76.9%	

Table 4.1: Mean T1 accuracy for the set-priming group in the dual target blocks and mean T2 accuracy in the negative lags for both groups.

4.2.3.1 The AB effect:

In block one there was a significant effect of *lag* ($F (3,84) = 13.627$, $MSE = 182.370$, $p<0.001$), a significant difference between the two groups ($F (1,28) = 4.388$, $MSE = 137.384$, $p<0.05$), and a *lag* by *set priming* interaction ($F (3,84) = 13.148$, $MSE = 182.370$, $p<0.001$). T2 accuracy decreased at lag 3 ($\bar{x}$ =54.99%) compared to the overall mean of 64.78% ($F (1,28) = 18.841$, $MSE = 145.042$, $p<0.001$). However this was primarily driven by the set-priming group who dropped to a mean of 39.85% at lag 3, as accuracy for the no-set-priming group remained high at $\bar{x}$ = 70.13% ($F (1,28) = 23.508$, $MSE = 145.042$, $p<0.001$) [10]. Overall the data revealed that participants in the no-set-priming group were performing significantly better that the set-priming group ($F (1,28) = 4.388$, $MSE = 137.384$, $p<0.05$). See figure 4.1a on page 122 for these effects.

In block two the results were very similar. Again participants in the no-set-priming group were performing significantly better than those in the set-priming

[10] A one-way ANOVA ensured that performance at lag 3 in the no-set-priming group was not significantly higher than performance across the other lags for this group ($p=0.936$), therefore the interaction can be attributed to performance in the set-priming group.

group (F (1,28) = 5.507, *MSE* = 130.868, $p<0.05$). There was a main effect of *lag* (F (3,84) = 6.691, *MSE* = 152.708, $p<0.001$) with T2 identification low at lag 3 (F (1,28) = 10.557, *MSE* = 159.515, $p<0.01$) compared to the mean, but high at lag 1 (F (1,28) = 12.457, *MSE* = 103.063, $p=0.01$). A significant *lag* by *set priming* interaction (F (3,84) = 5.501, *MSE* = 152.708, $p<0.01$) showed that in the set-priming group accuracy at lag 1 was higher than the mean (F (1,28) = 4.834, *MSE* = 103.063, $p<0.05$) and accuracy dropped at lag 3 (F (1,28) = 10.746, *MSE* = 159.515, $p<0.01$), see figure 4.1b, page 122.

For the third block completed there was again a significant difference between the two groups (F (1,28) = 5.269, *MSE* = 134.775, $p<0.05$), a main effect of *lag* (F (3,84) = 10.791, *MSE* = 94.685, $p<0.001$), and an interaction between *set priming* and *lag* (F (3,84) = 5.656, *MSE* = 94.685, $p=0.001$). Like the previous two blocks, participants in the no-set-priming group were showing higher accuracy than those in the set-priming group. This was particularly the case at lag 3, as although the main effect of *lag* was at lag 3 (F (1,28) = 34.009, *MSE* = 55.371, $p<0.001$) the low performance at this lag for the set-priming group ($\bar{x}$ = 58.16%) compared to the no-set-priming group ($\bar{x}$ = 79.2%) was driving this effect (F (1,28) = 17.333), *MSE* = 55.371, $p<0.001$), see figure 4.1c, page 122.

It is clear from these results that in each of the dual target blocks the set-priming group was showing an AB effect. Identification accuracy of T2 was significantly lower at 300ms SOA (lag 3) for this group, whilst accuracy for the no-set-priming group remained high across all four lags.

4.2.3.2 Magnitude of the AB across the first three blocks:

The magnitude of blink for each set-priming participant (determined using Equation 3.1 in Chapter Three) was compared across the three blocks. A one way ANOVA showed no significant difference in blink magnitude (the difference between the proportion of lag 3 and lag 5 trials in which participants correctly identified T1 and correctly identified T2) across the three dual target blocks ($F(2,42) = 2.146$, $MSE = 285.363$, $p = 0.130$). The average magnitude (out of a possible 100% [in which case T1 would be correctly identified in all trials and T2 would be incorrectly identified]) in each block decreased as the experiment progressed, from a mean of 43.73% at block one, to 36.66% at block two, to 30.97% at block three. There was still a substantial blink in each block, with only one participant showing a magnitude of less than 10% in all three blocks. Across the three blocks the lowest magnitude was 6.38% and the highest was 71.42%. It seems that with practice participants were actually performing better at detecting T2 after detecting a preceding T1, and were slightly less susceptible to the blink over time (although not significantly). This fits with accuracy data which shows that the set-priming participants improved across the three blocks (from a mean of 60.3% in block one, to 65% in block two, to 71.74% in block three).

4.2.3.3 The carry-over effect:

To assess the persistence of the attentional set from the dual target block to the single target block completed by the set-priming group the fourth block was compared between groups. The analysis showed an almost significant effect of *lag* ($F(3,84) = 2.562$, $MSE = 52.381$, $p = 0.060$). Instead of a drop in accuracy at lag three, as shown in the first three blocks, this effect was caused by an increase in accuracy at lag 1

($\bar{x}$ = 83.07%) compared to the mean (80.2%; F (1,28) = 8.189, *MSE* = 30.105, p<0.01). There was a significant interaction between *set priming* and *lag* (F (3,84) = 5.838, *MSE* = 52.381, p=0.01). Planned contrasts showed that accuracy was high at lag 1 compared to the group mean for the set-priming group, but not for the no-set-priming group (F (1,28) = 11.976, *MSE* = 30.105, p<0.01), and accuracy was low at lag 3 compared to the group mean for the set-priming group, but not for the no-set-priming group (F (1,28) = 10.809, *MSE* = 50.524, p<0.01), see figure 4.1d, page 122.

In this final block there was no overall significant difference between the two groups (F (1,28) = 1.713, *MSE* = 89.952, p = 0.201), with a mean T2 accuracy of 77.93% and 82.47% for the set-priming and no-set-priming groups respectively. Note that overall T2 accuracy in the positive lags increases for both groups across the four blocks completed (F (3,84) = 46.427, *MSE* = 30.817, p<0.001), and performance in block four is significantly better than performance in each of the other four blocks for both groups (p<0.05 for all contrasts). For the no-set-priming group accuracy does not increase substantially from block three to block four (p=0.060) compared to the set-priming group, but this finding (in addition to the increase in performance with practice) does not account for the significant difference found between the two groups at lag 3. Despite the lack of any overall difference between the two groups in terms of accuracy, the results show that in this last block, when both groups were asked to respond to T2 and ignore T1, the set-priming group were still affected by the previously relevant T1. This provides clear evidence that the attentional set from the dual target blocks has persisted to this single target block.

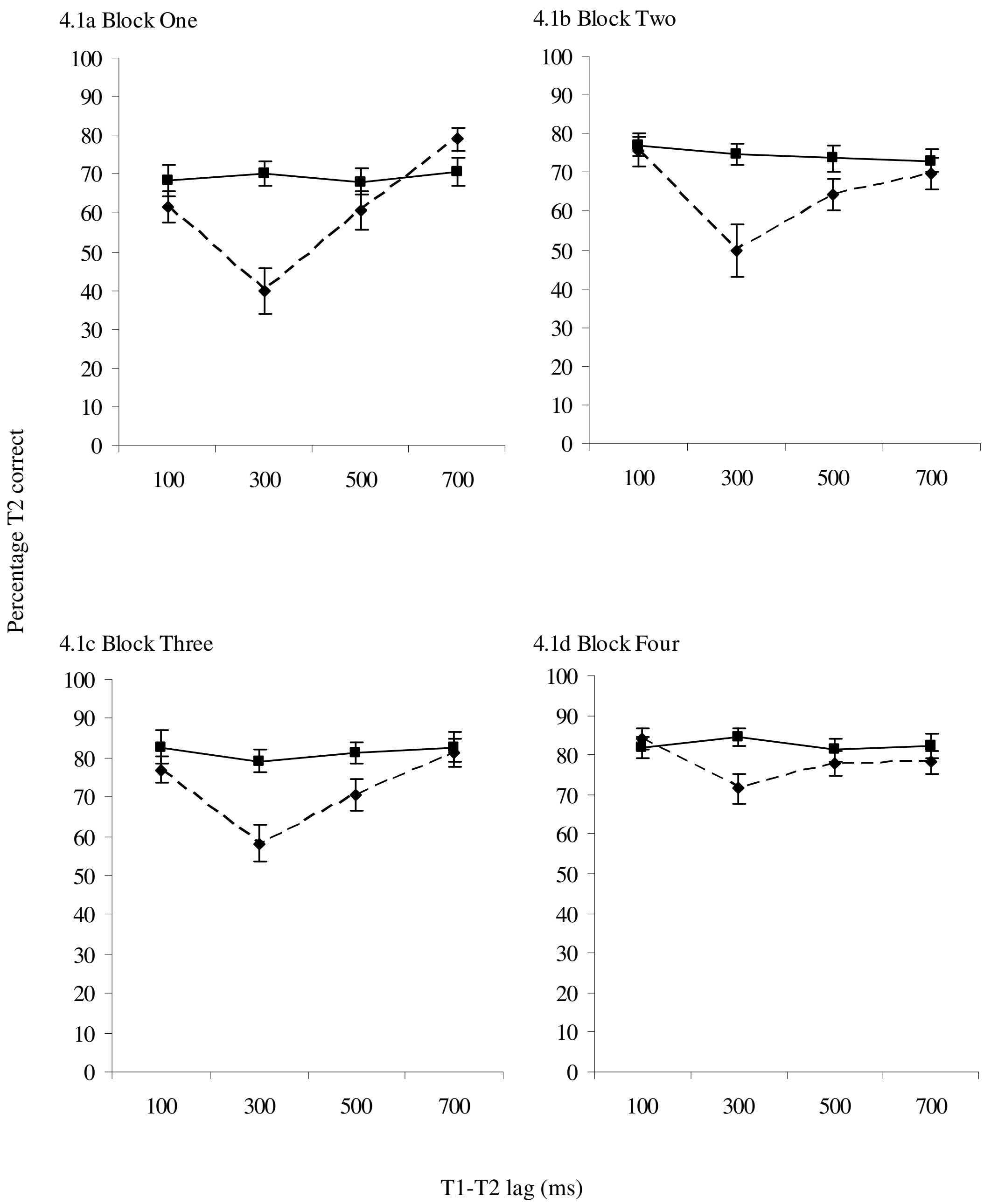

Figure 4.1: Identification accuracy of T2 for the set-priming (broken lines) and no-set-priming (solid lines) groups across the four blocks. Although there is no significant difference between performance in block 4, the set-priming group are still showing the U-shaped function associated with the AB effect. This is supported by a significant interaction between *set-priming* and *lag* at lag 3.

4.2.4 Discussion

The final AB experiment has proven successful in finding the predicted carry-over of attentional set from a dual target RSVP to a subsequent single target RSVP, as seen through an AB effect in both tasks. The studies presented in Chapter 3 did indicate that carry-over may be occurring from the dual target block to the single target block, however the results were lacking in statistical significance. The manipulation made to the current experiment (increasing practice with the dual target block) appears to have made a considerable impact on the carry-over effect. However, given the findings of Experiments Three and Four, there may be an alternative explanation for the present set of results. Whilst the previous two experiments did not initially reveal a significant interaction between set-priming and lag in the final block completed, further analysis showed that individual differences in blink magnitude were overshadowing any carry-over effect. After nonblinkers had been removed from the data set in Experiment Four there was a significant interaction in the final block, revealing a strong carry-over effect. It may therefore be the case that the present findings are purely due to the fact that participants who completed Experiment Five suffered from the AB to a greater extent than those in the previous studies and (consistent with predictions) were therefore more likely to show carry-over, regardless of their experience with the dual target RSVP.

Table 4.2 on page 124 shows the average AB magnitude found for the dual target blocks in Experiments Three, Four, and Five. Although the magnitude for the current experiment is slightly higher than the previous two there is very little difference between the samples. As a result it is concluded that the significant carry-over effect found in this experiment (without additional post-hoc analysis) is due to extended practice with the dual target block, not a greater number of blinkers.

Experiment	Participants			Blink Magnitude		
	Total	Blinkers	Nonblinkers	Overall mean *(and SD)*	Blinkers *(SD)*	Nonblinkers *(SD)*
3	15	8	7	41.59% *18.88%*	55.56% *14.18%*	25.63% *7.94%*
4	30	15	15	39.5% *17.34%*	53.13% *6.57%*	25.88% *13.5%*
5 (block 1)	15	8	7	43.73% *17.39%*	57.18% *11.22%*	28.34% *7.29%*
5 (block 2)	15	8	7	36.66% *17.72%*	49.51% *11.47%*	21.97% *10.52%*
5 (block 3)	15	8	7	30.97% *15.48%*	41.48% *7.89%*	18.97% *12.48%*

Table 4.2: Participants in Experiments 3, 4, and 5 were separated into 'blinkers' and 'nonblinkers' on the basis of AB magnitude in dual target blocks. This table shows the means and standard deviations for the blinkers and nonblinkers in each experiment (in each block for Experiment Five), along with the overall AB magnitude for all participants in each study. In Experiment Five participants were separated into blinkers and nonblinkers based on magnitude in block one, these groups were then consistent across the second and third blocks.

The fact that experience with the attentional set appears to increase the possibility that the set persists is consistent with the assumptions that practice would consolidate the set and make it more resistant to change. This prediction was made based on previous findings showing that cognitive control appeared to influence the AB and the carry-over effect. Studies in the AB literature report that blinkers show reduced activity in the ventrolateral prefrontal cortex (an area associated with early target selection) compared to nonblinkers (Martens et al., 2006). This would fit with the notion that nonblinkers process T1 earlier (due to increased activity) and can therefore move on to processing T2, reducing the size of the blink. In addition, blinkers are thought to adopt a more focused state of attention when completing the RSVP task compared to nonblinkers (Olivers & Nieuwenhuis, 2005); and they show higher levels of cognitive control than nonblinkers (Taatgen et al., 2007). More control may lead to reduced cognitive flexibility (Dreisbach & Goschke, 2004), and so blinkers are expected to suffer from carry-over more than nonblinkers.

Practice with the attentional set was expected to increase control and increase emphasis on set stability, and therefore reduce flexibility (in line with the above assumptions). According to previous findings this should also increase the blink in a dual target block. This was not the case however, and although participants in this experiment showed a slightly larger AB than those in Experiments Three and Four, AB magnitude decreased across the three dual target blocks. This decrease in blink was not significant, but the trend is inconsistent with the assumptions of cognitive control. If more cognitive control equates to reduced flexibility (Dresibach & Goschke, 2004) and increased blink magnitude, when flexibility is reduced due to extended practice the AB effect should increase. As such the largest blink would be expected in the final dual target block, but the blink was largest in the first dual target block (although not significantly).

As an alternative explanation it may be postulated that although Experiments Three and Four measured *micro-control* over the set, with an increase in control (through increased resources in the set) leading to carry-over, the design of Experiment Five affected the level of *macro-control* over the set. This means that even if participants did not invest more resources in the task (as would be evident from a greater blink magnitude over time) they still suffered from carry-over because enhanced experience resulted in the set becoming automatic and habitual (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Consequently the stimuli associated with the set elicited the set automatically without the need for control. A lack of control would mean that the task goals were not being monitored and the set was not altered in conjunction with a change in the task demands.

4.3 General Discussion of the Attentional Blink studies

4.3.1 Summary of the findings

The aim of this collection of AB experiments was to investigate the carry-over of attentional set using the RSVP paradigm. In this methodology participants are asked to search for targets within a stream of distracters; all stimuli are shown sequentially and usually to the same spatial location. In a single target RSVP participants are asked to identify one target (T2) presented amongst a series of distracters. In a dual target RSVP participants are asked to identify two targets (T1 and T2) presented amongst a series of distracters. The two targets are separated by a temporal lag; T1 appears first in the stream and then T2 is presented either immediately following T1 (at lag 1) or after a number of distracters following T1 (e.g., when T2 is presented at lag 3 two distracters are shown between T1 and T2). Both RSVP tasks (single and dual) incorporate the same stimuli, but in a single target RSVP participants are told to ignore T1. In a standard single target RSVP when T1 is task-irrelevant, identification of T2 is equal across all temporal lags, however in a dual target RSVP when T1 is task-relevant, accuracy to T2 follows a bimodal function: identification is poor between lags 2 and 5. This deficit in performance is termed the attentional blink effect (AB; Raymond et al., 1992).

When participants are asked to complete a dual target RSVP they should establish an attentional set which allows them to search for both T1 and T2. If the same participants are then asked to complete a single target RSVP they should establish an attentional set which allows them to respond to T2 but ignore T1. If participants fail to alter their attentional set between the two tasks they will continue to use a set which allocates attention to both targets; this will mean that T1 will continue to capture attention (on the basis of the previous attentional set) and will result in an AB. The impairment of T2 identification in the single target RSVP can be measured by comparing performance with that of participants who complete the same single target RSVP but have no experience with a dual target RSVP. It was predicted that participants would suffer from an AB in a dual target RSVP, but would show equal performance across all lags in a single target RSVP. However, if the single target RSVP is completed immediately after a dual target RSVP participants will again suffer from an AB because the attentional set from the dual target RSVP will carry over.

This prediction was based on previous studies which have found that T2 identification in a single target RSVP can be influenced by the allocation of attention to a task-irrelevant T1 when this initial target matches the attentional control settings. For example, Ghorashi et al. (2003) found evidence to show that an AB effect will occur in a single target RSVP when the task-irrelevant T1 matches the target defining features. This finding supports the contingent capture hypothesis (Folk et al., 1992). Previous findings have also shown that the top-down attentional set from a practice block of RSVP trials can persist to a second block of RSVP trials (Leber & Egeth, 2006), despite a change in task demands between the two blocks. The persistence of the set influences the allocation of attention in the second block, meaning that task-irrelevant stimuli will continue to capture attention due to the fact that they were task-relevant in the first block. These previous studies provide evidence that the RSVP methodology can be used to study attentional capture, and that the AB effect is an appropriate way to measure the persistence of attentional set. Given the distinctive pattern of performance when attention is allocated to T1 and T2, the paradigm appeared to be an ideal way to explore the carry-over effect.

As a starting point, Experiment One was completed to explore the conditions under which T1 may capture attention in a single target RSVP. The success of the design relied upon equal T2 performance across all temporal lags in a single target block. If performance varied across lag (a sign that T1 was capturing attention) in this control block there would be no way to effectively measure potential carry-over from a dual target block to a single target block. A pilot study was therefore completed to investigate this in addition to testing some sample stimuli and RSVP speeds. Although the results of this first experiment showed no apparent detriment to T2 identification at early lags (as predicted in the AB effect), the task-irrelevant T1 was having a large impact on performance. The results showed that participants learnt that because T1 always preceded T2 they could use it as a cue to the onset of T2. This substantially increased accuracy between 100 and 300 milliseconds SOA. Some alterations were therefore made to the design to remove this cuing effect in subsequent experiments. Specifically, an ISI was introduced between each item in the RSVP (standard practice in RSVP experiments), and the critical temporal lags used were expanded to cover a wider time frame to check for recovery from the blink.

The second pilot experiment made use of these methodological alterations and was the first attempt to find the AB effect in a dual target block and the predicted carry-over of top-down attentional set from a dual target block to a subsequent single target block. A three block, two group design was used and every participant took part in each condition. This allowed a large amount of data to be collected and a number of predictions to be tested. The results showed that the stimuli involved and the RSVP speed was able to elicit the well-known AB effect, however there was little statistical evidence for the carry-over of attentional set. In addition, the results again showed a large cuing effect, whereby in a single target block accuracy was artificially high at lags 1 (100 ms SOA) and 3 (300 ms SOA). It was concluded that participants were once again using T1 as a cue to T2 when they did not have to identify T2. This effect was not only potentially influencing any carry-over; it was also artificially enhancing the AB effect in a dual target block.

In Experiment Three the design was altered again in an effort to eliminate the cuing effect, whilst continuing with the aim of determining any evidence for the persistence of top-down attentional set. A negative lag was added to the experiment in which T2 was shown before T1. Half the trials completed were negative lag trials meaning that there was no benefit to using T1 as a cue to T2 in a single target block. This did mean that half the trials completed could not be used as evidence for the effects under investigation, therefore the overall number of trials completed were increased. In addition, as a further way to deter participants from attending to T1 in a single target block (when they had no prior experience of identifying this target) the similarity between T1 and the RSVP items was increased.

Two groups of participants were tested for the third experiment; a set-priming group who completed a dual target block followed by a single target block, and were therefore ‘primed’ to allocate attention to T1; and a no-set-priming group who completed two single target blocks and had no experience of T1 being task-relevant. It was predicted that the set-priming group would show an AB in both blocks because they would fail to switch set between blocks, therefore T1 would continue to match the top-down control settings in the second block, capturing attention, and impairing identification of T2. The introduction of a negative lag successfully removed the cuing effect, and raising the similarity between RSVP items did not influence the AB effect, beyond increasing blink magnitude overall. Although the results did not show a statistically significant carry-over effect, individual differences in the experiment seemed to suggest that whilst some participants were suffering from carry-over others were not. Crucially, set-priming participants who showed a U-shaped pattern of performance in the single target block also showed a more substantial AB in the preceding dual target block.

The variations in blink magnitude and carry-over in Experiment Three were ascribed to differences in cognitive control. This was based on previous findings from the literature which show that the AB is larger for participants who have more cognitive control and reduced cognitive flexibility (e.g., Olivers & Nieuwenhuis, 2005; 2006; Taatgen et al., 2007). To test this prediction, and to investigate carry-over whilst controlling for individual differences in AB magnitude, Experiment Four was completed. Thirty participants were separated into two set-priming groups (both groups completed a dual target block followed by a single target block) based on performance in the Embedded Figures Test (EFT; Witkin, 1969). A median split was performed and those who scored higher on the EFT (identified the embedded figures quicker) were classed as Field Independent (FI). FIs were predicted to show a large blink and suffer from carry-over, because they are thought to put greater emphasis on maintaining the set to focus on the targets and inhibit distracters. Those who scored less well on the EFT were classed as Field Dependent (FD) and were predicted to show a relatively small AB and no carry-over effect. This is because FDs are thought to have a more flexible cognitive style (Pask, 1976). Each group was compared with the no-set-priming group from Experiment Three.

Apart from FIs performing consistently better across the course of the experiment than FDs there were no differences between participants. The mean score on the EFT was however substantially different from those found by Witkin et al. (1954), suggesting that most of the current participants were actually FI (in absolute terms). This explained why nearly all participants showed an AB in the dual target block, but the lack of any significant carry-over effect failed to support the hypothesis that participants who show lower levels of cognitive flexibility (FIs) would also suffer from carry-over. As a further way to measure the carry-over effect the thirty set-priming participants were separated into two groups again, this time based on blink magnitude in the dual target block. This showed that participants who suffered from a large AB in the dual target block (blinkers) also suffered from an AB in the following single target block. Participants who showed a small AB in the first block (nonblinkers) appeared to switch set and did not show an AB in the single target block.

Experiment Four was therefore successful in finding the carry-over effect, but only after substantial post hoc analysis. In an effort to produce a significant carry-over effect without resorting to post hoc analysis a final AB experiment was completed. Taking account of findings which show that a top-down set will only carry-over once it has been consolidated through a large amount of practice (Leber & Egeth, 2006), the number of set-priming trials in Experiment Five were increased threefold. On the assumption that experience with the attentional set would make this set less flexible, a clear carry-over effect was predicted. Increasing practice with the dual target RSVP did result in a significant carry-over effect, however due to an increase in RSVP performance across the course of the experiment this finding was not attributed to increased cognitive control (at the micro-level). Instead the results argued in favour of a lack of cognitive control (at the macro-level) in this experiment. Participants completed the same task over a long period of time and as the task progressed the set would become more habitual, and would automatically be triggered by the stimuli associated with it (Schneider, Dumais, & Shiffrin, 1984). This reduces the requirement for control, unless the task changes (Posner & DiGirolamo, 1998), in which case a lack of control will mean that the habitual set persists to the new task.

4.3.2 Carry-over of attentional set in a RSVP

Taken as a whole the findings from the first five experiments do provide evidence for the carry-over of attentional set. Despite the fact that not all experiments revealed a clear carry-over, the reasons behind this are due to the experimental design (e.g., the cuing effect overshadowing the AB) and individual differences between participants (participants suffer from the AB to differing extents). As progression was made these factors have been eliminated, allowing the carry-over to be revealed.

The RSVP procedure lends itself well to the present work due to the distinctive patterns of performance in the dual and single target blocks. Carry-over from a dual target RSVP to a single target RSVP is therefore easy to detect, by searching for a bimodal pattern of performance in this second block. A standard single target block (which is not preceded by a dual target block) acts as a perfect comparison due to the constant high level of performance across all blocks. A decrease in performance across temporal lag in a single target block can therefore be attributed to the previous block. It must be noted however that other researchers have found an AB effect in a single target block when T1 was task-irrelevant, did not require a response, and did not follow a dual target block. For example, Chun (1997) and Christmann and Leuthold (2004) report an AB effect in a single target RSVP. In these studies both T1 and T2 were letters, therefore the blink in the single target block may have been due to contingent capture (Folk et al., 1992). In the present set of experiments the targets were kept sufficiently different to ensure that contingent capture does not occur. This means that the carry-over effect found here is due to the persistence of the attentional set, not the characteristics of the stimuli within the RSVP.

The findings outline the different conditions required for carry-over to occur, and these may not necessarily be consigned to studies using a RSVP. First, consistent with the results of Leber and Egeth (2006) an attentional set must be fully established before it will persist. They suggest that practice influences carry-over due to the balance of resources; if an individual has invested a great deal of resources into the establishment and consolidation of the set they will be less likely to switch set, despite the fact that a switch will benefit performance. Increased performance outweighs the costs associated with abandoning a less practiced set because fewer resources have been devoted to the initial set and therefore set switching requires less effort. Note that the 'weighing up' of resources is not assumed to be explicit but rather represents an implicit comparison of set switching and set maintenance.

This suggests that participants are showing the AB in a single task block (completed after a dual task block) because they are reluctant to change set. Task switching literature supports this viewpoint, stating that a more practiced set is easier to re-enable when necessary (Monsell, 2003) and more difficult to abandon (Allport et al., 1994); the original set is therefore carried over because the benefits of switching to a new set do not outweigh the costs of inhibiting the old set. The present experiments support these findings; however evidence from task switching may suggest that there is an alternative explanation for the carry-over effect. The persistence of attentional set in Experiment Five has been attributed to a lack of control over the goal representation, meaning that a more habitual set will persist to a new task because performance is not being monitored effectively. If the set has become automatic (through experience) there is also the possibility that a set switch does take place, but the stimuli that were consistently mapped to the previously relevant set (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) automatically reactivate the previous (stronger) set. Monsell (2003) states that stimuli tend to evoke the sets "that are habitually associated with them" (pp. 134) even when the set is irrelevant. He suggests that this causes a set which is not relevant to the task, but has become automatic, to override the current set.

Given that task switching studies show higher switch costs (in the form of increased response times) when a set is more practiced (Experiment Five) it would be expected that if participants had switched set from a dual target block to a single target block, only for the original set to be reactivated, performance in this single target block would suffer. In each AB experiment presented here accuracy has increased throughout the course of the experiment. This indicates that there were no costs of switching set, potentially because participants were failing to switch set. For example, in the task switching literature switch costs are found on switch trials but not on no-switch trials. These costs reveal themselves in slower response times and reduced accuracy and are attributed to the difficulty in reconfiguring a new set (e.g., Monsell, 1996), and the persisting activation of the old set (e.g., Allport et al. 1994).

If switching attentional set is similar to switching task set one may expect that a switch in set would result in a cost to performance on the new task. The current experiments show no such costs, and instead performance in the final block is always higher then the preceding block. This signifies that no switch is taking place, and the set from the dual target block is not exogenously reactivated by previously encountered stimuli. Note however that this does not necessarily mean that the attentional set used in the dual target block did not become automatic (particularly given the increase in performance within each experiment), it simply means that the results do not support the notion that the carry-over effect was caused by the automatic reactivation of the set. The author would argue that in effect the set did become automatic in Experiment Five, but this did not lead to reactivation of the set by previously encountered stimuli. Instead the increased automaticity reduced the need for control (macro-control) over performance, therefore when the task changed and a switch was required there was no ‘executive’ level of control to monitor this and the set persisted.

Although the results do not support the exogenous reactivation of the set, it is difficult to conclude that a set may not be triggered automatically without additional evidence. The lack of switch costs in the present set of experiments has been used to argue against automaticity, yet this is on the basis of task switching literature and it is not certain whether similar switch costs would be found in attentional set switching. To further investigate automaticity it would be useful to determine whether participants suffer from carry-over because of an inability to switch set, or because the original set is automatically triggered by a previously relevant stimulus. In the first instance no set switching would occur, however in the second situation there would be two switches; a switch from the original set to a new set, and then a switch from the new set back to the old set when it is reconfigured by a familiar stimulus. Rather than relying on a measure of switch costs this could be achieved by recording ERPs during the task to determine whether set switching, or set maintenance occurs at the critical points in the experiment. This has been done before to measure attentional set switching (e.g., Rushworth et al., 2002), but has not been used to research the carry-over of attentional set.

4.3.3 Implications of the findings on theories of the AB

Utilising the RSVP procedure, which results in an AB when two targets must be identified, has not only provided information regarding the carry-over effect, it has also provided additional evidence for the AB effect. Therefore it is important to assess how the main findings of the AB experiments in this thesis fit with theories of the AB. The results show that when T1 is substantially different from T2, and always precedes T2 it can be used as a cue to this second target in a single target RSVP. In addition, there was evidence for individual variation in AB magnitude, and crucially, AB magnitude was related to carry-over, with carry-over occurring when the blink was more substantial. Finally the studies have shown that increasing the similarity between RSVP items (including T1 and T2) increases the blink.

The cuing effect is not necessarily useful in supporting one theory over another; however it questions the suitability of using a single target block as a control condition. AB studies should allow for the possibility that an irrelevant T1 may alert attention to T2 and measures should be taken to avoid the effect. One way that this author attempted to eliminate any cuing was by increasing the similarity between items in the RSVP; if T1 is more similar in size and appearance to the distracters it may not capture attention in a single target block. Of course increasing the similarity between T1 and the distracters also increased the similarity between T1 and T2. It may be argued that making the target more similar would lead to contingent capture in a single target block; however the pattern of performance in the no-set-priming group is not consistent with this, and instead fits with the assumptions of Di Lollo, Kawahara, Ghorashi, & Enns (2005) that when faced with a set of highly similar stimuli the attentional set will be more specific in order for targets to be selected and distracters to be inhibited. The lack of contingent capture when T1 is task-irrelevant shows the importance of top-down control, and also shows that the orienting system can be configured to a specific level on the basis of task requirements.

In addition to including a negative lag in which T2 was presented before T1, raising the similarity of the stimuli effectively removed the cuing effect. It also increased the magnitude of the blink (from Experiment Two to Experiment Three). This increase in the size of the blink is consistent with previous studies showing that if RSVP stimuli are similar blink magnitude increases (e.g., Isaak et al., 1999; Olivers & Watson, 2006). This is assumed to be because the processing system has to work harder to select targets from distracters (e.g., Bundesen, 1990; Duncan & Humphreys, 1989; Visser et al., 2004). The finding is also consistent with limited capacity theories of the AB (e.g., Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998; Raymond et al., 1992). According to such theories, T2 processing is impaired at early lags because the system is busy processing T1, preventing T2 from being detected (Raymond et al., 1992), or causing the decay of T2 by post T2 distracters (Chun & Potter, 1995). As similarity increases more resources will have to be given to the detection and identification of T1, leaving fewer resources for T2 and causing a larger blink. This is contrary to other findings which show that the task difficulty of T1 does not alter blink magnitude (Shapiro et al., 1994).

One interesting finding however is that in Experiment Three T1 accuracy was higher for nonblinkers ($\bar{x}$ = 93%) than for blinkers ($\bar{x}$ = 85%). It may be presumed that if more resources were allocated to T1 (improving performance) this would have a greater impact on T2 accuracy, in which case blinkers should show higher T1 accuracy. Arnell, Howe, Joanisse, and Klein (2006) have also found that T1 accuracy correlates negatively with AB magnitude; the higher the accuracy the smaller the blink. They favour a limited-capacity account of the AB and propose that if an individual can encode T1 effectively the system can move on to processing T2. This means that T2 will suffer from interference from T2+1 to a lesser extent, reducing the size of the blink. Better T1 performance will therefore coincide with a smaller blink. Consequently it seems that although increasing similarity does increase processing demand of the RSVP task (enhancing the AB); some participants are still better able to encode T1 than others. Despite the individual differences found these results fit well with resource depletion explanations.

These explanations may be less suitable for adequately explaining why blinkers were more likely to suffer from carry-over than nonblinkers (a finding of Experiment Four). It has been concluded that the carry-over effect found in the present AB experiments is due to the investment of resources into an attentional set, and the perceived costs of changing this set. When participants put more effort into completing the RSVP task (and suffer from a larger AB as a result of this) the set strengthens and the costs of switching set increase, leading to carry-over. Although the carry-over effect is therefore attributed to a balance of resources (which would fit with a resource depletion account), it stems from the influence of top-down control; more control leads to more resources. Resource depletion theories do not attribute the AB effect to top-down control, other than stating that attention is allocated to the RSVP using top-down processing. It is possible to explain the present findings using these theories because processing resources appear to be key to both the AB effect and the carry-over effect, however limited-capacity theories may benefit by attributing a greater influence to top-down control.

The TLC model (Di Lollo, Kawahara, Ghorashi, & Enns, 2005) does attribute the AB to top-down control. The model states that the endogenous filter which allows targets to be selected requires constant feedback and when T1 enters the processing system these signals are interrupted. If T1+1 is a distracter it will trigger an exogenous set and the top-down set will have to be reconfigured to regain control. The reconfiguration is time consuming and effortful and it is this which causes an impairment to T2 identification. When more resources are allocated to the RSVP task the attentional set may strengthen; this will mean that reconfiguration of this set following a T1+1 distracter will be more costly (increasing blink magnitude) and it will be more likely to persist to a second task. This model can therefore effectively account for the link between AB magnitude and carry-over.

The present finding that increased similarity of RSVP items increases the magnitude of the AB cannot be so easily explained using the TLC model. Although the model attributes the AB to a loss of top-down control, this loss is directly influenced by the characteristics of T1+1, not the characteristics of T1. Blink magnitude should therefore not be affected by the processing resources allocated to T1. Di Lollo, Kawahara, Ghorashi, & Enns (2005) have based their model on findings showing that when T2 is presented immediately after T1, at lag 1, and a third target is situated at lag 2, there is no AB on the third target (T3). The model accounts for this by stating that T2 triggered the original attentional set, therefore there was no set switch and no associated processing costs. However, Dux, Asplund, and Marois (2008) completed a similar study and found that when greater attentional resources are given to T1 a blink will occur on T3, showing that the characteristics of T1 do have a role to play in the AB. Moreover they report that the findings of Di Lollo and colleagues were paired with low T1 accuracy, suggesting that T2 identification did not suffer because fewer resources were allocated to T1. The TLC model would predict no correlation between AB magnitude and T1 accuracy (even though it can explain the link between carry-over and AB magnitude), yet this has been found in the present set of results (Experiment Three) and by Arnell et al. (2006). This provides further support for a resource depletion account.

There are of course several other models to account for the AB effect; however the primary aim of the present AB studies was not to evaluate these models and as such focus has been given to the most prominent accounts. The findings of the five AB experiments completed for this thesis appear to lend more support to resource depletion theories; however the relationship between AB magnitude and carry-over cannot be sufficiently accounted for at present. This highlights the benefits of utilizing the AB paradigm to measure other aspects of attentional control; it can provide more varied support for particular theories. A study by Zhang, Shao, Nieuwenstein, and Zhou (2008) demonstrates this. They measured the effects of the AB on an individual's ability to orient attention to different spatial locations, and found that when a cue was presented in the time window between T1 and T2 it could effectively orient attention to the spatial location of T2. Zhang et al. state that their results support resource depletion accounts of the AB by showing that top-down control is not lost following the appearance of a distracter at T1+1. In addition, although an AB effect does occur, this does not prevent items presented at lags 2-5 from being processed to a certain extent (e.g., Vogel et al., 1998), or from acting as a cue to a later target (e.g., Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005; Shapiro et al., 1997).

It may therefore be concluded that although the present findings cannot definitively support a resource depletion account of the AB, the evidence is most in favour of such an account. Moreover, by using the RSVP methodology and the AB effect to study a different aspect of attentional control, the experiments in this thesis have provided more varied evidence for the theory.

4.4 Conclusion of the AB studies

The attentional blink experiments reported in Chapters Two and Three and in the present chapter provide evidence that an attentional set will persist from a task in which it is relevant to a task in which it is no longer relevant. Currently the evidence supports the argument that carry-over occurs because individuals fail to alter the attentional set on the basis that this reconfiguration is too costly. This means that an attentional set will only persist if a large amount of resources have been invested in its establishment, ensuring that the costs of switching set outweigh the benefits of adopting a new set. Experiment Five also provided evidence that the carry-over effect may also occur due to a lack of control, whereby the suitability of the set is not being monitored effectively and a set switch is not made when necessary (this is due to automaticity of the set which is in turn due to increased experience with the set).

In addition to finding the effect under investigation, the experiments have raised some important issues about the RSVP methodology and the AB effect. Most notably this had been the cuing effect of T1 in a single target block, and the variations in blink magnitude in a dual target block. Although individual differences in the AB have been found on previous occasions cited in the literature, the present finding that a large AB can be associated with carry-over has implications on the suggested causes of the AB. The use of this paradigm is therefore fully justified; it has prompted further research into the carry-over effect and it has also raised some interesting issues regarding the AB.

Chapter Five: Carry-over of attentional set between two visual search tasks

5.1 Rationale for Experiments Six to Ten

The AB experiments have revealed that an attentional set established for one task will persist to a second task, providing substantial resources have been allocated to the set. This carry-over influences the allocation of attention in the second task, causing irrelevant stimuli to capture attention on the basis that they were relevant in the previous task. Using a single and dual target RSVP to measure this effect was beneficial because performance in each usually follows a distinctive pattern; therefore any alteration to this pattern can be clearly seen. However, there are drawbacks to the RSVP design which limit the applicability of the findings to other tasks.

First, all stimuli were shown to the same spatial location, whereas in most visual tasks stimuli can be located in different areas of space. In addition, the stimuli and the layout of these stimuli were identical in both the single target and the dual target blocks and the task demands across both blocks were also very similar; participants had to search for a vowel (T2) presented among consonants, and the only difference was that in a dual target block participants also had to search for a number (T1). Yantis (2000) says that an attentional set is formulated on the basis of a "stored memory representation" (pp. 94) which is derived from instructions regarding the task and expectations and experience of the task. It may therefore be the case that if the instructions for a second task are similar to those from an initial task, and the layout of stimuli matches that of the first task, the attentional set from the first task may continue to be used because it appears appropriate. This is supported by theories developed to explain how selective attention allocates resources to certain objects or areas at the expense of others. For example, Rabbitt (1984) suggests that observers will make an initial analysis of a situation and then use the most appropriate strategy to complete the task involved. If the situation is very similar to a previous one the strategy from the previous task will be selected. It is therefore difficult to conclude whether the carry-over effect found in the AB studies can be fully attributed to the failure to switch set between the two blocks, or whether it was in part due to the similarity between the tasks required in each block.

The aim of the second set of studies in this thesis is to explore the carry-over of attentional set from one task to a second task, when the tasks are more varied. This will provide more detailed information regarding the conditions under which an attentional set is likely to persist. Furthermore, investigating the carry-over effect in a different task will help to overcome the task-imposed limitations from the RSVP procedure. To achieve this, a change detection task will be paired with a visual search task. Both tasks involve a search through a visually presented display (with items located in different areas of space), however whilst the visual search task will require the detection of a specific number of targets presented among a series of distracters, the change detection task (which will succeed the visual search task) will require participants to locate a change made to a single item. The visual display used in both tasks will be similar, and change detection performance will be measured based on whether the changed item is a target or a distracter from the preceding visual search task.

A total of five experiments have been completed by the author involving this ‘visual search – change detection’ methodology. The first two experiments were pilot studies designed to measure participants’ ability to detect changes made to a variety of search features in an effort to select two features to use for the remaining studies. These two experiments are presented in this chapter, together with an introduction to the visual search task and the change detection task. Chapter Six contains Experiments Eight and Nine. The first of these investigated the carry-over of search strategy from a visual search task to a change detection task when the stimuli in both tasks were identical. To explore the characteristics of the attentional set which carried over, Experiment Nine investigated the effect when the position of the stimuli in the array was changed between the two tasks. A final experiment (Experiment Ten) was then completed to investigate the possibility that the amount of resources required by the visual search task would influence the carry-over of attentional set to the change detection task. Experiment Ten can be found in Chapter Seven accompanied by a detailed review and discussion of the findings of these five studies.

5.2 Visual Search

5.2.1 The importance of a top-down attentional set

It was illustrated in Chapter One that a visual search task has been a popular methodology for modelling selective attention. For instance, a simple search for a unique target among homogenous distracters is thought to occur preattentively, without the need for focused attention, whereas a conjunction search in which the target differs from distracters in more than one feature value is thought to require focused attention (e.g., Treisman & Gelade, 1980). Research in this area initially supported two distinct levels of search efficiency; a simple search is efficient, producing a shallow search slope regardless of display set size, and a conjunction search is inefficient, resulting in a slope which increases with an increase in set size. Treisman and Gelade (1980) suggested that the steep search slope represents a serial search, in which every item in the display must be searched before the target can be found. This was questioned by studies showing that efficiency of a conjunction search can be improved by selectively searching through a "subset" of features. For example, Egeth et al. (1984) and Kaptein et al. (1995) showed that when searching for a target (e.g., a red circle) which shares one feature with some distracters (e.g., red squares) and another feature with other distracters (e.g., green circles) a feature-based attentional set will allow observers to selectively attend to one feature (e.g., the colour red) meaning that fewer items need to be searched to find the target (all green shapes will be ignored). Utilising a visual search task therefore allows researchers to investigate attentional selection, revealing how an observer may 'parse' a visual scene to make processing more manageable, and focus on task-relevant stimuli.

These findings regarding the selection of information for further processing have been accompanied by studies which have used visual search tasks to measure the relative influence of bottom-up and top-down control over the allocation of attention. For example Folk and colleagues (Folk et al., 1992; Folk et al., 1994) have made use of a spatial cuing task, and Theeuwes and colleagues (Theeuwes, 1991a, 1991b, 1992, 1994; Theeuwes & Burger, 1998; Theeuwes et al., 2006) have made use of a visual search for a feature singleton. The work by Folk et al. has provided evidence for the involuntary orienting hypothesis, whereby an irrelevant item presented in the visual field will only capture attention when it matches the top-down control settings established for the target search. They argue that this reveals the importance of top-down control over the exogenous capture of attention, and shows that attentional capture cannot occur solely on the basis of bottom-up processes. However the work by Theeuwes has shown that an irrelevant item can capture attention regardless of any 'feature relevance' to the task demands, therefore providing evidence that attentional capture can be driven purely on the basis of bottom-up control. Due to the substantial amount of evidence for both sides of the argument, from the respective paradigms, many researchers have claimed that the selected methodologies of the two research groups may partially account for the variations in findings (this has been discussed in Chapter One of the present thesis, but see also Folk & Remington [2006] for an overview).

5.2.2 Implications of past studies on the present visual search task

As previously mentioned, the focus of this thesis is not to look at the balance between top-down and bottom-up influences. Instead the work concentrates on how attention is allocated using a top-down attentional set, and whether a set has the potential to persist to a second task and influence attention despite being irrelevant for the new task. It is therefore critical to the present methodology that an attentional set is adopted for the visual search task (in order to determine any persistence of this set to the change detection task); and the above research is beneficial as it outlines instances in which the task demands result in extraneous variables that can affect the top-down set.

For instance, to allow any carry-over effect to be measured, the top-down set must be very specific. This rules out a conjunction search (e.g., Treisman & Gelade, 1980) because the task would always involve a search for more than one feature which may compromise set specificity. Although the search will therefore be a 'simple' search task, taking into account the findings that a search for a feature singleton among homogenous distracters can be completed preattentively without the need for focused attention (and without the need for an attentional set; e.g., Treisman & Gelade, 1980), the present task will require a search for more than one target presented among heterogenous distracters. The task instructions must also be such that they encourage the adoption of a specific set (e.g., feature-detection mode) as opposed to a more general set (e.g., singleton-detection mode; Bacon & Egeth, 1994), as this should benefit performance in the search task and prove that the set has indeed been adopted.

One further point to mention is that although the search should be sufficiently demanding to ensure the establishment of a top-down set, there should be no possibility that a task switch or a switch in attentional set occurs in this initial task. Kumada (2001) has criticised the methodology used by Theeuwes and colleagues because although the task is described as a simple search, it is in fact a ‘compound’ search (Duncan, 1984). In his task Theeuwes (e.g., 1990; 1992) asked participants to search for a target defined by a specific feature (e.g., search for a colour singleton), however they had to report a different feature of this target once found (e.g., the orientation of a symbol inside the singleton). The to-be-reported feature therefore did not match the to-be-searched-for feature meaning that any top-down set based on the target-defining feature would not benefit target identification. If participants have to search for the target using one feature and then identify the target using another feature this involves a switch in the goals of the task. This may influence any carry-over effect and should therefore be avoided in the present work.

5.2.3 Persistence of a visual search strategy

The following experiments completed by the author study the persistence of a visual search strategy from one task to a second task, yet this is not the first example of a strategy transferring between tasks. Research has shown that when participants are asked to search for a target among distracters, search efficiency is greater if a preview array is shown prior to the target array. This preview array contains a selection of distracters that will be present in the search array, and Watson and Humphreys (1997) suggest that these distracters are ‘marked’ so that when the search array is presented (containing the old distracters, the new distracters, and the target) attention will be inhibited from revisiting the already searched distracters and will instead be confined to the new items. This means that fewer items need to be searched to find the target compared to situations in which no preview is given. In the past this *visual marking* effect was only thought to occur for locations (Watson & Humphreys, 1997), however more recently the effect has been found for objects (Watson & Humphreys, 1998) and features (Olivers & Humphreys, 2002; 2003), supporting the findings of Egeth et al. (1984) and Kaptein et al. (1995) that attention can be selectively guided to a subset of features.

Visual marking is described as an inhibitory strategy which acts in a similar way to the attentional set proposed by Folk et al. (1992). Olivers and Humphreys (2003) state that whilst Folk et al. attribute contingent capture to an ‘excitatory’ attentional set, visual marking is an ‘inhibitory’ attentional set. Negative priming (e.g., Tipper, 1985) is very similar to this and is also indicative of an inhibitory strategy used in selective attention. Negative priming refers to the slow response to targets that have been distracters on previous trials. In line with contingent capture, when completing a search any item matching the target template will receive excitatory feedback, ensuring priority of these items in attentional selection. Houghton and Tipper (1994) also suggest that any item which does not match the target template will receive inhibitory feedback. Findings show that when inhibited items (distracters) subsequently become targets, responses to the targets are slower and less accurate than responses to new targets that have not been encountered previously.

The evidence outlined above shows the importance of top-down control in guiding attention through the visual field, and biasing attention to the most task-relevant items and areas within a scene. Crucially it also shows that an attentional set (albeit an inhibitory set) can carry-over and influence performance on a later portion of a task. Building on these findings the following set of experiments will explore how an attentional set established to complete one search task may impact upon performance in a subsequent search task. In order to expand upon previous data in the literature (and the findings of the AB experiments reported earlier) the experiments will ensure greater differentiation between the two search tasks.

5.3 Change Detection

5.3.1 Change detection methodology

A change detection task involves a visual search; however this is not a search for targets among distracters, but is instead a search for a change between two similar images. Participants are presented with two images separated by a brief ISI and told to find a change that has been made to the second image. Researchers have found that it can take a long time for a change to be found (up to an average of 20 seconds; Shapiro, 2000), despite the change being easily spotted when the ISI is removed. The inability to detect a change has been termed ‘change blindness’ (Rensink, O’Regan & Clark, 1997), and it is thought that the introduction of an ISI between the two images causes such disruption because it masks the motion transients that would normally occur when a change is made. Smilek, Eastwood, and Merikle (2000) state that the occurrence of a change is similar to an abrupt onset, which will always capture attention (e.g., Jonides & Yantis, 1988; Muller & Rabbitt, 1989; Yantis & Jonides, 1984), however when this onset is masked it will fail to capture attention, resulting in a longer search.

The many change detection studies cited in the literature make use of a variety of stimuli. This ranges from simple arrays of letters or digits (e.g., Pashler, 1988) to pictures of natural scenes (e.g., Rensink et al., 1997) and dynamic video clips (e.g., Levin & Simons, 1997). In addition, the types of changes made to a display have been varied (e.g., insertion or deletion of an object, substitution of an item, a change in layout, etc.), and the specific task required by the participant differs across studies (e.g., participants can be asked to detect a change, find the location of a change, or locate and identify the change [Rensink, 2002]). Regardless of the display used, the type of change made, or the task instruction provided, the majority of studies show that a change is always difficult to detect when masked by an ISI.

There are also many variations of the change detection methodology. Most research makes use of the "gap contingent" design outlined above, yet the characteristics of this gap differs from study to study. In the most common gap contingent paradigm the two images (the original and the modified image) are separated by a blank screen, therefore it appears as though the change was made between this interval. There are two forms of the gap contingent design; a "repeated change" paradigm (also known as the flicker paradigm; Rensink, et al., 1997) in which the two images are continuously shown alternately, separated by the ISI until the change has been found; and a "one-shot" paradigm in which the two images are shown once (e.g., Pashler, 1988; Simons, 1996). The one-shot paradigm is a forced choice detection paradigm (Simons, 2000). In the flicker paradigm the dependent measure is usually the time it takes participants to locate the change, whereas in the one-shot paradigm both RT and accuracy have been used to measure performance. The present work will make use of the flicker paradigm.

One of the first attempts to study change detection was a set of experiments completed by Rensink et al. (1997) who used (and developed) the flicker paradigm. Participants were shown one image (A) twice, each time for 240ms, and each time a grey blank screen was shown after the image for 80ms. Following this they saw the modified image (A`), which was identical to A with the exception that a change had been made to the image. This change could be a change to the colour of an item, the addition of an item, or the deletion of an item, and changes could be made to areas in the image of "central interest" or "marginal interest". Again the modified image was presented twice, each time for 240ms, and the grey blank screen was shown between each presentation. The presentation of the images therefore followed a pattern of A, A, A`, A`, A, A, A`, A`, and so on, only ceasing when participants had found and responded to the change. The results showed that changes made to marginal interest areas took an average of 10.9 seconds to detect, whilst changes made to central interest areas took an average of 4.7 second to detect. Rensink and colleagues compared this to change detection without the ISI and found that changes could be found in an average of 0.9 seconds (this did not differ according to area of interest). The grey blank was therefore having a substantial impact upon change detection ability.

5.3.2 Explanations for change blindness

The fact that the motion transient is masked in a change detection study is an influential factor in change blindness, yet Rensink et al. (1997) discovered that an ISI does not impair visibility of the scene. Therefore, even if the change is masked, participants should still be able to detect the change by comparing the stored representation of image A, with the stored representation of image A`. In the past it has been assumed that observers are capable of forming a representation of a scene, and storing this representation in memory, providing a detailed view of the world across eye fixations (Rensink, 2000), however the findings from the change detection literature show that this may not be the case (see Noë, Pessoa, & Thompson [2000] for a discussion). Rensink et al. (1997) initially suggested that an observer fails to detect a change because although they can create a representation of the first image (A), creating a representation of the second image (A`) overwrites the first, preventing any comparison. Rensink (2000) has since provided a ‘coherence model’ for change blindness. This account suggests that before focused attention is allocated to areas of a display a series of “proto-objects” are formed in parallel. These proto-objects are not coherent and therefore not stable over time, meaning that if a new item appears in an already occupied location this new item will overwrite the previous one. Once focused attention is given to a selection of the proto-objects it allows them to have greater coherence, creating a stable representation, therefore if a new object replaces an old one it is viewed as a change.

Even when participants are cued to the location of the change before the change has been made, and the change is not masked, they still suffer from change blindness (Wolfe, Reinecke, & Brawn, 2006). Based on their findings Wolfe et al. have attributed the effect to the capacity limitations of visual short term memory. A change will only be found if the memory of an item persists once the change has been made, in order for the changed representation to be compared to the original representation. However Varakin and Levin (2006) have reported evidence that even if a change cannot be found, memory for the visual image is good, supporting the notion that change blindness is a failure of perception or encoding, not a memory failure.

Regardless of which explanation can account for the findings of change detection experiments, they all agree on two key points. The first is that attention must be allocated to the location of the change. This is supported by findings showing that changes made to areas of central interest are detected faster than changes made to areas of marginal interest (e.g., Rensink et al., 1997). The second is that the changing item must be processed in order to create a representation of this item. This is supported by findings showing that change blindness occurs even when a change is made to an item at the centre of attention (e.g., Levin & Simons, 1997; Simons & Levin, 1998).

5.3.3 Guidance of attention in a change detection task

In a visual search task participants are usually told to search a display for a specific target (or targets). Task instructions ensure that participants know the characteristics of the target; therefore attention can be guided based on top-down factors. In a change detection task participants are simply told to find the change, they are often given no information regarding the features of the stimulus that will change, and so are unable to confine their search to specific features, objects, or locations on the basis of top-down information. In the absence of specific instructions how do observers allocate attention to search for a change? Stirk and Underwood (2007) have found that when searching for a change made to a natural scene, observers will use prior expectations of the scene to guide their search, resulting in faster detection of changes made to “scene-inconsistent” items compared to “scene-consistent” items. This supports the findings of Rensink et al. (1997) that changes made to central areas of interest are detected faster than changes made to marginal areas of interest. It is also consistent with the results of Kelley, Chun, and Chua (2003) who found that high-interest changes were detected faster than low-interest changes when a natural scene was presented upright, yet when the scene was inverted (disrupting the global representation) the benefit for high-interest changes decreased.

It therefore appears that attention in a change detection task is guided in the same way as attention in a standard visual search of natural scenes. Attention is more likely to be deployed to informative areas of a scene (e.g., Mackworth & Bruner, 1970; Mackworth & Morandi, 1967), and incongruent items are fixated before congruent items (e.g., Loftus & Mackworth, 1978; Underwood & Foulsham, 2006). Once again this highlights the importance of top-down control over selective attention. However, contrary to the findings of Stirk and Underwood (2007), Wright (2005) found that salience could predict change detection, with changes made to more salient regions detected faster than changes made to less salient regions. This supports models of visual search which attribute a strong role for bottom-up processing in the guidance of attention and eye movements (Itti & Koch, 2000).

The results from the literature therefore show that visual search in a change detection task can be mediated by top-down control and bottom-up influences. Yet these findings are all derived from studies using natural scenes. How would attention be guided in a more simplistic visual image, which does not vary greatly in terms of salience, and observers are unable to use their expectations of the image? It may be predicted that in the absence of any top-down or bottom-up guidance, observers will resort to a serial search through the display, allocating attention to each item in turn until the change can be found.

5.4 An introduction to the current visual search – change detection experiments

5.4.1 Design of the experiments

The following set of experiments (with the exception of the pilot studies [Experiments Six and Seven]) will involve participants completing a visual search task followed by a change detection task. The visual search will be a sentence verification task (SVT); participants will be presented with a visual array and will be required to search this array for a specific number of targets in order to respond to a previously presented statement. Each item in the array can be defined on the basis of two features, and the SVT will require a search through one of these features. Following this task the array will be presented again, followed by a blank screen, followed by a modified array (identical to the original but with one item changed). Participants will be asked to search this array for a change, and report the location of the change. The original and modified images will continue to alternate (separated by the blank) until the change has been found.

In order to measure the influence of the SVT on the change detection task changes will be made to items that were targets in the SVT, or distracters in the SVT. In addition, the type of change made will be congruent or incongruent to the search feature in the SVT. For example, if participants are asked to search for a triangle among a series of heterogeneously coloured shapes (squares, diamonds, etc.) in the

SVT, a change to a previous target would be a change to one of these triangles (e.g., triangle changes to a circle), whereas a change to a previous distracter may be a change to one of the squares in the display (e.g., a square changes to a diamond). A congruent change would be a shape change (e.g., a red square changes to a red diamond), and an incongruent change would be a colour change (e.g., a red square changes to a blue square).

5.4.2 Predictions of the experiments

Given the findings of the AB experiments that have been described and the findings of visual marking (e.g., Olivers & Humphreys, 2003) it is predicted that the attentional set from the SVT will persist to the change detection task. This will result in faster detection of changes made to items that were targets in the SVT compared to changes made to items that were distracters in the SVT. It is also predicted that congruent changes will be detected faster than incongruent changes, showing evidence for the carry-over of a feature-based attentional set.

5.5 Experiment Six: Selecting a feature pair

5.5.1 Rationale of Experiment Six

Before embarking on a study to explore the effects of a top-down set from the SVT on change detection performance, it was important to ensure that a change could be detected without the addition of the SVT, and that any change was not too easy to detect as this may undermine any effects of the carry-over. A selection of features was therefore piloted in a change detection task in order to select two that would be used for the future experiments.

Although the SVT is not an example of the most basic visual search task (search for a feature singleton), the search features were selected on the assumption that they were ‘basic features’ (Wolfe, 1994) and attention could be allocated to these features selectively. The intention was to use two search features, therefore in the first pilot study three feature pairs were chosen; colour and shape, height and width, and spatial frequency and orientation. It is generally accepted that colour is a basic search feature and studies show that observers can selectively attend to a subset of colour (e.g., Egeth et al., 1984; Kaptein et al., 1995). Wolfe also suggests that orientation and size are basic search features. Size was manipulated by altering the height of an item, or the width of an item. Orientation was paired with spatial frequency, using grating patterns with different spatial frequencies, with the gratings slanting to the left or the right. Wolfe suggests that spatial frequency is similar to size in basic visual search, and cites work by Sagi (1988) which agrees with this. In addition, previous research has shown that the spatial frequency and orientation of centrally located grating patterns can influence detection of peripherally located grating patterns (Rossi & Paradiso, 1995). Specifically, when a participant is asked to detect the orientation of a central grating pattern they are more sensitive to the same orientation of peripheral grating patterns, and when a participant is asked to respond to the spatial frequency of a central grating they are more sensitive to similar spatial frequencies of peripheral gratings. However, Rossi and Paradiso also found that when responding to spatial frequency, the orientation of the central grating could not be ignored and it also enhanced performance for orientation search in the peripheral gratings.

As there was a different pattern of performance for orientation and spatial frequency it indicates that spatial frequency may not be a basic feature. However, given the success of this previous study in showing selective attention to features, and transference of this selective attention to additional visual images, the feature pairing was retained for the pilot study.

In his 1994 paper Wolfe does not describe shape as a basic feature, however he later described it as a "probable guiding attribute" (Wolfe & Horowitz, 2004) illustrating that there is uncertainty regarding whether it can be defined as a basic feature. However, like the findings of spatial frequency reported by Rossi and Paradiso (1995), Ghirardelli and Egeth (1998) found that shape could guide visual attention. If participants were told the shape of a target before completing a search task only distracters matching that shape interfered with target detection. Yet when participants were not told which shape the target would be before the search array was presented they suffered interference from all distracters equally. As in the previous instance, shape was retained as a feature because there is evidence to suggest that it can influence the allocation of attention, despite the fact that it may not be a basic feature.

Change detection performance was therefore measured for six features (making up three feature pairs). The ideal feature pair would be one in which change detection performance was relatively equal for both features, and that the change was fairly difficult to detect (to allow for possible benefits of a congruent SVT to be determined). Participants completed three blocks of trials, one for each feature pair.

5.5.2 Method

5.5.2.1 Participants:

Sixteen participants completed the experiment, seven males and nine females. All were aged between 19 and 28 with a mean age of 21.8 years. All reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

5.5.2.2 Design

The study used a within-participants design with two variables, the first was *feature pair*, and the second was *feature*. *Feature pair* represented the three pairs of features which were combined in each block; these were height and width, colour and shape, and spatial frequency and orientation. *Feature* referred to the two different features within each *feature pair*. The dependent variables were accuracy in locating the changing item, and RT to detect the change.

5.5.2.3 Apparatus and Stimuli:

A total of 384 visual arrays were used for the experiment; 192 original arrays and 192 modified arrays. Each modified array was identical to an original array with a single item changed. The arrays consisted of 16 shapes on a white background, placed at one of 25 locations within an invisible 5x5 grid. Each array measured 20.8°, and each individual item measured a maximum of 3.3°. In the height-width block the shapes were black rectangles and were either ‘short and wide’, ‘tall and wide’, ‘short and narrow’, or ‘tall and narrow’. In the colour-shape block the shapes were a mixture of diamonds and triangles and were coloured blue or purple with a black outline of 2mm. In the spatial frequency-orientation block the shapes were all circles filled with black and white bars (similar to a sinusoidal grating pattern); spatial frequency was either low (1.5 cycles per degree) or high (3 cycles per degree) and the bars were either slanting 30º to the left or 30º to the right.

Items were placed within the grid in a pseudorandom manner. Locations (1-25) were assigned to each item for each array; items in an already occupied location were moved to the nearest available location and 9 locations were left unoccupied. There were never more than 5 or less than 3 identical items in any array. The type of change was pre-selected at random, ensuring that there were an equal number of changes made to each of the four different items within each block. See figure 5.1 (page 161) for an example of the images used in the experiment.

5.5.2.4 Procedure:

The 192 trials each began with a black fixation cross shown to the centre of the screen for 500ms. After this an original array was shown for 3000ms[11]. A blue blank screen then replaced the original array for 200ms and following this the original array was shown for a further 500ms. A blue blank screen was again shown for 200ms before the matching modified array was presented for 500ms. The two arrays then continued to alternate (separated by the blue blank screen and presented for 500ms each time), until participants had successfully located the change in the array. Once the change had been found participants were told to press the spacebar, they then saw a response screen separated into five numbered sections (these sections corresponded to the horizontal rows of stimuli in the arrays). They had to press numbers 1-5 to state which row the changing shape had been located. After making a response feedback

[11] The original array was shown initially to represent the display of an array in the SVT task. In the pilot studies participants were simply told to view this array and no response was required, however it was important to set up the study in a similar way to later experiments to ensure that any carry-over effect was due to the search required in the SVT, and that additional effects of the display were controlled for in this baseline measure of change detection performance.

was provided for 400ms before the next trial began. See figure 5.2 on page 163 for the sequence of events in every trial.

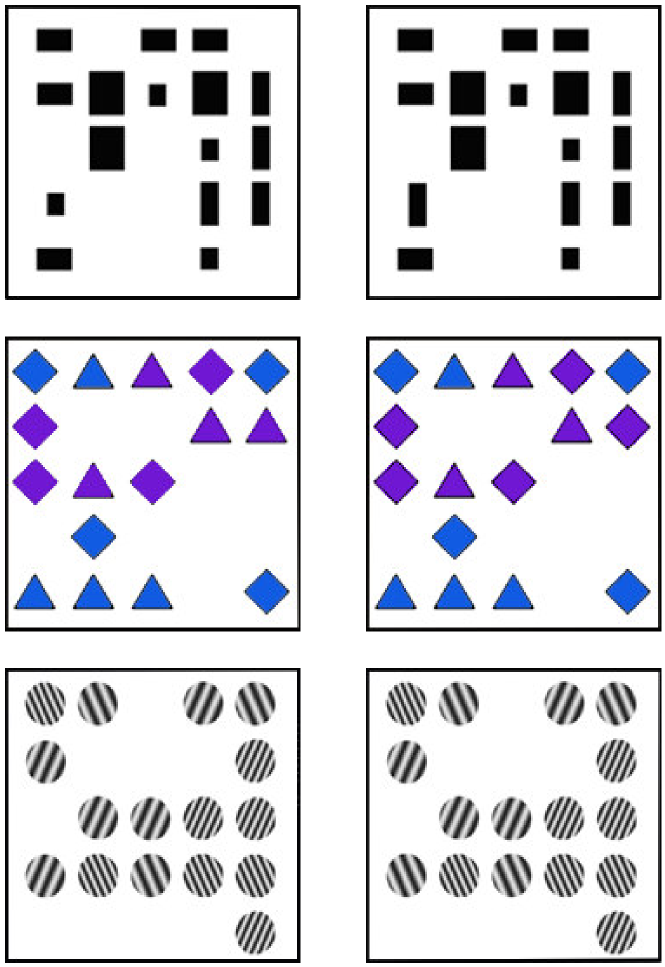

Figure 5.1: Examples of the original and modified arrays used in the experiment. The uppermost arrays were used in the height-width condition, here the change is to the first item on the fourth row and is a height change. In the colour-shape arrays the change has been made to the last item on the second row and this is a shape change. In the spatial frequency-orientation arrays the first circle on the fourth row has changed its orientation, with the bars moving from right to left.

Trials were separated into three blocks (colour and shape, height and width, and spatial frequency and orientation) and the order of these blocks was randomised across participants. This allowed 64 trials for each feature pair. There were four different items in each array and each item could change in two different ways (see table 5.1), in 32 of these trials items changed by feature 1 (e.g., colour), in the other 32 trials items changed by feature 2 (e.g., shape). As there were a total of 8 possible changes in each array, each change-type occurred 8 times in each block. All trials were presented randomly.

Block	**Original**	**Change (feature 1)**	**Change (feature 2)**
Height-Width	Short and wide	Tall and wide (H)	Short and narrow (W)
	Tall and wide	Short and wide (H)	Tall and narrow (W)
	Short and narrow	Tall and narrow (H)	Short and wide (W)
	Tall and narrow	Short and narrow (H)	Tall and wide (W)
Colour-Shape	Blue diamond	Purple diamond (C)	Blue triangle (S)
	Purple diamond	Blue diamond (C)	Purple triangle (S)
	Blue triangle	Purple triangle (C)	Blue diamond (S)
	Purple triangle	Blue triangle (C)	Purple diamond (S)
Spatial frequency-Orientation	Low SF left	High SF left (SF)	Low SF right (O)
	High SF left	Low SF left (SF)	High SF right (O)
	Low SF right	High SF right (SF)	Low SF left (O)
	High SF right	Low SF right (SF)	High SF left (O)

Table 5.1: The possible changes that could be made to items in the experiment separated into the three *feature pairs*. Changes made to feature 1 were height (H), colour (C), and spatial frequency (SF), changes made to feature 2 were width (W), shape (S), and orientation (O).

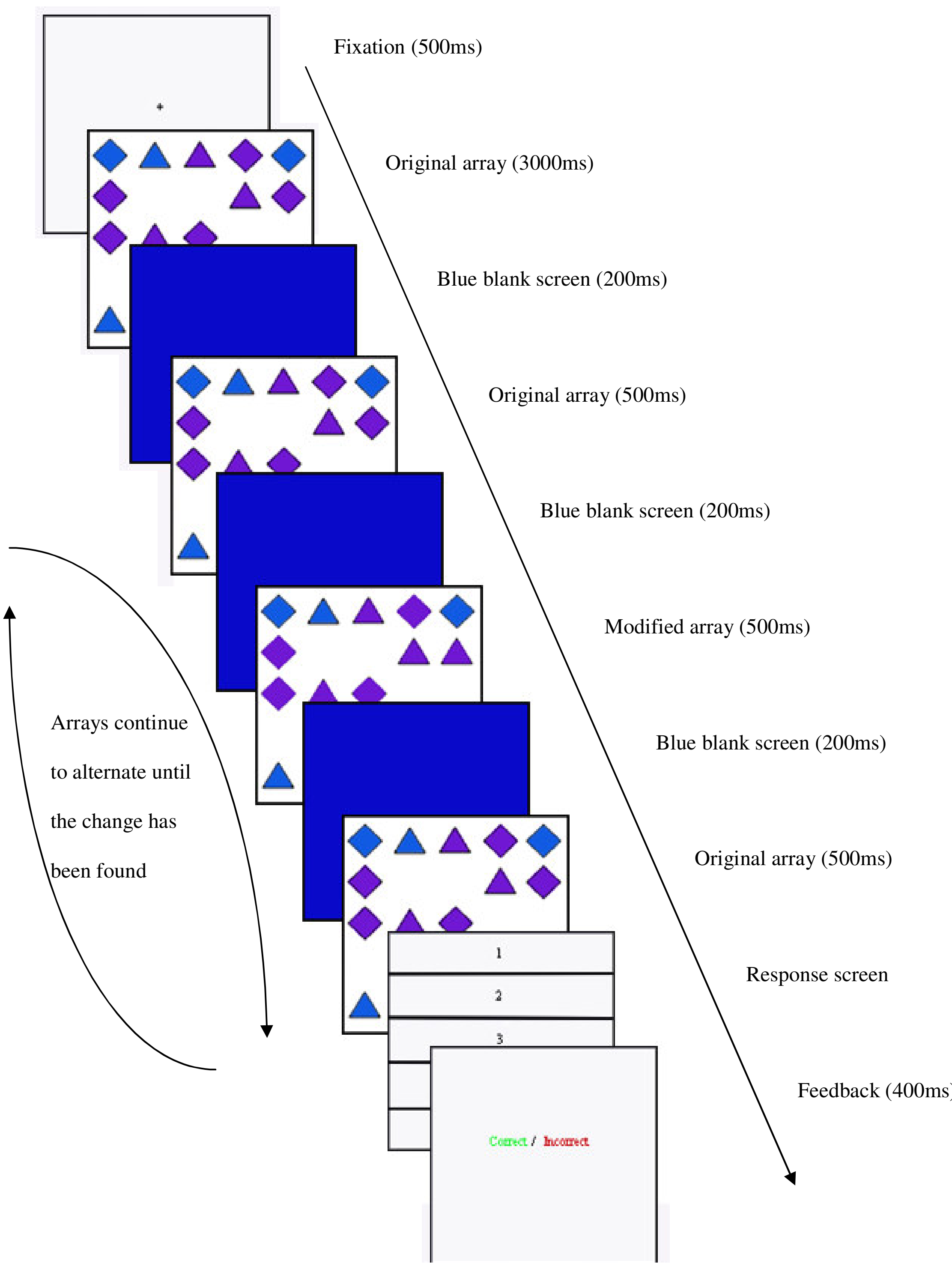

Figure 5.2: The temporal sequence of events in Experiment Six.

5.5.3 Results

Analysis consisted of two 1x3 within-participants ANOVAs which compared accuracy and RT between the three *feature pairs*. Paired samples t-tests were then carried out to compare the two *features* within each *feature pair*. Prior to the analysis any responses made before 800ms[12] and after 30 seconds were removed from the data. In addition, a correlation was conducted for each condition to check for any speed-accuracy trade-off. This showed no relationship between accuracy and speed, indicating that participants were not completing the experiment using a specific strategy whereby they place more emphasis on accuracy (and are therefore slower) or speed (and are therefore less accurate).[13]

For change detection accuracy there was no significant difference between the three *feature pairs*, and performance was reaching an average of 98%. This level of accuracy is standard for a change detection task, and accuracy is not often used as a dependent measure in most flicker paradigms. Incorrect trials were removed from the analysis at this stage, following the practice of previous flicker experiments cited in the literature. For RT to correctly detected changes there was a main effect of *feature pair* ($F(2,45) = 31.570$, $MSE = 2.213$, $p<0.001$). Post-hoc comparisons using the Bonferroni correction showed that RT in the spatial frequency-orientation block ($\bar{x}$ = 9.43 seconds) was significantly longer than RT in the other two blocks ($p<0.016$). RT in the height-width block ($\bar{x}$ = 5.47 seconds) did not differ from RT in the colour-shape block ($\bar{x}$ = 6.3 seconds). There was no significant difference between the two *features* within each *feature pair* with regard to accuracy, and there was no

[12] The modified array did not appear on the screen until 700ms after the first presentation of the original array and the blue blank screen, therefore a change could not have been detected before 800ms.

[13] These steps were taken for all subsequent experiments using the visual search-change detection methodology, but will only be mentioned again in instances where outliers (or a relationship between speed and accuracy) were found in each experiment.

difference in RT between height and width. Participants were however detecting a colour change faster than a shape change (t (15) = -2.355, $p<0.05$), and were detecting a change to spatial frequency faster than a change to orientation (t (15) = -4.732, $p<0.001$). See figure 5.3 for these findings.

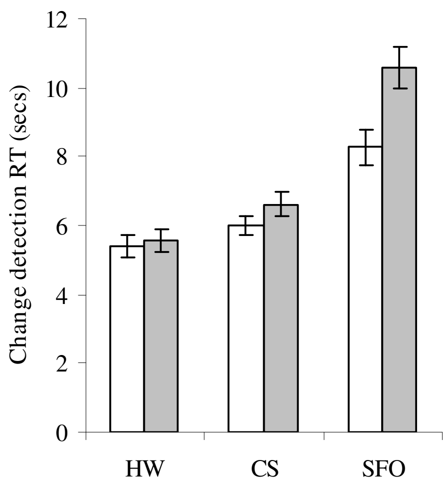

Figure 5.3: Mean change detection response times for each *feature* within each *feature pair*, height and width (HW), colour and shape (CS), and spatial frequency and orientation (SFO).

5.5.4 Discussion

The aim of the pilot study was to measure change detection of six features separated into three feature pairs. This was in order to select a feature pair to use for subsequent experiments in this area. Change detection had to be sufficiently difficult to warrant focused attention, and to ensure that any carry-over from the SVT could be measured. Three feature pairs were contrasted and findings showed that changes to height and width were possibly too easy to detect and changes to spatial frequency and orientation were possibly too difficult to detect. Whilst this did not reveal itself in the accuracy data, changes to spatial frequency and orientation took significantly longer to detect than changes made to the other two pairs of features. Although it was necessary to use features which required focused attention, if the changes take a long time to find it will prolong the experiment, reducing the number of trials which can be completed. The pairing of colour and shape was therefore selected as the most suitable for the subsequent experiments.

Aside from determining the most appropriate feature pair to use for later experiments, the pilot study did raise one interesting finding which was that an orientation change was more difficult to detect than a spatial frequency change. According to Wolfe (1994) orientation is a basic feature, and Rossi and Paradiso (1995) have demonstrated that whilst participants can selectively attend to spatial frequency, attention is allocated to orientation regardless of the task demands. In light of this it would be expected that an orientation change would be easier to detect. The present finding may have been due to the stimuli used in the experiment, as it is difficult to quantify if changes to orientation were as substantial as changes made to spatial frequency. Yet it implies that orientation may only be defined as a basic feature when it is presented as a single feature, and not part of a feature conjunction. To illustrate, in visual search studies cited in the literature, a search for orientation involves a search for a single line which is slanted to the left or right. In the present search task orientation was part of an object that could be defined on the basis of two separate features, or a conjunction of features. In this latter instance it may be more difficult to search selectively. This suggestion would of course require additional investigation, and whilst the finding does have implications regarding the requirements to be defined as a ‘basic feature’, these implications are not directly related to the focus of this thesis.

5.6 Experiment Seven: Piloting the detection of colour and shape changes

5.6.1 Rationale of Experiment Seven

The first pilot study in this section indicated that shape and colour were appropriate features to use for the visual search tasks outlined (the SVT and the change detection task). Following this a second pilot study was conducted to specifically test change detection of colour and shape using a larger number of feature values. Using two values of each feature in the initial pilot (Experiment Six) was suitable for selecting a feature pair and the visual arrays for this first study were produced relatively quickly. However in subsequent experiments more trials would be necessary and having two feature values limits the number of changes that can be made (and expected by the participants), therefore a greater number of feature values were required. Stimuli were produced to meet this requirement, and to check that a change blindness effect could still be elicited a second pilot study was conducted. This would also provide a baseline measure of change detection performance.

The overall aim of the visual search experiments in this thesis was to investigate the carry-over of attentional set between two different tasks. The AB experiments provide evidence for the carry-over effect but due to the similarity of the two RSVP tasks it may be presumed that carry-over was more likely in this situation. Exploring the effect across two tasks with substantially different aims would therefore provide greater information regarding the conditions under which the effect will occur. In the AB studies the stimuli were identical between the two tasks and the task instructions were very similar. In the forthcoming visual search experiments the stimuli will again be identical but the two tasks that comprise each trial will be different. Providing that carry-over could be found in this initial scenario (Experiment

Eight; same stimuli, different task) a long-term aim for the visual search studies was to further increase the differences between the tasks by also altering the stimuli (different stimuli, different task). This would again allow more evidence to be obtained regarding the conditions for carry-over. In preparation for this, whilst measuring baseline change detection performance to a new set of stimuli with an increased number of feature values, the second pilot study will also measure baseline change detection when the change detection arrays are the same as (static), or different (jumbled) to the initial array (this would be the SVT array but in this pilot study there is no SVT, participants simply view the array prior to the change detection task).

5.6.2 Method

5.6.2.1 Participants:

Fourteen participants completed the experiment (11 females and 3 males) for a payment of £5. All were aged between 18 and 30 with a mean age of 24.9 years, and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

5.6.2.2 Design:

The experiment used a within-participants design with two variables; *change feature* and *array*. The ability to detect shape and colour changes was compared using the variable of *change feature*. *Array* corresponded to the difference between the array initially presented (the SVT array) and the arrays used in the change detection task. In the static condition the same array was used (with one modification for the change detection task), and in the jumbled condition the arrays were different (they had the same targets but different distracters and all targets were in different locations). See figure 5.4 for an illustration of this variable in the trial sequence. The measures taken were accuracy and RT to detect the change.

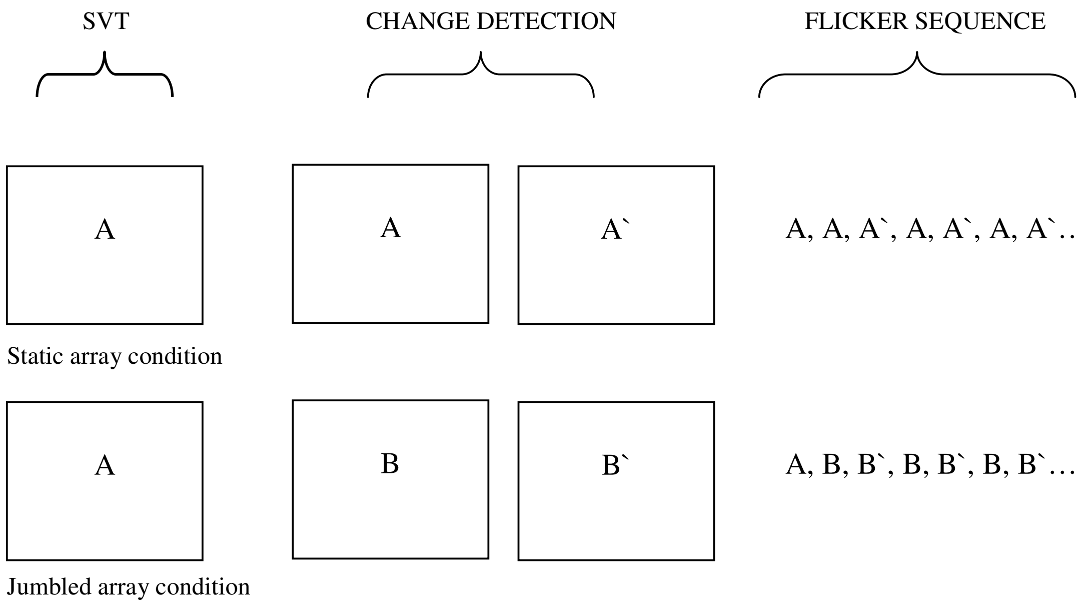

Figure 5.4: An illustration of the trial layout for the variable of *array.* In a static condition participants would see the same array in both the SVT and the change detection task. In the jumbled condition participants would see different arrays for both tasks. The terminology used (A, A`, B, and B`) is taken from Rensink et al. (1997). Note that when referring to the SVT in the current study this simply means that the array was presented; participants did not have to respond to this array.

5.6.2.3 Apparatus and Stimuli:

Stimuli consisted of 500 arrays. There were 200 original arrays, a further 100 arrays were identical to 100 of these originals but with one item changed (static condition). Another 100 arrays were used for the change detection task in the jumbled condition (which had the same targets as the original array [but in different locations] and different distracters to the original array), and one item was changed in each of these to make the matching modified arrays. Each array contained sixteen coloured shapes placed at one of 25 locations within an invisible 5x5 grid. There were five shapes (square, triangle, circle, pentagon, and diamond) and five colours (red, yellow, green, blue, and purple). The shapes were completely filled with colour with a black outline of 2mm. Each item measured a maximum of 35mm x 35mm and was at least 10mm away from a neighbouring item. Each array measured 20.8°, and each individual item measured 3.3°.

Items were placed within the grid in a pseudorandom manner. Locations (1-25) were assigned to each item for each array; items allocated to an already occupied location were moved to the nearest available location and 9 locations were left unoccupied. In each array there was at least one of each shape and one of each colour. There could never be more than 4 of any one shape or colour and there were never more than two items sharing both the same colour and the same shape. Once the change had been made there were still never more than 4 of each shape or colour in the array. See figure 5.5 for an example of the images used.

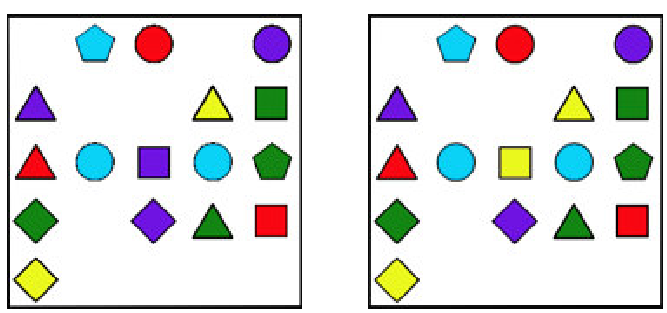

Figure 5.5: Examples of images used in Experiment Seven. Here the change has been made to the item in the very centre of the array and it is a colour change.

5.6.2.4 Procedure:

Every trial began with a black fixation cross shown in the centre of the screen for 1000ms. An array was then presented for 3800ms[14]. A blue blank screen was then shown for 200ms followed by either an identical array (static) or a different array (jumbled) for 500ms. The blue blank screen was again shown for 200ms before the second array was shown again with one item changed. The arrays continued to alternate (separated by the blank) until the change had been found. Participants were asked to view the initial array and when the display began to 'flicker' they should try to find a change as quickly as possible. Once the change had been found participants pressed the spacebar and were then asked to state which row (1-5) the change had been located on. On-screen feedback was then provided for 400ms. There were 100 trials in the static array condition and 100 trials in the jumbled array condition. Of these trials half involved a shape change and half involved a colour change. Wherever possible there was always the same number of changes from one feature value to another (for example there was the same number of trials in which an item changed from red to blue as there were in which an item changed from red to purple). All trials were presented randomly.

5.6.3 Results

Analysis consisted of two 2 (*change feature*) x 2 (*array*) ANOVAs. For accuracy there was a significant effect of *change feature* ($F(1,13) = 12.519$, $MSE = 3.566$, $p<0.01$) and a significant effect of *array* ($F(1,13) = 13.702$, $MSE = 3.258$, $p<0.01$). There was also an interaction between the two variables ($F(1,13) = 7.951$,

[14] Preliminary testing showed this to be the average time it took to search for a particular colour or shape within an array (SVT task).

MSE = 3.962, $p<0.05$). Accuracy was higher to colour changes ($\bar{x}$ = 98%) than to shape changes ($\bar{x}$ = 96.5%), and accuracy was higher in the jumbled condition ($\bar{x}$ = 98%) than in the static condition ($\bar{x}$ = 96.5%). However, the effect of *array* only existed for a shape change with means of 98% and 95% for the jumbled and static conditions respectively, compared to a colour change which showed an average of 98% correct in both conditions. For RT there was a significant effect of *change feature* but no effect of *array*. Again a colour change ($\bar{x}$ = 6.3 seconds) was easier to detect than a shape change ($\bar{x}$ = 7.7 seconds; $F(1,13) = 42.217$, *MSE* = 0.614, $p<0.001$).

5.6.4 Discussion

Using a wider variety of feature values did not increase the average time it takes to detect a change, and consistent with the previous pilot study, a difference was found between the change detection of shapes and colours. Participants were more accurate at detecting colour changes and faster to detect colour changes than shape changes. This fits with claims that colour is a basic search feature whilst there is disagreement over whether shape is a basic feature (Wolfe, 1994). Initially the aim across the two pilot studies was to select two features which were comparable; however the variation in difficulty may result in some interesting findings for the carry-over effect. For example, it may be the case that when focused attention is given to the second task, and greater top-down control is exerted over this task, any carry-over from an initial task may be overridden. This suggestion is similar to the findings regarding the persistence of a habitual behaviour (Reason, 1984); a habitual behaviour will only be triggered in an inappropriate situation if an individual is not focusing attention on the task at hand. Focused attention therefore prevents any intrusion of the habitual behaviour. If it is more difficult to find a shape change this may require more top-down control and greater resources, in which case any carry-over effect may be attenuated. This difference can therefore be used to an advantage.

One further important finding is that the variable of *array* had a significant influence on accuracy to detect shape changes. Accuracy was lower when the array was consistent (static condition) across both the initial viewing and the change detection task (with the exception of the change made to the modified array). The purpose of including the variable of array was to provide a baseline measure of change detection performance with no preceding SVT. It is predicted that in the forthcoming experiments the attentional set established for the SVT will persist to the change detection task and influence accuracy and RT, therefore it was important to determine the level of performance without the addition of this task. This second pilot study already suggests some form of carry-over because accuracy to detect a shape change was reduced in the static condition in comparison to the jumbled condition, even though participants were given no task to perform when first viewing the array for 3800ms.

One possible explanation for this finding is that participants focus on colour in the initial viewing (because it is easier to process than shape) and as such a change to colour is easier to detect than a change to shape because shape is inhibited. This does account for the difference in performance for the two features, but it does not explain the interaction between *change feature* and *array*. Alternatively it may be the case that participants put more effort into encoding shape in the initial viewing (because it is harder to process) in order to allow for an explicit shape comparison when the arrays start to flicker. This strategy will make a shape change more difficult to detect in the static condition because participants are attempting to hold the shapes in memory and make a comparison. Whereas in the jumbled condition they may simply abandon any memory for the initial array (assuming it has no benefit), allowing them to compare the two arrays without any intrusion of an explicit memory. As colour is a basic feature and can be processed easily the effect is only found for shape changes.

5.7 Conclusion of the two change detection pilot studies

This chapter has outlined some of the important issues in visual search and change detection, setting out the aims of the experiments which will be completed using these two areas of study. As a starting point two pilot experiments were conducted to test a variety of stimuli in the change detection task. These experiments revealed that shape and colour were appropriate features for the task, they could both elicit the well known change blindness effect, and there was a clear difference in change detection for each feature, with colour changes being easier to find. Although this was initially viewed as a problem, further reflection shows that this may provide a greater understanding of the conditions under which carry-over will occur.

Chapter Six: Visual search influences attention in a subsequent change detection task

6.1 Overview of Chapter Six

In this chapter two visual search experiments will be presented. In both studies a SVT will precede a change detection task and change detection performance will be measured in relation to whether the change was made to a relevant or irrelevant item from the previous SVT. The aim of both experiments was to measure the carry-over of attentional set from the SVT to the change detection task, the main difference between the studies being that in Experiment Eight the visual displays in both tasks were always identical (static) and in Experiment Nine the visual displays in both tasks could be the same or different (static or jumbled). The first experiment provided evidence for the carry-over effect; and to further study the characteristics of the set that carried over (specifically whether the carry-over was location-dependent) the second experiment was conducted to find if the effect could be replicated when the arrays were different in both tasks. The results from each study will be outlined, and after both experiments have been presented there will be a detailed discussion of what the key findings can reveal thus far about the allocation of attention using an attentional set and the carry-over of an attentional set.

6.2 Experiment Eight: The influence of visual search on later change detection

6.2.1 Rationale of Experiment Eight

This experiment was the first attempt to study carry-over between two tasks that involved identical stimuli but had different goals and task instructions. Using the features selected on the basis of the pilot studies the experiment compared change detection of shapes and colours when preceded by a SVT that required a search for either shape or colour. This meant that a change could be made to a target or distracter from the previous SVT. It was predicted that changes made to previous targets would be detected faster than changes made to previous distracters. For example, if blue shapes are the focus of the SVT, changes made to blue shapes should be detected faster than changes made to shapes of a different colour.

This prediction has been made based on previous findings showing the importance of top-down factors in the guidance of attention, and the carry-over of attentional set from one task to another. Folk and colleagues (Folk et al., 1992; Folk et al., 1994; Folk & Remington, 2006) suggest that a visual search is completed with the use of an attentional set which prioritises attention to task-relevant stimuli. The attentional set is established based on task instructions and expectations, and target-defining features are determined. In the present set of experiments it is hypothesised that participants will adopt an attentional set to complete the SVT. Participants will be given the 'target-defining' features prior to the search, therefore they will be able to selectively search for items which share these features (utilising the attentional set). Similar to the findings of Leber and Egeth (2006) and the results of the AB experiments outlined in Chapters Two to Four of the present thesis, this set is expected to persist to the change detection task, therefore once again attention will be directed to items matching the target defining features of the SVT, resulting in faster change detection of previous targets compared to previous distracters.

The design of the experiment also allowed for a change to be congruent or incongruent to the search feature in the SVT. For example, if participants are asked to search for blue shapes this should induce a search for colour (as opposed to shape), a change to a blue shape would be a 'target' change, but if this change was a colour change (e.g., from blue to green) it would be congruent with the search feature. If the change was however a shape change (e.g., from a blue triangle to a blue diamond) it would be incongruent with the search feature[15]. It has long been assumed that when attention is allocated to a specific spatial location, or a specific object in space, all attributes of the location/object are processed equally (Duncan, 1984; Kahneman & Treisman, 1984). This conclusion was based on findings showing that when responding to a single dimension in a multi-dimensional object the other dimension(s) interfere with responses (for example in the Stroop task).

In a spatial cuing paradigm Remington and Folk (2001) tested this by asking participants to respond to one of two stimulus dimensions (and ignore the other dimension) after being cued to one of four target locations. In two locations a neutral distracter was presented, a foil was presented in a third location and the target appeared in the final location. The foil could either be compatible or incompatible with the relevant target dimension, and they found that when attention was cued to the location of the foil, interference with target identification only occurred when the foil was compatible with the relevant target dimension. They propose that this offers evidence for selective attention to relevant features within a multi-dimensional object, and shows that attention was biased towards the relevant dimension due to the top-

[15] These two levels of *feature congruence* are the same for changes made to previous targets and changes made to previous distracters.

down attentional set. It is therefore predicted that in the present set of experiments, congruent changes will also be detected faster than incongruent changes. To summarise, it is predicted that carry-over of attentional set will be observed through (a) faster detection of changes made to previous targets from the SVT in comparison to changes made to previous distracters; and (b) faster detection of changes for which the feature that changes (shape or colour) is congruent to the search feature in the SVT.

6.2.2 Method

6.2.2.1 Participants:

Sixteen participants (14 females and 2 males) took part in the experiment for a payment of £5. All were aged between 18 and 32 with a mean age of 23.5, and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

6.2.2.2 Design:

A within-participants design was used with three independent variables; *search feature*, *target congruence* and *feature congruence*. *Search feature* referred to the target feature in the SVT; this could be colour or shape. *Target congruence* referred to the item that was changed in the change detection task: the change could either be to one of the targets (a congruent change) or to one of the distracters (an incongruent change) from the previous visual search. For example if participants were asked to search for triangles in the SVT and a triangle changed either shape or colour in the change detection task this would be a ‘target change’. A ‘distracter change’ might involve a colour or shape change to one of the squares in the display. *Feature* *congruence* corresponded to whether the changed item was changed by the search feature involved in the SVT (congruent) or by the non search feature (incongruent), see table 6.1 for an example. Accuracy and RTs were recorded for the SVT and the change detection task.

	Search feature	Colour		Shape	
	Target congruence	Target	Distracter	Target	Distracter
		Example: There are 4 green items		Example: There are 3 squares	
Feature congruence	Congruent	green square changes to yellow square	red circle changes to blue circle	blue square changes to blue triangle	blue circle changes to blue diamond
	Incongruent	green diamond changes to green pentagon	purple circle changes to purple diamond	red square changes to yellow square	yellow triangle changes to green triangle

Table 6.1: Examples of the types of changes that can be made in each experimental condition

6.2.2.3 Apparatus and Stimuli:

Stimuli consisted of 480 arrays. 240 original arrays were for the SVT and one item was changed in each to make a further 240 modified arrays for the change detection task. The arrays were produced in the same way as those for Experiment Seven, with the addition that the shape and colour of the targets in the SVT was based on the trial conditions. Distracter colour and shape was then determined using pseudorandom sampling based on the rules given. To control for differences between items (e.g., luminance of different colours) there were the same number of trials in which the targets were made up of a combination of each possible colour (or shape). In the change detection arrays the location of the change was chosen at random, depending on whether the change item was a previous target or distracter in the preceding SVT. The type of change made (shape or colour) was governed by the condition of the trial, but wherever possible there was always the same number of changes from one feature value to another (for example there was the same number of trials in which an item changed from red to blue as there were in which an item changed from red to purple). Once the change had been made there were still never more than 4 of each shape or colour in the array. If a distracter changed shape or colour it would never to change to the specific target shape or colour.

6.2.2.4 Procedure:

Every trial began with the SVT. A black fixation cross was shown in the centre of the screen for 1000ms followed by a visual search statement regarding the following visual array. The statement involved 3 or 4 targets, for example, “there are 4 green items”, or “there are 3 squares”. After 1000ms the SVT array was shown and participants had to respond TRUE or FALSE to the statement by pressing marked keys on the keyboard. When participants had completed the SVT they were given on-screen feedback for 400ms. The same array was then shown again for 500ms followed by a blue blank screen for 200ms and then the matching ‘modified’ array for 500ms. The trials then continued in the same manner as those in Experiment Seven. There were 240 trials in total; in the SVT 120 trials involved a colour search and 120 involved a shape search, and there were 24 trials for each individual colour or shape. Of these 24 trials there were 12 trials for each number of targets (3 or 4), 6 of these trials required a FALSE response, and 6 required a TRUE response. In the change detection task there were 30 trials for each *search feature* (colour or shape) for each *target congruence* (target or distracter), at each level of *feature congruence* (congruent or incongruent). All trials were presented randomly and participants received no information about the set-up of the trials other than the fact that they had to search for shape and colour and then search for a shape or colour change; they had no probabilistic information regarding the type of change that would take place, but were told that the search task was not predictive of the change detection task.

6.2.3 Results

6.2.3.1 Sentence Verification Task:

The SVT was analysed using t-tests for accuracy and RT; comparing a search for shape with a search for colour. On average participants were responding correctly to the SVT 91% of the time. However participants were responding correctly to colour more often than shape (t (15) = 7.671, p<0.001; with means of 96% vs. 86% respectively). Reaction times to correct trials also showed a difference between the two search features (t (15) = -10.769, p<0.001). Participants were responding quicker to colour ($\bar{x}$ = 1.6 seconds) than to shape ($\bar{x}$ = 3.7 seconds).

6.2.3.2 Change detection task:

The change detection task was analysed using two 2 (*search feature*) x 2 (*target congruence*) x 2 (*feature congruence*) ANOVAs. Responses to this task were only analysed if participants had responded correctly to the preceding SVT; any trials in which an incorrect response was given to this first task were removed (9% of all trials completed). Incorrect change detection trials were taken out, and any trials in which correct responses were made in less than 800ms or more than 30 seconds were also removed. In total the number of trials removed accounted for 17% of all trials completed. The number of trials removed did not vary according to the independent variables under investigation. Accuracy to the change detection task was affected by *search feature* (F (1,15) = 17.360, *MSE* = 14.032, p<0.001), whereby searching for colour during the SVT led to higher accuracy of responses in the change detection task than searching for shape (means of 92% vs. 89%). The mean change detection performance across all trials was 91% therefore it appears that a shape SVT was reducing change detection accuracy. There was also an interaction between *search feature* and *target congruence* ($F(1,15) = 9.465$, $MSE = 30.604$, $p<0.01$). When a previous SVT target changed there was no difference in accuracy in relation to the *search feature*. However when a previous distracter changed, accuracy was higher when participants had been previously searching for colour ($\bar{x}$ = 93%) than shape ($\bar{x}$ = 87%) regardless of whether the changed feature was congruent with the *search feature*, see figure 6.1a on page 183. Again, in comparison to the average change detection accuracy, it seems that a shape SVT is having a negative impact on performance.

A further interaction was found between *search feature* and *feature congruence* ($F(1,15) = 6.425$, $MSE = 15.743$, $p<0.05$). Accuracy to congruent trials did not alter with regard to the *search feature*, however in incongruent trials the initial search feature did influence performance in the change detection task. When participants had been searching for colour in the SVT and the change made to the array was a shape change (C→S), accuracy was high ($\bar{x}$ = 92%). However when a colour change followed a search for shape (S→C) mean accuracy was lower (88%; see figure 6.1b on page 183). Once again, a colour SVT is having little impact, whereas a shape SVT is reducing accuracy in the subsequent change detection task.

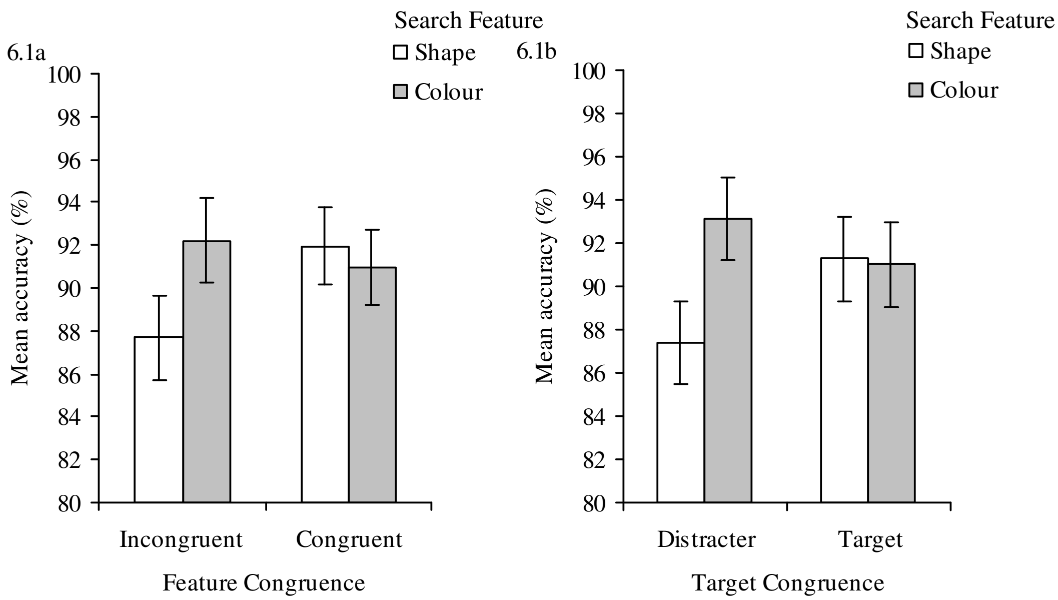

Figure 6.1: The interaction between *search feature* and *feature congruence* (a). Change detection accuracy was only different for each search feature when the change was incongruent. The interaction between *search feature* and *target congruence* (b): search feature only influenced detection of distracter changes.

A second 2x2x2 ANOVA on RT revealed main effects of *search feature* (F (1,15) = 29.816, *MSE* = 1.487, p<0.001), *target congruence* (F (1,15) = 11.744, *MSE* = 6.791, p<0.01), and *feature congruence* (F (1,15) = 6.277, *MSE* = 0.644, p<0.05). The average time it took to find a change was 6.8 seconds, however participants were faster at detecting a change if they had been previously searching for colour ($\bar{x}$ = 6 seconds) than shape ($\bar{x}$ = 7.5 seconds). Responses were also significantly faster to a change made to a previous target ($\bar{x}$ = 6 seconds) than to a change made to a previous distracter ($\bar{x}$ = 7.5 seconds), and responses to congruent trials ($\bar{x}$ = 6 seconds) were significantly quicker than to incongruent trials ($\bar{x}$ = 7.3 seconds).

The analysis also showed an interaction between *target congruence* and *feature congruence* ($F (1,15) = 5.448$, $MSE = 0.596$, $p<0.05$). When the change was made to a previous distracter participants were significantly slower when the trial was incongruent ($\bar{x} = 7.9$ seconds) compared to congruent ($\bar{x} = 7.2$ seconds). In comparison to this, when the changed item was a previous target performance did not alter with regard to *feature congruence* (see figure 6.2). Note that a congruent change made to a previous distracter did reduce RT, but the time it took to find the change was still longer than the average time taken to detect changes made to a previous target.

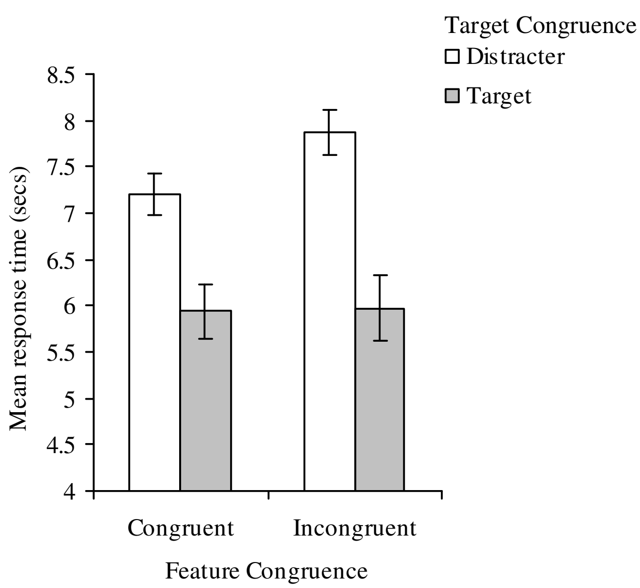

Figure 6.2: The interaction between *target congruence* and *feature congruence*. *Feature congruence* only affected RT when the change was made to a distracter.

6.2.3.3 Comparison to the previous pilot study

In Experiment Seven participants were correctly detecting changes in an average of 97% of trials and in an average of 7 seconds. Moreover participants were significantly quicker to detect changes made to colour ($\bar{x}$ = 6.3 seconds) than to shape ($\bar{x}$ = 7.7 seconds). Participants in the present study were performing substantially worse in the change detection task with regard to accuracy, only detecting changes in 91% of trials; however changes were detected slightly quicker, with a mean RT of 6.8 seconds. A further important difference was that participants were equally good at detecting changes made to both features (a mean of 6.8 seconds for a colour change and 6.7 seconds for a shape change). Although this second experiment involved a different sample of participants, and the design of the study was slightly different from the previous, it appears that the SVT is having an impact upon change detection performance. Specifically, it is decreasing accuracy but also decreasing RT, particularly to the detection of shape changes.

6.2.4 Discussion

Experiment Eight has shown that the attentional set adopted to complete the SVT persists to the change detection task and influences the allocation of attention, and therefore performance on this second task. In particular, participants were quicker to detect changes made to items that were targets in the preceding SVT compared to changes made to distracters, revealing that they allocated attention to previously relevant items first. If the change was made to a previous distracter participants were also faster to detect a change made to the feature that was congruent with the SVT search feature, in comparison to a change made to an incongruent feature. This not only shows that the set from the SVT carries over to the change detection task, it also shows that participants were selectively attending to specific features within an object without processing the object as a whole.

It is clear that the SVT reduced accuracy to the subsequent change detection task, therefore showing that the task had an overall carry-over effect whereby completing the first search task left fewer resources to complete the second. This is supported by the finding that a shape SVT resulted in lower accuracy and slower responses in the change detection task. If colour is definitively claimed to be a basic feature (e.g., Wolfe, 1994; Wolfe & Horowitz, 2004) it should be represented at a preattentive level, speeding attention to areas of high activation (which meet the target criteria) faster than in situations where no initial analysis can be used (shape). As a colour search is quicker and easier than shape (as evidenced by higher accuracy and faster RTs in the SVT) more resources are available once the task has ended, resulting in better performance in the change detection task.

There are countless studies which show that a colour search is very efficient, and many suggest that colour "pops-out" of the display (e.g., Pomerantz, 2006). Although most visual search literature supports the notion of pop-out, studies in this area generally investigate the effect using a colour singleton among homogenous distracters. The present experiment shows that colour search is efficient even when there is more than one target to search for, and these targets are presented among a heterogenous set of distracters.

Performance in the SVT is presumed to be the product of the top-down attentional set. The current results also indicate that the deployment of attention in the change detection task is also based on this preceding top-down set. Recall that participants are told that the targets in the SVT are not predictive of the change, and using the attentional set from this preceding task will have no overall benefit to performance, therefore it is carried over despite its irrelevance. As there are no bottom-up factors to guide attention in the change detection task, and no top-down information available regarding the change, it may appear that using the previous strategy is more useful than completing the task by making a serial search through the display. If this is the case, there will be little motivation to abandon the set used for the SVT once the task has been completed.

The results provide evidence that the attentional set from the SVT has persisted to the change detection task, but what are the specifics of this set? In particular, is it an excitatory set which facilitates activation of items matching the target-defining features (e.g., Folk et al., 1992)? Or is it an inhibitory set which facilitates target search by inhibiting anything which does not match the target-defining features (e.g., Olivers & Humphreys, 2003)? Consistent with an excitatory set, some studies provide evidence for facilitation at target locations (e.g., LaBerge, 1997), with an increase in attention near to the target locations. However others show evidence of inhibition of distracter locations. For example Cepeda, Cave, Bichot and Kim (1998) found that when searching for a coloured probe following a search for a coloured target among differently coloured distracters, detection was fast when the probe appeared in a previous target location, but slow when it appeared in a previous distracter location. This suggests inhibition of distracter locations rather than facilitation of target locations and it fits with the findings of visual marking (Watson & Humphreys, 1997). In the present experiment (contrary to the findings of Experiment Seven) overall change detection accuracy was the same for both features. Even though a colour SVT had little impact on change detection performance, the fact that a shape search reduced accuracy when detecting changes made to previous distracters argues in favour of inhibition rather than facilitation, as a facilitation account would predict that the accuracy in detecting shape changes would increase following a shape SVT. In addition, as RT in the change detection task increased when a previous distracter changed (compared to the mean), this also supports an inhibition account.

Whilst the actual task demands of the SVT did appear to influence change detection performance (in Experiment Seven overall change detection performance was better for colour than for shape[16], whereas in Experiment Eight performance is equal for both features), it was noted in the results section above that a colour SVT had little influence upon accuracy, whereas a shape SVT decreased accuracy. In addition to this when the change was incongruent to the search feature, a shape SVT reduced accuracy in detecting colour changes, but a colour SVT did not reduce accuracy to shape changes. In Chapter Five it was suggested that as a colour change was easier and quicker to detect than a shape change, change detection of colour would be influenced by carry-over more than change detection of shape. This is because shape change detection is more effortful and will therefore require greater top-down control. This fits well with the idea that focused attention will attenuate any intrusion of an irrelevant, but previously relevant behaviour (Reason, 1984). However, this finding can alternatively be explained by the amount of top-down control required for the SVT. As shape is a more difficult feature to search for it will require more resources, and greater top-down control. Consistent with the current findings of the AB experiments, greater investment in the initial attentional set will increase the chances that this set will persist to a second task. It may therefore be hypothesised that a shape SVT carried over and a colour SVT did not because the difficulty of a shape SVT search required more resources. This consolidated the attentional set, making the costs of changing set greater than the benefits. In comparison, as a colour search is much easier, a more 'passive' search may have been

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[16] This was accounted for by the proposal that participants search for colour changes first because they are easier to find (colour is easier to process) than a shape change.

conducted (e.g., Wolfe, 1994) which results in a less controlled, more flexible set, that is easier to modify or abandon when necessary (Olivers & Nieuwenhuis, 2005).

To summarise the findings so far; RT data showed that overall changes to previous targets were detected faster than changes to previous distracters, and congruent changes were detected faster than incongruent changes. This shows that the top-down attentional set from the SVT is influencing the allocation of attention in the change detection task. In particular it shows that attention is allocated to items (or locations) that were task-relevant in a previous instance, and also that attention is allocated to the feature (shape or colour) that was task-relevant previously. This is consistent with the findings of Remington and Folk (2001) that it is possible to selectively attend to a single feature within a multi-dimensional object whilst ignoring the irrelevant feature.

However, one critical finding from the study raises an interesting issue about these carry-over effects. Although congruence between the search feature and the change feature did influence the time it took participants to find the change, this was only when the change was made to a previous distracter; when the change was made to a previous target there was no difference in RTs between a congruent change and an incongruent change. This indicates that participants may have completed the visual search using two strategies; a strategy to search for *features* (shape and colour) and a strategy to search for *feature values* (triangle and circle, blue and green, etc.). As the 'set' to search for feature values is 'stronger' it carries over to a greater extent in the change detection task. The 'set' to search for features is weaker and carries over to a lesser extent, only impacting upon the change detection of previous distracters. Additionally, as the feature set only influenced change detection of previous distracters (and not targets) it implies that when searching through the previous targets participants were processing the item as an object, and not selectively processing one feature (congruent) at the expense of another (incongruent). When a distracter changed the changing item was not processed as an object, but was instead ‘parsed’ into a ‘relevant’ and ‘irrelevant’ feature (on the basis of the preceding SVT), and only the relevant feature was processed.

The SVT impairs accuracy on the change detection task, presumably because it results in some form of ‘resource depletion’ and this leaves fewer resources for change detection. This effect was greater following a shape SVT, which is consistent with the notion of resource depletion as a shape search takes significantly longer to complete than a colour search. A shape SVT impaired colour change detection, but a colour SVT did not impair shape change detection (this was found in the accuracy data of the change detection task). This may be because an attentional set for colour does not suffer from carry-over, or because the top-down requirements of detecting a shape change overrides the carry-over effect.

The first experiment completed using the visual search – change detection methodology has therefore found evidence for the carry-over of attentional set between two different visual search tasks. Although the visual arrays remained the same across both tasks the task demands were different, which should have motivated a change in set. This shows that carry-over occurs even when the top-down factors vary between the two tasks. The study has raised several issues regarding the characteristics of the attentional set; whether it is an excitatory or inhibitory set; and whether attention is allocated to features in addition to locations or objects. In addition to this the findings have also questioned the route of the carry-over; whether it is due to the resources invested in the original set (and therefore top-down control in the first task), or whether it is due to the level of control in the second task. The final two visual search – change detection experiments were completed to further investigate these issues.

6.3 Experiment Nine: The influence of visual search on later change detection when the visual stimuli differs across the two tasks

6.3.1 Objective of Experiment Nine

Experiment Eight addressed the issue of carry-over between two tasks which shared the same stimuli but involved differing instructions and task demands. The results from this experiment led to the following conclusions:

1. The attentional set established to complete the SVT does carry-over to the change detection task.
2. The influence of carry-over varies according to the difficulty of the visual search tasks.
3. Attention is allocated to both features and objects (or locations).

However, the results have also raised the following questions:

1. Does the attentional set facilitate target detection through activation of task-relevant information, or inhibition of task-irrelevant information?
2. Is carry-over reliant upon the amount of resources required for the first task, or the amount required for the second task?

3. Can top-down factors guide attention at a variety of levels (e.g., features, objects, and locations)?

Experiments Nine and Ten have been conducted to explore some of these issues, and the present experiment will focus upon the guidance of attention and whether attention in the SVT is deployed to objects or locations.

6.3.2 Evidence for space-based versus object-based attention

Space-based theories of attention (e.g., Eriksen & Eriksen, 1974; Eriksen & St James, 1986; Eriksen & Yeh, 1985; LaBerge & Brown, 1989; Posner, 1980) state that attention is guided to locations in space regardless of the objects contained in this space. Object-based theories of attention (e.g., Kahneman & Henik, 1981; Kahneman & Treisman, 1984) state that attention is directed to objects not areas of space, and argue that when attention is allocated to an object, all aspects of this object are processed (although see page 177 of this chapter for an alternative viewpoint). More recent work outlines a role for both space-based and object-based attention, dependent upon the task demands. For example, Vecera and Farah (1994) found that when participants were asked to report one or two dimensions from one of two overlapping objects they were equally quick to report one dimension as two. However, when participants had to report one dimension of each object performance was worse than reporting two dimensions from a single object. This indicates that they were processing the two overlapping objects as separate items and were not simply allocating attention to the objects as a whole. When the task demands changed and participants were asked to detect a dot appearing on one of the objects that was either validly or invalidly cued they found evidence for location-based attention; detection

RT did not vary according to cue validity. Vecera and Farah suggested that if the task requirements are simply to detect or identify a target location-based attention is used, however if the task involves greater processing and the target needs to be encoded object-based attention is used.

Soto and Blanco (2004) have also shown that attention can be directed both on the basis of locations, and on the basis of objects. Participants viewed trials in which 4 differently coloured circles were shown arranged around a cross-piece[17]. One circle was cued after which the circles appeared to 'move' across the screen as they were gradually occluded by the cross-piece on successive displays. The circles would either 'move' to a new location or back to their original locations and a target (a titled line) was then shown within one of the circles. This yielded four experimental conditions; the target could appear in the cued location and the cued circle, the cued location but an uncued circle, an uncued location and the cued circle, or in an uncued location and an uncued circle. In addition to these four conditions participants were split into two groups and the probabilities of spatially cued trials and object cued trials were altered for each group.

Results showed evidence for both object-based and space-based attentional selection as responses were faster to targets appearing in validly cued locations and validly cued objects (compared to invalidly cued targets). Additionally spatial cuing was more pronounced than object cuing and the object cue-validity effect only occurred when the spatial cue was invalid. A further finding showed that spatial cuing was modulated by task demands as the effect was enhanced when the probability of spatial cues was higher than object cues; object cuing did not vary across the two groups of participants. Together these results show that attention can be directed to

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[17] This was experiment one in a two-experiment paper.

objects and locations, they also show that location-based allocation of attention may be favoured over object-based attention, with attention initially directed to locations before objects. This fits with suggestions made by other researchers that space-based attention is ‘primary’, for example Tsal and Lavie (1988).

6.3.3 Rationale and predictions for Experiment Nine

Although recent evidence shows that selective attention can be allocated to objects and locations, it is still important to determine which mode of allocation is being used in the present instance. This is to gather further information regarding the characteristics of the attentional set (used for the SVT), and to establish how attention is guided through the (change detection) visual display following the persistence of this set. Experiment Nine will directly assess whether attention is directed to objects or locations using the variable of *array* (as manipulated in Experiment Seven). In half the trials the arrays will be the same in both the SVT and the change detection task (static) and in half the trials the arrays will be different (jumbled). Adding this variable into the experiment would substantially increase the length of the study, and as a result the variable of *search feature* was removed in this experiment, and participants were only ever asked to search for shape in the SVT. In every trial participants were asked to search for a specific shape among a series of distracters, and then asked to detect a change which would either occur to a target or distracter, and would either be congruent to the SVT (a shape change) or incongruent (a colour change). In half the trials the arrays remained identical across both tasks (static), however in the remaining trials the arrays were different and the targets were always presented in a different location (jumbled).

If the set that carries over is location-specific, detection of changes made to previous targets will only be faster than changes made to previous distracters in the static condition. However if the set is independent of location a carry-over effect will be apparent in both conditions. If attention is directed to features in addition to objects (or locations) the congruency effect will also be found in both conditions. The experiment will therefore provide evidence to show whether the carry-over effects are location-specific.

6.3.4 Method

6.3.4.1 Participants:

Sixteen participants (12 females and 4 males) took part in the experiment for a payment of £5. All were aged between 18 and 30 with a mean age of 24.5, and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

6.3.4.2 Design:

A within-participants design was used with three independent variables; *target congruence, feature congruence* and *array*. *Array* referred to the difference between the SVT arrays and the change detection arrays paired together in each trial. The change detection arrays were either identical (except for the change) to the SVT arrays (static condition) or they contained the same targets but different distracters as the SVT arrays and all items were in a different location (jumbled condition). The other two variables remained the same as the previous study. Accuracy and RT were recorded for both tasks.

6.3.4.3 Apparatus and Stimuli:

Stimuli consisted of 500 arrays; 200 arrays were for the SVT, another 100 arrays were identical to 100 of these but with one item changed (static condition). A further 100 arrays were made which contained the same targets as the remaining 100 SVT arrays (the targets were located in a different area of the display in comparison to the preceding SVT array) but different distracters (jumbled condition). The final 100 arrays were the same as these jumbled arrays with one item changed. Production of the arrays followed those rules outlined in the previous experiments.

6.3.4.4 Procedure:

The procedure followed that of Experiment Eight with two exceptions: in the SVT participants were only asked to search for shape, and there was the inclusion of the *array* variable whereby the array that was presented immediately after feedback from the SVT could be identical to the SVT array, or different (with the same targets in different locations and different distracters). Participants completed 200 trials presented at random. In the SVT there were five possible shapes to search for, giving 40 trials for each individual shape. Of these 40 trials there were 20 trials for each number of targets (3 or 4), 10 of these trials required a FALSE response, and 10 required a TRUE response. In the change detection task there were 100 jumbled trials and 100 static trials. Of these there were 25 trials for each level of *target congruence* (target or distracter from the preceding SVT), at each level of *feature congruence* (congruent or incongruent). As shape was the only search feature a congruent change was a shape change and an incongruent change was a colour change.

6.3.5 Results

Prior to analysing the data from the change detection task, any trials in which participants failed to correctly answer the SVT were removed. This accounted for 15% of all trials completed. In addition to this, incorrect change detection trials were also removed and any trials in which correct responses were made in less than 800ms or more than 30 seconds were removed. In total 20% of all trials completed had to be removed from the analysis. It should be noted that the number of trials removed from analysis did not vary with regard to the independent variables. On average participants were responding correctly to 85% of the SVT arrays, and this search took an average of 3.8 seconds. Performance in this task is therefore equivalent to the shape SVT in Experiment Eight which reported an average of 86% for accuracy and 3.7 seconds for RT.

Accuracy and RT to the change detection task were analysed using two 2x2x2 ANOVAs. There was a main effect of *target congruence* for both accuracy ($F(1,15) = 5.468$, $MSE = 29.563$, $p<0.05$) and RT ($F(1,15) = 32.836$, $MSE = 2.490$, $p<0.001$). Participants identified a change to a previously searched for target more accurately and significantly quicker than a change to a previous distracter from the preceding SVT, see figure 6.3a and 6.3b (page 198). There was also a main effect of *feature congruence* for accuracy ($F(1,15) = 4.618$, $MSE = 71.930$, $p<0.05$) and RT ($F(1,15) = 20.199$, $MSE = 2.203$, $p<0.001$) as an incongruent change (colour) was correctly detected more often and significantly quicker than a congruent change (shape), again see figure 6.3a and 6.3b (page 198). There were no main effects of *array* and no further interactions between the variables.

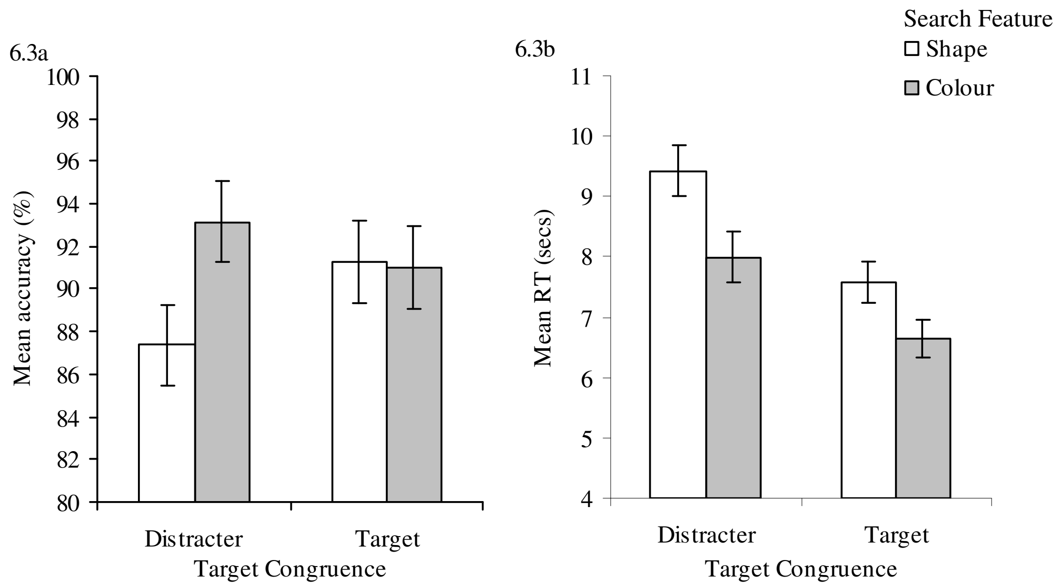

Figure 6.3: The effects of *target congruence* and *feature congruence* (shape is congruent and colour is incongruent) on accuracy (a) and RT (b) in Experiment Nine.

6.3.6 Discussion

After completion of Experiment Eight there was evidence for the carry-over of a feature-value-based attentional set (changes made to previous targets were detected faster than changes made to previous distracters), and the carry-over of a feature-based attentional set (congruent distracter changes were detected faster than incongruent distracter changes). The aim of Experiment Nine was to determine whether this carry-over was location-specific. The results showed that changes made to previous targets were detected faster than changes made to previous distracters, regardless of whether the targets in the array remained in the same spatial location between tasks. This reinforces findings showing that the carry-over from the SVT to the change detection task favours targets over distracters and shows that attention is allocated to objects rather than locations. This is not to say that attention may not be allocated to locations in the SVT but these locations are not carried over to the change detection task.

As the experiment reveals a carry-over effect, a conclusion can be drawn that a feature-value-based attentional set has the potential to persist to a second task. However, in this study congruent changes were not detected faster or more accurately than incongruent changes (providing no evidence for the carry-over of a feature-based attentional set). In fact the opposite effect occurred and incongruent changes (colour) were detected faster and more accurately that congruent (shape) changes. This indicates that even when participants were searching for a specific feature, they were attending to the object as a whole and processing the irrelevant feature (i.e., they were searching for shape but processed the colours of the shapes despite the fact that this feature was not relevant to the task).

In addition to providing evidence for the carry-over of a feature-value-based attentional set, the null effect of *array* shows that decreasing the similarity between the two tasks does not attenuate the carry-over effect. Monsell (1996) claims that transference of one task set to another task is more likely when the two tasks share similar stimuli because the stimuli will automatically trigger the set that it was previously associated with. Research from Lien, Ruthruff, Remington and Johnston (2005) supports this suggestion as larger switch costs have been found when the stimuli is the same in both tasks (bivalent) compared to when the stimuli is different across the two tasks (univalent). In the AB experiments reported earlier in this thesis the carry-over effect was found between two highly similar tasks which involved identical stimuli. Experiment Eight measured carry-over when the stimuli were identical and the tasks were different and this revealed both a feature-value-based and a feature-based carry-over effect (as shown through the interaction between *target congruence* and *feature congruence*). Experiment Nine measured carry-over when both the stimuli and the tasks were different, and once again found the feature-value-based carry-over effect to be occurring, but the subtle interaction between the *target congruence* and *feature congruence* was lost. In addition, the change detection of colour following a shape SVT (S→C) is better than the change detection of shape (S→S), whereas in Experiment Eight the change detection of colour and shape was equal. Importantly, increasing the variation between the two tasks across the different experiments has not removed the feature-value-based carry-over effect, suggesting that it is not reliant upon task similarity.

6.4 Discussion of Experiments Eight and Nine

6.4.1 Characteristics of the attentional set

The two visual search – change detection experiments presented in this chapter have provided evidence for the carry-over of a feature-value-based attentional set. Despite the SVT being non-predictive of the change made, participants continued to use the attentional set from the SVT, allocating attention to previously relevant items in the search for a change before allocating attention to previously irrelevant items. This resulted in changes made to previous targets being detected faster than changes made to previous distracters. This effect was found in both experiments (for accuracy and RT) regardless of whether the items remained in the same spatial location between the two tasks, suggesting that participants were allocating attention in the SVT using a feature-value-based attentional set, and this set persisted to the change detection task.

Although not replicated in Experiment Nine, Experiment Eight showed that if participants had not found a change after searching through the previous targets they searched through previous distracters by selectively attending to the previously relevant search feature before attending to the previously irrelevant search feature. This resulted in a feature congruency effect whereby changes made to previous distracters that were congruent with the search feature in the SVT were detected faster than changes that were incongruent with the preceding search feature. Not only does this support the claims made by Remington and Folk (2001) that attention can be biased to select specific features in a multi-dimensional object whilst ignoring other (irrelevant) features, it also implies that in the SVT attention may have been 'set' to select items on the basis of two properties; the feature (e.g., shape or colour), and the feature value (e.g., blue or green). In their 1992 paper Folk et al. raised the question as to what level the attentional allocation system is configured, suggesting that a "hierarchy" of properties may be configured as relevant or irrelevant. They proposed that this hierarchy ranges from very general properties (for example discontinuities in the preattentive information) to more specific properties (for example variations in colour across the visual display) to even more specific properties (for example the difference between red and green).

This can be illustrated further: based on a two- stage model of selective attention (e.g., Broadbent, 1958; Cave & Wolfe, 1990; Neisser, 1967; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Treisman & Gelade, 1980; Treisman & Sato, 1990), an initial 'preattentive' analysis is completed before attentional resources are deployed. This analysis works on the whole visual display in parallel, using a series of basic features (e.g., colour, orientation) and activation is given to areas and items of the display which vary in comparison to neighbouring items and areas (Wolfe, 1994). For example a static discontinuity would be one in which a certain item is given an activation level higher than its neighbouring item (representing a change in the visual display). According to Folk and colleagues, a search for such ‘discontinuities’ would be configuration at a general level. A search for specific discontinuities on the basis of colour would be configuration at a more specific level, and following this a search for feature values within the feature of colour would be highly specific configuration.

These ‘hierarchical’ levels fit well with the modes of processing outlined by Bacon and Egeth (1994); a singleton detection mode enables a search for a unique item in a display, whereas a feature detection mode enables a search for an item on the basis of a specific feature. Indeed these modes of processing have been labelled general and specific respectively (e.g., Folk and Remington, 2006). The effect of *feature congruency* found in Experiment Eight shows that participants were selectively attending to previously relevant features.

In their fourth experiment Folk et al. (1992) demonstrated that the system is configured for specific features (they only conclude this for the feature of colour). Yet the findings from the two studies presented above show that the system can also be configured for feature values (both shape and colour values). This can be concluded primarily on the basis of the carry-over effect; change detection was faster for previous targets than previous distracters, proving that attention was ‘set’ to focus on those specific feature values initially. Importantly, it shows that in these experiments participants were attending to both features and feature values. Again this conclusion is drawn based on the carry-over effect. In both experiments participants were faster to detect changes made to previous targets than changes made to previous distracters (therefore attending to the feature values). In Experiment Eight participants were also faster at detecting congruent changes made to previous distracters than incongruent changes made to previous distracters (therefore attending to features). These effects occurred for both shape and colour. This implies that the allocation system can be configured at a feature level and a feature value level at the same time. The finding that previous search feature only influenced the detection of (previous) distracter changes fits well with the hierarchy of levels proposed by Folk et al. (1992). An individual will allocate attention to the relevant feature initially (colour or shape) and then allocate attention to the specific feature value (e.g., triangle or blue). Although attention is oriented at a general level before being oriented at a more specific level, the carry-over effects found suggest that orientation at the feature value level is stronger than that at the feature level. This may be related to the effort one needs to put into the task; at the feature level participants only have to attend to one from two instances, yet at the feature value level participants must attend to one from five instances.

To summarise, given the findings of carry-over it is hypothesised that when completing the SVT participants will adopt a strategy whereby the allocation of attention is configured at a feature level (fairly general level), allowing them to focus on either the colour or the shape of each item in the display. The system is also configured at a more specific (feature value) level, allowing them to selectively attend to the relevant shape or colour. When the SVT is completed and the change detection task begins the attentional set persists, with attention allocated at the specific level (previous targets have priority) before it is allocated at the more general level (previous search feature has priority). This has led to the proposal of two forms of attentional set; a feature-based attentional set and a feature-value-based attentional set. It also implies that an individual is capable of maintaining two distinct attentional sets at the same time. This is not dissimilar from the conclusions drawn by Adamo, Pun, Pratt, and Ferber (2008) who found that participants could selectively attend to blue targets in one spatial location (whilst ignoring green items) whilst also selectively attending to green targets in a different spatial location (and ignoring blue items). In the past it has been assumed that the allocation of attention is configured at a single level, however the present results challenge this view.

It is important to keep in mind that the congruency effect was only found in Experiment Eight. The fact that the effect could not be replicated does limit its reliability somewhat, however there is the possibility that the design of Experiment Nine had an influence over any ‘feature-based’ attentional set. In the Guided Search model Wolfe (1994) states that the activation of basic features preattentively can be based on top-down factors, so if one feature has no bearing upon the search it will not be activated. He provides the example of colour; if an observer knows that all items in the search display are the same colour, searching for colour will not be beneficial. In Experiment Nine participants were told that they would always have to complete a search for shape, and following this one of the shapes would either change shape or colour. If participants have to search for both shape and colour on different trials it would be important to establish a set which selectively allocates attention to either shape or colour, however if they have to search for shape on every trial there is no need to ‘set’ a search feature on each trial. This means that the attentional set will only be based on feature values; there will be no set for features. If there is no feature-based set there is nothing to carry-over, therefore there is no congruency effect. This highlights the flexibility of the attention system; configuration for relevant and irrelevant information can occur at varying levels dependent upon the task demands.

Although the pattern of results fit with the notion of a hierarchical level of processing, whereby different levels are configured in order to allocate attention to task-relevant items (and features), it is still not clear whether the ‘set’ established for the current experiments was an excitatory set (e.g., Folk et al., 1992) or an inhibitory set (e.g., Olivers & Humphreys, 2003). The discussion above is biased towards a set which allows a search to be completed via activation of items meeting the top-down settings. Yet, the SVT could equally have been completed using active inhibition of items which do not match the top-down settings. Indeed the results from the change detection task point towards an inhibition strategy. This is due to the fact that changes made to previous distracters and incongruent changes took longer to detect in comparison to the overall mean change detection time in each experiment, whereas changes to previous targets and congruent changes did not vary a great deal from the mean. Further research would be useful to allow for a solid conclusion to be drawn.

6.4.2 Implications for carry-over

Using the variations in individual performance in the AB studies presented earlier, it was predicted that carry-over occurs because an individual fails to switch set when the task demands change. Participants who suffered from a smaller blink in the dual target block appeared to change set when the single target block ensued, but those who suffered from a large blink continued to use the same set in the single target block (Experiments Three and Four). It was therefore suggested (similar to the claims made by Leber & Egeth, 2006) that reconfiguration of the attentional set occurs through the ‘weighing-up’ of the costs and benefits of set switching. If the costs of abandoning the original set and reconfiguring the processing system to a new set of features is greater than the benefits to performance which stem from a set change, a switch will not occur. If more resources (and more top-down control) are invested in the initial set this will increase the costs of switching, therefore participants who suffered from a larger blink in a dual target block (and allocated high levels of control to this task) did not switch set. Experiment Ten (presented in the next chapter) was conducted to specifically test the notion that greater investment in the set will enhance the carry-over effect.

Chapter Seven: Characteristics of a top-down attentional set revealed through carry-over in visual search tasks

7.1 Overview of Chapter Seven

This is the third and final chapter to focus on the carry-over between a visual search task and a change detection task. There will be a brief summary of the findings collected so far using the methodology, which will help to outline the rationale for Experiment Ten. The final experiment in this area will then be presented and the results will be discussed. The findings of Experiments Eight, Nine, and Ten will then be reviewed with regard to the carry-over effect, and also their implications for theories of visual search and change detection. To conclude the chapter the main findings of carry-over will be compared with those revealed by the AB experiments.

7.2 A summary of the visual search findings to date

Experiment Eight showed evidence for two separate forms of carry-over; carry-over of a feature-based attentional set, and carry-over of a feature-value-based attentional set. This was revealed through faster detection of congruent changes made to previous distracters than incongruent changes made to previous distracters, and faster detection of changes made to previous targets than previous distracters. The fact that congruency only influenced change detection of previous distracters led to the proposal that attentional selection may be completed hierarchically, with attention allocated to the relevant feature initially, and then to the relevant value within this feature (although the latter results in stronger carry-over).

One drawback to this experiment was that carry-over only appeared to be occurring for one feature. There were two alternative suggestions made at this point. First, the search for both shape and colour carried over, but due to the difficulty of detecting a shape change, and therefore the increased top-down control required, the carry-over from a colour SVT was overshadowed. On the other hand it may be the case that a colour SVT was so easy, it did not require a 'controlled' attentional set, and therefore there was little to carry over to the change detection task. On the basis of the previous AB findings that increased investment in the task (due to more resources being allocated to the task) will increase the chance of carry-over, it was argued that the shape SVT carried over but the colour SVT did not.

With the proposal that shape carried over but colour did not, Experiment Nine was completed to investigate whether the carry-over from the SVT to the change detection task was location-specific (i.e., was attention directed to the locations of the SVT targets, or was it directed to the targets as objects?). Whilst this experiment revealed that changes made to previous targets were again detected faster than changes made to previous distracters regardless of whether they remained in the same location in both tasks (evidence for object-based selection), the effect of congruency disappeared. As the SVT always involved the same feature of shape it was argued that a feature-based attentional set was not necessary and therefore not established, in which case it could not have an effect on change detection performance.

7.3 Experiment Ten: The influence of visual search difficulty on the carry-over of attentional set

7.3.1 Objective of Experiment Ten

Given the findings from the AB experiments reported earlier that carry-over increases when participants show a larger blink in the dual target block, or are given more practice with the dual target block, it seems more plausible that carry-over is influenced by the resources invested in the original set, rather than the difficulty of the second task (which the set persists to). In addition, in Experiment Eight whilst a shape SVT decreased accuracy of detecting colour changes in comparison to the mean change detection accuracy across the experiment, a colour SVT did not influence the accuracy of detecting shape changes in relation to the mean. If the carry-over effect was related to the second task it may be expected that shape changes would be more difficult to detect than colour changes, yet this is not the case. As such it is predicted that carry-over is directly linked to the difficulty of the first task and therefore the level of top-down control required in the first task.

In an effort to gain further evidence for a feature-based attentional set, and the carry-over of this set, a final experiment was completed which reverted back to the original design of using shape and colour in the SVT. In addition, to ensure that a colour set would carry-over, and to test the hypothesis that carry-over is linked to the amount of resources required by the initial task, the difficulty of the SVT was varied. This was achieved by increasing the number of feature values (within each feature) that participants had to search for. In half the trials participants were asked to search for one feature value (e.g., “there are 3 circles”, or “there are 4 green items”), and in half the trials they were asked to search for two feature values (e.g., “there are 4 circles and squares", or "there are 4 green and red items"). Searching for two feature values did not involve searching for a greater number of items, yet it did involve searching for more than one instance of a feature. It was therefore expected that this search would require greater control of the top-down set, more resources would have to be allocated to the task, and a carry-over effect would be found for both features (in comparison to a SVT for one feature value). The aim of Experiment Ten was therefore to replicate the findings of Experiment Eight, and extend these previous findings by showing carry-over for colour.

It was predicted that once again participants would be better at detecting changes made to previous targets compared to previous distracters. As participants had to search for shape or colour in the SVT a congruency effect was expected, with congruent changes detected faster than incongruent changes. It was also predicted that when searching for two feature values participants would show carry-over for colour in addition to showing carry-over for shape.

7.3.2 Method

7.3.2.1 Participants:

Twenty participants (12 females and 8 males) completed the experiment for a payment of £6. They were all aged between 18 and 39, with a mean age of 22.9 years. All reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

7.3.2.2 Design:

The experiment followed a 2 (*search feature*) x 2 (*search set size*) x 2 (*target congruence*) x 2 (*feature congruence*) within-participants design. This was the same design used in Experiment Eight with the addition of *search set size*[18]; this referred to the number of values of each search feature that participants were asked to search for. They could either be asked to search for a single value (e.g., red, or diamond), or they could be asked to search for two values of a feature (e.g., red and blue, or diamond and triangle). *Search set size* could therefore be ‘1’ or ‘2’. Accuracy and RT was recorded for both the SVT and the change detection task.

7.3.2.3 Apparatus and Stimuli:

The experiment required 480 arrays; 240 SVT arrays and for each of these a second array was produced with one item modified for the change detection task. As participants now had to search for more than one instance of each feature the number of shapes and colours increased and therefore the number of items in the array also increased, from 16 to 20. This left 5 unoccupied locations in each array. There were 8 colours (blue, brown, purple, yellow, orange, green, pink, and red), and 8 shapes (cross, circle, moon, triangle, star, pentagon, square, and heart). Assignment of features and locations within each array was completed pseudorandomly in accordance with the rules already detailed in previous experiments. In this study there was always at least one of every shape and colour in the array, there were never more than 4 of any one colour or shape, and never more than two items which shared the same shape and the same colour. When participants had to search for two feature values (e.g., red and blue) the number of trials comprised of each value was equal. When 3 targets were present this meant that there were the same number of trials showing 2 red shapes and 1 blue shape as there were showing 1 red shape and 2 blue

[18] Note that this should not be confused with the notion of ‘set size’ often used in the literature which refers to the number of items in the visual display. Participants were required to search for the same number of targets among the same number of distracters in both conditions, and the variable can therefore be more appropriately viewed as the size of the ‘perceptual set’.

shapes (for example). When 4 targets were presented there were the same number of trials incorporating 3 reds and 1 blue, 2 reds and 2 blues, and 1 red and 3 blues (for example). See figure 7.1 for an example of the arrays used.

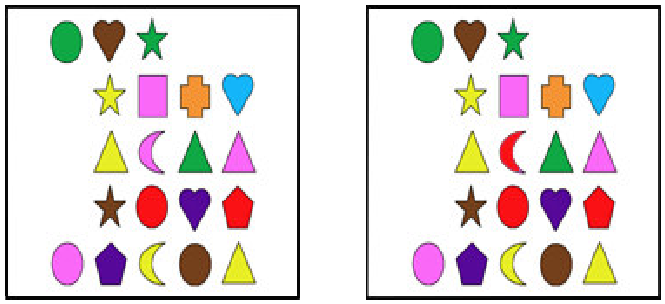

Figure 7.1: Two arrays used in Experiment Ten. The changed item can be found in the very centre of the array and is a colour change.

7.3.2.4 Procedure:

Participants completed 240 trials and the trial layout was identical to that of Experiment Eight. In the SVT participants were either asked to search for one feature value (e.g., “there are 3 stars”), or two values (e.g., “there are 3 stars and moons”) and respond TRUE or FALSE to the search statement[19]. There were 120 trials for each *search feature*, 60 in which the *search set size* was 1 and 60 in which it was 2. Within these 60 trials, 30 comprised a search for 3 targets and 30 comprised a search for 4 targets (15 required a TRUE response and 15 required a FALSE response). For the change detection task 60 of the 120 shape, and 120 colour search trials had a congruent change and 60 had an incongruent change; 30 of each of these involved a change to a previous target and 30 involved a change to a previous distracter. The

[19] Note again that in a ‘search set size 2’ trial participants were still searching for 3 or 4 targets but these targets are comprised of two feature values (i.e., they were not searching for 3 stars *and* 3 moons). This was made clear to participants before the experiment began.

number of changes for each *search set size* was 15. All trials were presented randomly.

7.3.3 Results

7.3.3.1 Sentence verification task:

Performance in the SVT was analysed using two 2 (*search feature*) x 2 (*search set size*) ANOVAs; one for accuracy and one for RT. For accuracy there was a significant main effect of *search feature* (F (1,19) = 16.746, *MSE* = 91.356, p=0.001) and of *search set size* (F (1,19) = 17.747, *MSE* = 86.998, p<0.001). Participants found it easier to search for colour ($\bar{x}$ = 90%) than for shape ($\bar{x}$ = 81%), and search for a single feature value ($\bar{x}$ = 90%) was easier than a search for two feature values ($\bar{x}$ = 81%). The same pattern of results was found for RTs with significant main effects of *search feature* (F (1,19) = 132.655, *MSE* = 0.978, p<0.001) and *search set size* (F (1,19) = 117.524, *MSE* = 0.562, p<0.001). Again participants found it easier to search for colour ($\bar{x}$ = 2.5 seconds) than for shape ($\bar{x}$ = 5 seconds), and for one feature value ($\bar{x}$ = 2.9 seconds) than for two ($\bar{x}$ = 4.7 seconds). There was also an interaction between the two variables for RT (F (1,19) = 13.035, *MSE* = 0.294, p<0.01). When searching for shape the difficulty of the SVT increased more substantially with an increase in *search set size* in comparison to when searching for colour (an increase of 2 seconds compared to 1 second respectively), see figure 7.2 on page 214.

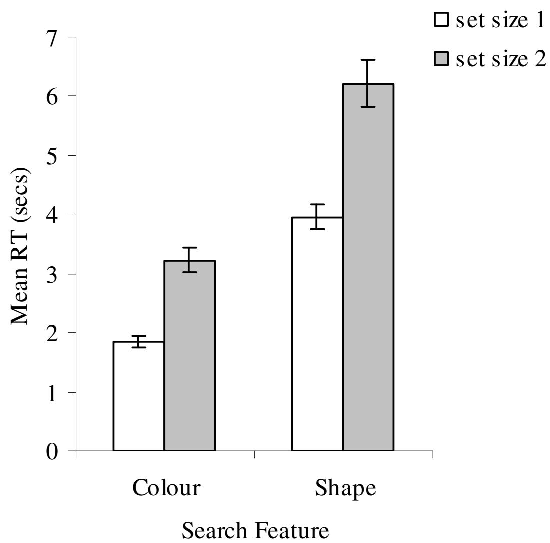

Figure 7.2: The interaction between *search feature* and *search set size* for RT in the SVT. Responses were longer for shape than for colour, particularly when two different shapes had to be searched for.

7.3.3.2 Change detection task:

Responses were only analysed if participants had correctly responded to the preceding SVT in each trial, and any trials in which responses were made before 800ms and after 30 seconds were removed prior to the analysis. In total 26% of all trials completed were discarded. Analysis consisted of two 2x2x2x2 ANOVAs, but the first showed that accuracy in the change detection task was not affected by any of the variables under investigation (mean accuracy across all conditions was 93.85%). For RT to the change detection task there was a main effect of *target congruence* ($F(1,19) = 15.281$, $MSE = 17.074$, $p=0.001$) with changes to previous targets detected faster than changes to previous distracters (means of 7 seconds vs. 8.8 seconds). There was also an almost significant interaction between *target congruence* and *search set size* ($F(1,19) = 4.037$, $MSE = 3.615$, $p=0.059$), see figure 7.3 on page 215. When a distracter changed there was little difference in change detection RT with regard to the *search set size* (t (19) = 0.666, p=0.513). When a target changed, RT was longer at set size 2 ($\bar{x}$ = 7.3 seconds) than at set size 1 ($\bar{x}$ = 6.7 seconds; t (19) = -2.141, p=0.045). However, this difference was no longer significant when the alpha level was adjusted using the Bonferroni correction. It is important to note that the overall mean RT for the change detection task was 7.9 seconds. Taking into account the RT to previous target and distracter changes, this pattern of results does not appear to be fully supportive of either an inhibitory attentional set or an excitatory attentional set in the SVT.

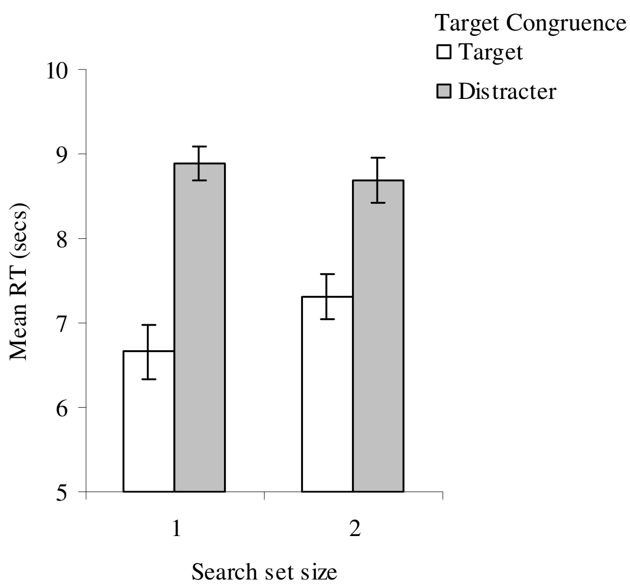

Figure 7.3: Variations in RT due to the interaction between *target congruence* and *search set size*.

7.3.4 Discussion

Similar to Experiment Nine, the only carry-over effect found was for the feature-value-based attentional set, as once again changes made to previous targets were detected faster than changes made to previous distracters. Contrary to the hypothesis, a congruency effect was not found, and congruent changes were not detected faster than incongruent changes. Although this fits with the findings of Experiment Nine, it was suggested that the lack of any feature-based carry-over in that experiment was due to a feature-based attentional set being unnecessary in the SVT (as participants searched for shape in every trial). This cannot explain the lack of any effect in the current experiment, in which case the evidence for a feature-based attentional set, and the carry-over of this set is more limited.

In Experiment Eight accuracy to detect colour changes was reduced (compared to mean accuracy) when the change detection task succeeded a shape SVT, however a colour SVT had little influence over accuracy to detect shape changes. This led to the conclusion that an attentional set to search for shape will persist to a second task because the SVT is demanding and more resources are required to complete it (in comparison to an SVT for colour). The present experiment directly tested this by increasing the difficulty of the search task using the variable of *search set size*. This did have an effect on the SVT showing that it did increase task difficulty but it had no effect on accuracy in the change detection task, indicating that once again an attentional set for colour has not persisted to the change detection task. However, in the current experiment there was also no evidence to suggest that an attentional set for shape had persisted to the change detection task. In addition to showing no congruency effect (for either search feature), the results also revealed that detection accuracy of colour changes did not vary according to whether the change was preceded by a colour SVT or a shape SVT.

The variable of *search set size* did influence accuracy in the SVT, with higher accuracy in set size 1. However for RT, a larger *search set size* only increased the time it took to correctly complete a shape SVT, and had no effect on RT for a colour search. This suggests that the variable did not make a colour search more difficult.

This may have been the reason why a colour set did not carry-over, yet as a shape set also showed no sign of carry-over this is unlikely.

7.4 General Discussion of the visual search studies

7.4.1 Summary of the findings

The aim of the visual search – change detection experiments was to provide more evidence for the carry-over of attentional set, therefore supplementing the findings of the AB studies and increasing the applicability of the findings. In particular the intention was to measure carry-over when participants had to search through different spatial locations (rather than different temporal locations), and explore the effects of enhancing the differences between the two tasks. A change detection task was used which was preceded by a visual search task, and changes made could be relevant or irrelevant to the previous search. A carry-over effect was predicted and it was expected that attention in the change detection task would be biased towards task-relevant stimuli and features from the previous search because they continued to match the top-down control settings.

Overall the three experiments conducted using this methodology were successful in meeting the aims outlined. They all provided evidence for the persistence of attentional set from the SVT to the change detection task showing that an attentional set established for searching through different spatial locations can carry-over in a similar way to an attentional set established for searching temporally. It also shows that carry-over occurs despite the different demands of each task and despite different stimuli in each task, and there is no evidence to indicate that this carry-over is tied to locations (Experiment Nine). This expands upon the findings from the AB studies.

The only result that was found consistently across all three experiments was the carry-over of a feature-value-based attentional set which biased attention to previously relevant items at the expense of previously irrelevant items. The SVT was not predictive of the change, and there was no benefit in using the previously relevant items to guide search, therefore there should have been no difference between the detection of changes made to previous targets and previous distracters. Despite this, in all three experiments participants selectively attended to previous targets in the change detection task before attending to previous distracters. This effect occurred regardless of whether the targets remained in the same locations across both tasks. The carry-over of this attentional set resulted in faster change detection for previous targets than previous distracters. In Experiment Nine the effect also extended to accuracy, with change detection of previous targets more accurate than change detection of previous distracters.

The other main effect found using the methodology was the carry-over of a feature-based attentional set, which biased attention to the previously relevant search feature and resulted in a congruency effect. However congruent changes were only detected faster than incongruent changes in Experiment Eight and the finding was not replicated in the other two experiments. Importantly, the congruency effect was found in the RT data rather than the accuracy data. This is encouraging as studies using the flicker paradigm usually concentrate on RT data and do not use accuracy as a dependent measure (Simons, 2000). Yet the lack of a congruency effect in Experiments Nine and Ten does challenge its reliability.

7.4.2 The carry-over of attentional set

There is clear evidence to show that the attentional set established to complete the SVT persisted to the change detection task, but what caused the set to carry-over? There are two possible reasons, the first is that participants switched set between the tasks but the original set was automatically triggered by the stimuli involved in the change detection task, therefore attention was deployed on the basis of this feature-value set despite its irrelevance to the task. The second possibility is that participants did not switch set. According to the proposal of Leber and Egeth (2006) this is because the costs of switching set outweighed the benefits.

The automatic reactivation of a set by previously relevant stimuli is one explanation given for the costs associated with task switching. For example, Allport et al. (1994) suggest that the costs arising from task switching are due to the carry-over of an old task set, and Goschke (2000) states that they are due to 'persisting activation' of the old task set. The costs arise because resources must be given to the suppression of the old, previously relevant set, leaving fewer resources to complete the task. Whilst this thesis does not focus on the costs of any set switch and instead focuses upon the costs of maintaining a previously relevant but now irrelevant set, task switching literature is important because the persisting activation of an old set is thought to be caused by previously relevant stimuli (and the experiments presented thus far use similar, if not identical, stimuli in both tasks). Monsell (1996) argues that a previously task-relevant set is *exogenously* activated by the demands and stimuli involved in a new task, which explains why switch costs are greater between two very similar tasks (e.g., Lien et al., 2005). Therefore it is plausible that in the visual search experiments participants switched set between tasks and reconfigured the set to the demands of the change detection task, but the original set was reactivated by the stimuli involved because it was identical to that of the preceding SVT. Even in Experiment Nine when half the arrays were ‘jumbled’, the targets from the SVT were still present in the array, and as attention was focused on these targets in the SVT they may have triggered the original set in the change detection task.

Attentional set switching is not the same as task switching though, and it can be argued that automaticity and reactivation of the SVT set is not the cause of the present findings of carry-over. First, it is unlikely that the set used to complete the SVT became automatic due to the short amount of experience participants had with the set in each trial. This is particularly the case in Experiments Eight and Ten when the SVT required either a search for colour or a search for shape. The fact that carry-over differed according to the task demands (across the three experiments) also argues against an automaticity account. Instead it is predicted that participants were able to switch set between the two tasks, but they chose not to. This was because the perceived benefits of adopting a new set to complete the change detection task were less than the costs associated with abandoning the set that had been configured for the SVT (it should be reiterated that this is not an ‘explicit’ comparison of costs and benefits).

There are several key details which lend support to this conclusion. The first is that there was greater evidence for carry-over of shape compared to carry-over of colour. If carry-over is due to the balance of costs and benefits, the greater the cost of switching set, the higher the chance of carry-over will be. A task which is more demanding (such as a search for shape) will require greater top-down control and this will make the set more stable and less flexible (Taatgen et al., 2007). A flexible set is much easier to alter when necessary so the costs associated with switching set would be low. Therefore a set for colour is unlikely to persist. However a more stable set is difficult to alter, increasing the costs and making carry-over more likely. A second important point to note is that although the two tasks did have very distinct task instructions and goals, the change detection task may have encouraged set maintenance rather than set switching. Specifically, the stimuli used in the experiment lacked variations in salience and apart from being told to find a single item changing participants were given no information about the change. This means that there was nothing to guide their attention. This was the main reason why the task was chosen for the current research as any patterns in performance would highlight a carry-over effect. However with no guiding features, the perceived costs of continuing with the search strategy from the SVT may appear low in comparison to the costs of completing the task using a serial search through the display. This would encourage set maintenance rather than set switching.

In addition to the above reasons, the conclusion that the carry-over is due to a failure to switch set is also consistent with previous findings. The individual differences found in the AB studies support this conclusion, and Leber and Egeth (2006) have also attributed the carry-over effect they found to a failure to switch set rather than a reactivation of a previously relevant set.

7.4.3 The attentional set

7.4.3.1 Type of top-down attentional set

The visual search experiments provided strong evidence for carry-over, and this in turn revealed that an attentional set was established to prioritise selection of task-relevant items over task-irrelevant items in the SVT. Yet there were discrepancies between the three experiments in terms of the 'type' of carry-over revealed. All three studies showed that a set to search for specific target *feature values* was established in the SVT and this persisted to the change detection task resulting in faster detection of changes if they occurred to the objects containing these relevant feature values. Before Experiment Nine was completed there was uncertainty as to whether attention was being allocated to objects or locations. However, changing the spatial location of targets between the two tasks in Experiment Nine proved that top-down allocation of attention was focused on objects rather than locations. This does not mean that attention cannot be deployed in a space-based manner (e.g., Eriksen & Eriksen, 1974; Posner, 1980), it merely shows that in the current experimental design attention was allocated to objects. Recent evidence shows that this may well be due to the task demands (e.g., Soto & Blanco, 2004; Vecera & Farah, 1994), however it can be concluded that in the present collection of experiments the processing system is 'set' to search for feature values and this set can persist to a task in which it is no longer relevant.

Selective attention using a feature-value-based attentional set was found in all three experiments but Experiment Eight also provided evidence for a feature-based attentional set. This was revealed through faster detection of changes that were congruent to the search feature in the SVT compared to changes that were incongruent to the search feature[20], implying that participants were biasing their attention to specific features within multi-dimensional objects (although this does not necessarily mean that they were not processing the other feature of the object, as this cannot be concluded from the present carry-over effects). This is not a new finding, Rossi and Paradiso (1995) and Remington and Folk (2001) also provided evidence for preferential selection of a single feature within a multi-dimensional object, but the fact that a feature-based attentional set was working in conjunction with a feature-value-

[20] Although this effect was not replicated in the subsequent visual search studies it is still an important finding and therefore warrants discussion.

based attentional set is not widely acknowledged in the literature. Instead the attentional allocation system is thought to be configured at a single level within a hierarchy depending upon the task demands (Folk et al., 1992).

Fanini, Nobre, and Chelazzi (2006) have also found evidence for selective processing of a single feature within a multi-dimensional object, and they claim that selection of the relevant feature is paired with inhibition of the irrelevant feature. Using a negative priming paradigm they presented participants with a prime object which could be described in terms of two features. For example a green bar slanted to the left could be described by colour (green) or orientation (left). Participants were told to report one feature from the prime and following this a probe object was presented that could only be described in terms of a single feature. For example a green square could only be described on the basis of colour, and a grey bar slanting to the left could only be described on the basis of orientation. When the probe was presented participants were asked to respond to its feature, so if the probe was a square they would respond to its colour (either green or red for example) and if the probe was a grey bar they would respond to its orientation (either left or right)[21]. This gave a large number of conditions, but critically the probe feature could be congruent to the relevant prime feature or congruent to the irrelevant prime feature. They found that responses were slower to the probe when it was defined by the irrelevant prime feature, representing negative priming of this feature. They also found positive priming when the probe was defined by the relevant prime feature[22]. Fanini et al. concluded that they have evidence for feature-based facilitation and feature-based inhibition within the same object. However they also found a result which (they said) was unexpected, and this was negative priming of one feature value (e.g., green)

[21] Motion was also a feature used in the experiment.
[22] This is in comparison to a condition when the probe feature did not match the relevant or irrelevant prime feature.

within a feature (e.g., colour), following the presentation of a prime in which a different feature value (e.g., red) of this feature (colour) was irrelevant. To illustrate, when participants were presented with a red slanted bar as the prime and told to respond to the orientation of the prime, they were slower to respond to a green square probe (in addition to a red square probe).

They suggest that this finding may be due to spreading inhibition to the whole feature following inhibition of a single feature value (e.g., inhibition of red spreads to inhibition of all colours). However, this author argues that their results are consistent with two forms of attentional selection; feature-based selection (e.g., for colour) and selection of the feature value (e.g., for red). Their findings show inhibition and selection of both features and feature values, in line with the present findings, and this again indicates that the attentional allocation system can be configured at a number of levels, and possibly be configured at more than one level at any given time. In their model for the exogenous allocation of attention, Folk et al. (1992) suggest that configuration can occur at different levels, according to the requirements of the task and this highlights the flexibility of the system. The findings from the visual search – change detection studies reported here would support an even greater level of flexibility. For instance an observer can flexibly select the relevant feature upon which to focus attention, and then select the relevant feature value for further processing. The carry-over results from Experiment Eight show that each level of selection will be utilised at a particular point to maximise performance (the feature-based attentional set was only used when searching through the previous distracters for a change). The results therefore agree with the findings of Adamo et al. (2008) and indicate that it may be possible to maintain more than one attentional set at once.

7.4.3.2 Facilitation or inhibition?

Despite concluding that an attentional set is formulated to complete the SVT, and that this set persists to the change detection task, it is still unclear whether an attentional set works by facilitating the detection of targets or by inhibiting the selection of distracters. Folk et al. (1992) outline a top-down set which allows for the activation of targets; anything matching the set will have a high level of activation and will therefore capture attention. On the basis of visual marking Olivers and Humphreys (2003) suggest that there may also be an inhibitory attentional set which benefits target selection by actively inhibiting items which do not match the top-down control settings. Given the findings of Fanini et al. outlined above it appears that attention can be allocated using both facilitation and inhibition. The current findings also support this viewpoint. In Experiments Eight and Nine there was greater evidence for the inhibition of irrelevant items (and features) which manifested itself through slower change detection of previously task-irrelevant information compared to the overall mean RT. In Experiment Ten it appeared that the search was completed either by facilitation of relevant stimuli, or by both facilitation of relevant stimuli and inhibition of irrelevant stimuli. This was because in the change detection task changes to previous targets were detected faster than the overall mean and changes to previous distracters were detected slower than the overall mean.

Similar to the proposal that an observer can maintain two attentional sets at one particular time (following Adamo et al., 2008) and use these sets flexibly, it could also be proposed (following Fanini et al.) that selection can occur through both activation and inhibition. Given the variation between the findings across the three experiments this may be due to the task demands. For example in the first two experiments there were fewer distracters and fewer feature values than in Experiment

Ten. It may therefore be easier to inhibit task-irrelevant items in the former because there are fewer items to inhibit, whereas in Experiment Ten it is more efficient to facilitate selection of targets rather than to suppress distracters. This suggestion is supported by the effects of *search set size* in the SVT of Experiment Ten. In Experiments Eight and Nine it took an average of 3.7 seconds to search for shape, and in Experiment Ten it took an average of 3.9 seconds to search for one shape value and an average of 6.2 seconds to search for two shape values. If participants were using an inhibitory strategy in Experiment Ten it may be expected that RT for one feature value would also be longer than that of the previous experiments because there were more items to inhibit. In addition, if an inhibitory strategy were carrying over in Experiment Ten RT would be similar for both search set sizes as there are the same number of items to inhibit in each condition. It can therefore be concluded that RT was longer when searching for two values because participants had to activate twice the number of feature values.

Direct evidence for inhibition is revealed through the differential carry-over of shape and colour. It has been postulated that as colour is an easier feature to search for and pops-out of the display (e.g., Pomerantz, 2006), the set used to select colour can be more passive and flexible, and as such the set does not persist to the change detection task. In Experiment Eight a search for shape reduced accuracy to detect colour changes compared to the mean level of accuracy for this task. This implies that because colour pops-out participants may have had to inhibit the colour of each item in order to focus on the shape of each item (and this strategy persisted to the change detection task). As shape is not necessarily defined as a basic feature (e.g., Wolfe, 1994) there is less need for inhibition of this feature when searching for colour, and this can be seen through accuracy in the change detection task when detection of shape changes was not influenced by a preceding colour SVT. This result has also been found by Rossi and Paradiso (1995) when comparing orientation and spatial frequency. They determined that participants were able to selectively attend to the orientation of an object without interference from the spatial frequency of this object, but when attending to spatial frequency they were unable to ignore the orientation. When attending to a feature of a multi-dimensional object, greater inhibition of the other feature is therefore required if this other feature is a basic search feature. Fanini et al. (2006) conclude the same and state that "the greater the power of a given feature to intrude into discrimination of another feature …. the stronger might be the engagement of inhibitory mechanisms" (pp. 601).

7.4.4 Implications for visual search

The carry-over effect found by the experiments using a visual search task has shown that top-down control over the allocation of attention will influence search behaviour in several ways. Based on the task demands participants selectively attended to task-relevant objects in different spatial locations and to task-relevant features. They were also able to selectively attend to a single feature within a multi-dimensional object. In addition, the carry-over effects provided evidence for selection through the facilitation of task-relevant information in conjunction with the inhibition of task-irrelevant information. Given the prediction for inhibitory processing these findings are very similar to visual marking (e.g., Olivers & Humphreys, 2002; 2003; Watson & Humphreys, 1997) and to negative priming (e.g., Fanini et al., 2006; Houghton & Tipper, 1994; Tipper, 1985), however the carry-over of an inhibitory or facilitatory search strategy occurs between two tasks which have different goals. The present findings therefore extend previous results reported in the literature by showing that the set persists to a different task.

Importantly, the results indicate that an observer may be able to search selectively by configuring the control system at two different levels. For instance, when searching for red shapes among heterogeneously coloured distracters the system will be configured for the relevant feature (colour) and the relevant feature value (red). Clearly this would maximise performance as both task-irrelevant features and task-irrelevant feature values may be inhibited. The control of attention to different levels of processing has also been proposed by Bundesen (1990) in his theory of visual attention. He outlines that attention is directed to different areas and objects within the visual field on the basis of attentional weights; anything which matches the target template will be given a high weight in comparison to anything which does not match the template. Attention is then deployed to the areas with highest weightings. Using an example task of identifying each red digit in a display of black digits, Bundesen argued that categorisation of red digits will occur faster than black digits as higher weights will be given to items belonging to the category of red. Following this, a high “perceptual bias parameter” will also be set for all digits 0-9 to ensure that the processing of digit-type is faster than the processing of any other attribute of the targets (e.g., size). If one were to assume that an attentional set is used to allocate these weights and biases and then direct attention appropriately it would appear that two sets would be required. An initial set would be needed for the category of ‘red’ and a second set would be vital for the additional processing of each target item. This is consistent with the present hypothesis, the allocation of attention is configured for the category of red and also for the category of digits.

The proposal of multiple forms of an attentional set does not conflict with findings in the literature which show selective attention on the basis of a single feature (e.g., Egeth et al., 1984; Kaptein et al., 1995) but it does imply selection is more flexible than previously suggested. It may be the case that there is limited evidence for multiple sets because many visual search experiments involve a search for a single target, often presented among homogenous distracters, and target detection can occur through the search for a single feature value (e.g., red). This means that previous experimental designs do not impose the need for configuration at multiple levels.

On the basis of the results found from the three change detection experiments this author argues for the presence of a 'feature filter' that is used in the allocation of attention. The feature filter acts on all items in the display and prioritises selection of relevant features as opposed to irrelevant features. When an individual is searching for a specific feature (e.g., shape) attention will be biased towards this feature and away from other features (e.g., colour). If the individual has to search for a specific feature value (e.g., square) the feature-value-based attentional set will bias attention towards items matching the target-defining feature (square) and these items will be selected. As these items are selected for further processing on the basis that they match the target-defining feature they will be allowed through the feature filter and the filter will no longer act upon them. Therefore both features of the item (shape and colour) will be processed, despite the fact that colour is not relevant. This means that if the set persists to a subsequent task previously relevant items (relevant according to the feature value) will be processed both in terms of the relevant feature (shape) and the irrelevant feature (colour) because the feature filter did not act upon them. As previously irrelevant features were processed by the feature filter alone they will subsequently be processed in terms of the previously relevant feature (shape) before attention is given to the previously irrelevant feature (colour). This proposed form of selection will be discussed further in Chapter Nine.

7.4.5 Implications for change blindness

Theories which attempt to account for the difficulty to find a change when the motion transient associated with this change is masked tend to attribute the effect to a problem with the representation of the original image and the modified image. This may be a problem with the creation of the two representations (e.g., Rensink et al., 1997), comparing the two representations (see Simons, 2000), or holding the representations in memory (e.g., Wolfe et al., 2006). The results presented in this thesis are unable to provide support for any of these accounts because the ability to develop a representation of the arrays and the memory for these arrays was not explicitly tested (however, equally, this was not the aim of the studies). The studies did show that participants suffered from change blindness, and that attention was necessary to find the change (supporting the literature). The importance of attention can clearly be seen through the carry-over effect. Changes were easier to detect if the item which changed had been the focus of attention in the preceding SVT.

It may be suggested that the studies do provide some evidence for the coherence model developed by Rensink (2000). He suggests that the change detection arrays are analysed at a preattentive level initially, and using this analysis focused attention is given to a series of proto-objects. Focused attention allows the representation of the proto-objects to be stable and therefore any change to the objects is detected. If a change occurs to an item which is not the focus of attention it will not be detected because the representation is not coherent and the change will simply overwrite the initial representation. As focused attention is allocated to targets in the

SVT the representation of these targets would become stable and coherent (compared to the representation of distracters). These representations may have persisted to the change detection task meaning that a change to a previous target was easier to detect than a change to a previous distracter due to the stability of the representation. Obviously this would require further study, and again this was not the primary aim of the experiments, yet it is worthwhile outlining any possible implications the current findings may have.

The most important finding with regard to the change detection task was that when there is no other information to guide attention and a serial search may be required, observers may use an alternative strategy to search for the change. A study by Scholl (2000) supports this conclusion. In a change detection flicker task participants were presented with a visual array containing several line drawings (e.g., a hairbrush, a tennis racket); this was the original image (A). To create the modified array (A`) one of the drawings was either replaced or flipped, and these two arrays were then presented alternately separated by a blank screen. Participants were assigned to three conditions. In the control condition the experiment proceeded as a normal flicker task would. In the 'late-onset' condition an abrupt onset appeared on the initial viewing of A, and in the 'colour singleton' condition a coloured item appeared on the initial viewing of A. The three conditions were then compared based on whether the change was to a 'critical' item (congruent to the distracter presented in first viewing of A), or 'non-critical' item (incongruent to the distracter). Results showed that congruent changes were detected faster than incongruent changes, even though participants were explicitly told that these distracters were irrelevant to the change detection task. This shows that in the absence of any other influences upon attentional capture, visual search in a change detection task will be guided by alternative factors. In the case of the study completed by Scholl attention was exogenously captured by stimuli matching the task-irrelevant distracter. In the case of the experiments completed for this thesis attention was captured by stimuli that had been relevant in a previous task.

It must be reiterated however that the visual search – change detection methodology did not make use of natural stimuli. This was to ensure that there were few other factors to guide attention and therefore allow any carry-over from the SVT to be measured. For example the displays did not vary greatly in terms of salience and other than the task instructions there was little top-down information (such as expectations) to guide attention. Whilst this did have the required effect of revealing the persistence of attentional set, it also reduced the applicability of the findings to more real-world tasks. It may be suggested that the carry-over effect would be less apparent when there is more information in the second task to guide attention in that task.

7.5 Conclusion of the visual search studies

The objective of the visual search – change detection methodology was to gather further evidence for the persistence of attentional set under different conditions. The AB experiments showed carry-over when all items were presented to the same spatial location, the stimuli were identical in both tasks, and the task demands were very similar (in the dual target and single target blocks). The experiments presented here have expanded upon these findings by showing carry-over between two tasks which have substantially different goals, they may include different stimuli (Experiment Nine), and items are presented to different spatial locations.

The findings are also consistent with the AB experiments because carry-over appeared to be stronger for the feature of shape than the feature of colour. Like the claims made in Chapter Four, this result was attributed to the amount of top-down control there is over the initial set, the amount of resources invested in the set, and therefore the flexibility of this set Carry-over is therefore assumed to have occurred because participants failed to switch set between the two tasks.

The visual search experiments have also outlined evidence for a possible inhibitory attentional set, whereas the attentional set in the AB studies was most likely a facilitatory set. This means that both forms of top-down selection can persist to a second task when they are not relevant to this task. Moreover the results have shown carry-over of a feature-value-based and a feature-based attentional set, leading to the prediction that attention can be configured at more than one level of processing at any one time. This has implications for top-down control, suggesting that it is more flexible than previously imagined, but also more influential than expected.

The drawback of the studies was that the change detection task was devoid of any additional influences upon the guidance of attention (as required for the experimental aim) which would be unlikely in a natural setting. At present the evidence for carry-over is therefore limited to simple tasks. This will be rectified by Experiments Eleven and Twelve in Chapter Eight.

Chapter Eight: The persistence of a location-based attentional set to a real-world visual scene

8.1 Rationale for the final two experiments

To date the work in this thesis has shown evidence for the carry-over of attentional set from a task in which the set is relevant to a task in which the set is no longer relevant. The AB results show that given sufficient practice with the initial set, or providing there is a large amount of control over the initial set, it will persist to a second task, despite impairing performance on this task. The data from the visual search experiments shows that a feature-value-based attentional set will carry-over from a visual search task to a change detection task. The carry-over biases the allocation of attention in the change detection task towards previously relevant items and away from previously irrelevant items, even though relevance in the preceding search has no relation to relevance in the change detection task. At present the results also support the notion that the attentional set persists due to a failure to change set, not the automatic re-activation of the set by previously relevant stimuli which are associated with the original set.

Although successful with regard to the investigation of carry-over, the methodologies used thus far are limited in their applicability to real world tasks. In addition they have raised some questions concerning carry-over, and selective attention which need to be answered. In particular, whilst the visual search experiments endeavoured to measure carry-over when the two tasks were substantially different (given that it could be found when they were highly similar in the RSVP paradigm), the two search tasks still involved identical stimuli (with the exception of Experiment Nine). Would the effect still be found with more substantial differences between the two tasks? Also, although search in the change detection task was based on the attentional set from the preceding SVT, there were few other influences on attentional capture in this experiment, possibly increasing the chances that carry-over may occur. Would the effect remain if the stimuli used for the second task had the ability to guide attention, both in terms of bottom-up and top-down factors not related to the task? A final area for further research was the possibility that attention can be guided to different elements of the environment. Experiments Eight, Nine, and Ten showed that attention is allocated using a feature-value-based attentional set, and there was tentative evidence for a feature-based attentional set from Experiment Eight. This led to the proposition that the orienting system may be configured at several levels depending upon the task demands. As the visual search literature also shows attentional selection of locations (e.g., Posner, 1980) in addition to objects (e.g., Duncan, 1984; Soto & Blanco, 2004; Vecera & Farah, 1994) is there evidence for a location-based attentional set and the carry-over of this set? The results from Experiment Nine would indicate not, yet this is perhaps an unfair test because location was not important in the change detection experiments, and the features and feature values had more bearing on the task than the location of each shape.

Although there is evidence to show that attention can be allocated to areas of space (e.g., Eriksen & Yeh, 1985; LaBerge & Brown, 1989) it does not necessarily follow that attention is ‘set’ to search specific locations on the basis of the task demands (i.e., top-down control). Yet there is research to suggest that attention is biased to specific locations in accordance with the top-down control settings. This is revealed through experimental evidence showing that observers concentrate their search to the most informative areas of a scene (e.g., Loftus & Mackworth, 1978) and they use pre-existing knowledge of the spatial configuration of a scene to guide their search (e.g., Brockmole & Henderson, 2006). Furthermore, the application of ‘spatial priors’ (built up through experience; e.g., Tatler, 2007) in relation to the task demands indicates that the orientation of attention to different spatial locations can be controlled by top-down influences.

This final experimental chapter attempts to provide evidence to show whether attention is oriented to areas of space in a top-down fashion, and whether this ‘location-based’ attentional set has the capacity to persist to a second task which is highly dissimilar to a preceding task. Two experiments will be presented which study the carry-over of attentional set from a visual search task to a natural image, and the natural image will be a photograph of a roadway. Research shows that drivers have pre-defined visual search strategies, and Experiments Eleven and Twelve were completed to investigate whether a preceding visual search task could override these existing search strategies. Real-world stimuli will involve more top-down and bottom-up influences, therefore it will be possible to see whether carry-over can override these influences. The two experiments will explicitly measure the allocation of attention to areas of space, and the carry-over of space-based selection. They will also extend the current findings to a more naturalistic task, enhancing the applicability of the work reported in this thesis.

8.2 Outline of Chapter Eight

Before the final two experiments are presented there will be an overview of pertinent literature from the field of driving psychology which shows the importance of top-down control in the driving task. The evidence for a location-based attentional set in the driving task will be described, and the predictions regarding the carry-over of attentional set in the driving task will be outlined. The two experiments and their findings will then be described, and the results will be discussed with regard to the previous findings of carry-over in this thesis, and selective attention in the driving task. The results will also be related to the visual search of other naturalistic stimuli, and the implications of carry-over in a real-world task will be discussed. The chapter will then end with a short conclusion.

8.3 Attentional set in a real world task

8.3.1 Control of attention in the driving task

It could be argued that simplistic laboratory experiments do not give a very realistic measure of how selective visual attention works as many studies fail to represent the level of visual clutter that is found in the real world. This is particularly the case in very low-level studies which typically involve few simple stimuli arranged on a blank background. In no way does this capture the essence of a real world scene in which selective attention is so important. Without studying attentional control in a real-world setting it is impossible to know how well any laboratory findings can be applied to real life situations (Kingstone, Smilek, & Eastwood, 2008).

One way in which selective attention has been measured to a more realistic level is by investigating visual attention in the driving task. Driving is an example of a real-world dynamic task in which the visual world is constantly changing and there are numerous items to perceive and attend to at any given moment. Allocating attention to the task-relevant stimuli and areas within this changing environment is important and there are direct safety implications if attention is not set to search selectively in the most appropriate locations for the most useful information. As such, research in this area not only helps to further the understanding of selective attention, it also has the potential to improve road safety.

Psychologists who study driving behaviour are able to apply their findings to real-life situations because they measure visual attention in the laboratory and on the road. To begin, driving researchers will test their hypotheses using simple laboratory experiments. The possibility of replicating these findings in real driving can then be assessed using a driving simulator (without the safety implications of real driving). Following this any results found can be studied in real on-road driving, taking into account any safety measures which have been highlighted by the previous simulator studies.

The field of driving psychology has a very active research community and there is a large body of work pertaining to visual attention in the driving task. For this reason, and because driving is an area where success has already been found in applying theory to practice, the final two experiments will utilise driving stimuli to test the carry-over of attentional set in real-world scenes.

Although driving researchers agree that selective attention is vital in the driving task few have tackled the issue of how selection works. Trick, Enns, Mills and Vavrick (2004) have proposed 4 modes of attentional selection, see figure 8.1 on page 239, stating that selection falls into two categories: *automatic* and *controlled (*this is very similar to modes of selection outlined by Schneider & Shiffrin [1977] and Shiffrin & Schneider [1977]). Automatic selection involves *reflexes* which are an automatic shift in attention triggered purely by the environment, and *habits* which are operations that are completed so frequently they become automatic. Reflexes are therefore exogenous processes but habits are endogenous as they can change over time with practice. Trick et al. state that habits are situated along a 'continuum of automaticity', becoming more or less automatic with differing levels of practice. Controlled selection includes *deliberate* selection whereby conscious goals determine the processing strategy used in a given situation based on the level of experience and knowledge one has with the situation, and *exploration* which occurs when no specific goals are outlined. Exploratory selection occurs when there are no expectations about the environment and attention is not triggered reflexively. Again, controlled attention can be both endogenous (deliberation) and exogenous (exploration).

	Exogenous	**Endogenous**
Automatic	Reflex	Habit
Controlled	Exploration	Deliberation

Figure 8.1: A model of selective attention, taken from Trick et al., 2004 (pp. 394).

Research shows that selective attention is beneficial because it allows for the allocation of attention to task-relevant items and the inhibition of task-irrelevant items. Although this is efficient in terms of processing resources, problems arise when a behaviourally relevant object appears that does not match the top-down control settings. In laboratory studies a task-relevant stimulus which does not capture attention has no lasting implications beyond contributing to a lower task performance, but in the real world the inability of a task-relevant item to capture attention could be more costly. A recent driving study conducted by Most and Astur (2007) can help to illustrate this. Participants were asked to ‘drive’ along a simulated route and follow either yellow or blue direction arrows. Towards the end of the route a motorcycle veered in front of the participant. The motorcycle was also coloured yellow or blue and therefore congruent or incongruent with the attentional set. They found that participants had more collisions with and took longer to respond to an incongruently coloured motorcycle than a congruently coloured motorcycle.

The finding that driving stimuli such as motorcycles capture attention more slowly if top-down processes are not specifically set to search for these stimuli follows the contingent capture hypothesis (Folk et al. 1992). However, in real-world tasks, such as driving, it is possible to see that the establishment and the application of attentional control settings can also be influenced by experience; practice with a task builds expectations about what is task-relevant and these expectations alter the attentional set. This has been shown in the driving task by Velichkovsky, Dornhoefer, Kopf, Helmert, and Joos (2002) using a change detection experiment. Participants watched video stills of traffic and had to spot changes made to the scene. Detection was faster to changes that were relevant to the driving situation than to those which were irrelevant. Drivers were therefore using their knowledge of the driving situation to allocate their attention to the most informative items within the scene.

Trick et al. (2004) suggest that drivers have a ‘perceptual set’ whereby expectations cause them to look in certain locations for certain objects. One way to obtain evidence for this has been to look at failures in detection caused by expectations. For example Hancock, Wulf, and Thom (1990) suggest that the high number of motorcycle accidents may be due to the fact that motorcycles are unexpected. They state that unexpected stimuli will not be represented within the perceptual set and attention will therefore not be allocated to them. This predicted cause of expectancies upon the allocation of attention is supported by the findings from several studies. For example Brüde and Larsson (1993) found that the risk of a traffic accident involving a cyclist at a specific intersection reduced when the number of pedestrians and cyclists at that intersection increased. Low numbers of cyclists mean that they are unexpected, they are not represented within the perceptual set and so a driver may not allocate attention to them, increasing the chance of a collision. Increasing the number of cyclists means that expectancies (and the perceptual set) will be updated to include them and drivers will search for them.

Crundall, Bibby, Clarke, Ward, and Bartle (2008) suggest that more exposure to unexpected vehicles such as motorcycles will influence a driver's search schema used to represent the driving task. This ensures that the driver will search for these unexpected items. Using a questionnaire designed to measure driving behaviour and record attitudes towards motorcyclists they found that dual drivers (those who drive cars and motorcycles) are more aware of the risks of motorcycles and the need to search for them whilst driving. Consistent with this, Magezzù, Comelli, and Marinoni (2006) have found that dual drivers have fewer collisions with motorcycles than car drivers.

8.3.2 Location-based attentional set in the driving task

Driving research not only outlines a role for a visual search strategy based on objects (searching for items that are most often encountered and are most relevant to the task), it also shows clear evidence of a location-based visual search strategy. For example, Shinoda et al. (2001) conducted a simulated driving study in which participants had to follow a lead car and adhere to normal traffic rules. Part-way through the drive a stop sign would be located on the road; for half the participants this sign was at an intersection, for the other half the sign was placed on a straight stretch of road. This sign changed from a stop sign to a no parking sign and at the end of the drive participants were asked if they had noticed a sign change at any time. Participants were more likely to detect the sign, detect the change made to the sign, and make an eye movement to the sign when it appeared at an intersection than when it appeared on a straight section of road. Shinoda et al. state that this provides evidence that individuals will selectively allocate attention by "using learnt knowledge of the probabilistic structure of the environment to initiate task-specific computations at likely points" (pp. 3536-3537). A stop sign is only expected at intersections; consequently drivers did not search for the sign on straight roads and did not notice the sign changing.

The study of Shinoda et al. emphasises the importance of expectations on the visual search of driving stimuli, and expectations change with experience. As such one would expect that visual search would also change in accordance with experience. The influence of driving experience on visual search has been widely researched and findings show that the visual search strategies of novice and experienced drivers are substantially different. Mourant and Rockwell (1970) found that novice drivers have a smaller spread of horizontal search than experienced drivers. More recent work has expanded these preliminary findings to show that a major factor in the differences between drivers of varying experience is how they adapt their visual search due to changes in demand. Crundall and Underwood (1998) found that whilst novice drivers have a similar spread of search across all roads, experienced drivers change their search in relation to demand with a narrower spread of search on the least demanding roads. Consistent with this Theeuwes (1992), as cited by Martens and Fox (2007) tested this using driving stimuli and found that when participants were asked to search for a traffic sign in a driving video experienced drivers moved their eyes to locations most likely to contain traffic signs first, leading to slower response times to signs situated at unlikely locations.

The fact that experience affects the visual search strategy used in the driving task fits with the theoretical assumptions of Ullman (1984), who states that individuals will use specific visual routines to search an environment and these routines are based on past experience of a situation. If a situation is novel and has not been encountered in the past a *universal routine* is applied to gather an initial analysis of the scene. This analysis is then used to determine which *visual routine* is the most appropriate and should be applied in that situation to gain a full representation of the scene. It may therefore be proposed that the differences found by Crundall and Underwood (1998) in the spread of search between novice and experienced drivers were due to the fact that novice drivers do not have a set of visual routines stored for each driving situation due to their lack of experience. Instead they have to apply a universal routine (the same search strategy) to all situations. More experienced drivers will have established different routines, allowing them to use different search strategies on different road-types.

8.3.3 Carry-over of attentional set in the driving task

The driving literature presented in this chapter has outlined the importance of top-down control in the driving task and the influence of experience upon this control, but what about the possibility of carry-over of attentional set? With the exception of the study completed by Most & Astur (2007) there have been few studies which directly measure the influence of the attentional set from one task (either related or unrelated to driving) on the allocation of attention in the driving task. Despite this, several researchers have investigated 'habitual behaviours' in the driving task.

Building on their framework for attentional selection in the driving task Trick et al. (2004) outline two forms of selective attention; attention with awareness and attention without awareness. Although an action may begin requiring selection with awareness, it may end up as a 'habit', therefore representing selection without awareness. As the action becomes more practised less proprioceptive feedback is required and the response can be executed directly by the stimulus trigger. Take for example a situation in which a driver approaches a roundabout which has the addition of traffic lights. Drivers are most used to encountering a roundabout without traffic lights and it is more unusual for a roundabout to have traffic lights. As such, when a driver approaches such a roundabout they may slow down to give way to traffic on the roundabout, even though the traffic light is on green, purely because they are used to stopping at a roundabout when there is conflicting traffic. Only after processing the traffic lights will the driver then increase their speed and pull onto the roundabout. The roundabout therefore automatically triggers the response most usually associated with it. Trick et al. give the following definition of this process and its disadvantage:

"A given action is repeated so many times in a certain context that the context begins to evoke the appropriate response directly (the appropriate motor program in long term memory is activated 'bottom up'), and the action no longer demands conscious awareness. It becomes a habit. Although this is efficient, there is a danger that these motor programs will sometimes be activated in circumstances where they are undesired." (pp. 388).

The application of an action in an inappropriate situation due to the action being automatically triggered is referred to as 'habit lag' (Mannell & Duthie, 1975). The habit is the automatic response and the lag is the time for which the habit persists once is has been incorrectly activated. Trick et al. state that a habit can be overridden but this requires conscious control. In line with this Mannell and Duthie say that habit lag will only occur when attention is engaged elsewhere in a task that requires enough resources to leave insufficient resources to inhibit the habit. Consider the cause of a driver slowing down at a roundabout even though the traffic lights on the roundabout are green; most drivers will say that if they have ever done this it has been when they were having a conversation or were deep in thought about something other than the driving task; attention is directed elsewhere therefore there is nothing to prevent the habitual response from intruding. This supports the conclusions made by Reason (1984) that 'lapses of attention' occur when a task is highly practiced, and sufficient attention is not being devoted to the task.[23]

8.3.4 The set-up of Experiments Eleven and Twelve

Experiments Eleven and Twelve will examine the persistence of a location-based attentional set from a simple visual search task to a visual search of driving stimuli. The design of the experiments attempts to portray the effects of a secondary driving task on the visual search of the primary driving task. Consider the display of information which is available to the driver; not only must they focus their attention on the road ahead, check their mirrors, etc., they may also need to allocate attention to road signs, information bulletins, in-car displays, etc. The visual search required for such displays will be different to the visual search required in the primary driving

[23] Carry-over in Experiment Five of the current thesis has been attributed to the intrusion of a habitual set due to a lack of awareness and control.

task. If the search strategy from a display persists to the driving task it may therefore alter the search given to the road. For example, when a driver searches a vertical sign cluster their vertical search will increase relative to their horizontal search. Studies show that the most appropriate search strategy for driving is to sample a wide portion of the environment, concentrating search in front of the car and along the horizontal axis using a series of short fixations (e.g., Crundall & Underwood, 1998). Therefore if the search strategy used for the sign cluster persists to the driving task it will represent an inappropriate strategy, artificially narrowing the search area, increasing the vertical spread of search, and possibly reducing the horizontal spread of search. This could make the subsequent spread of search in the driving task less suitable compared to the search strategy usually employed.

Taking the above scenario the final two experiments were designed to measure the persistence of a search strategy from a display of letters to a photograph of a roadway taken from the drivers' perspective. In every trial participants completed a search through letter strings arranged on the screen. Following this a driving photograph was displayed and participants were asked to view this picture for a later memory test. The letter strings were presented either horizontally, vertically or randomly and it was predicted that whilst a horizontal letter search will increase horizontal variance in the picture search, a vertical letter search will increase vertical variance in the picture search. The two experiments were identical in their design with the exception that participants in Experiment Eleven were not given a memory test and those in Experiment Twelve were given a memory test (although participants in both studies were told that they would be given a memory test).

8.4 Experiment Eleven: Carry-over of visual search in natural scenes (1)

8.4.1 Method

8.4.1.1 Participants:

Twenty participants took part in the experiment (9 male and 11 female) for a payment of £4. All were aged between 19 and 43 with a mean age of 24.8, and all reported normal or corrected-to-normal vision. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham.

8.4.1.2 Design:

A within-participants design was used with two independent variables, *orientation* and *repetition* of the letter search task. *Orientation* of the letter search task involved three levels; the letters to be searched could be arranged horizontally, vertically or randomly across the screen. *Repetition* of the letter search task referred to the number of times participants were given a letter search prior to viewing a road picture. In any trial participants could be given one letter search (R1), two searches (R2), or three searches (R3) before a picture appeared. Letters were always in the same orientation for every search within a trial, but the targets and distracters were different in each search. Accuracy and RTs were recorded for the letter search and a series of eye movement measures were taken whilst participants viewed the road photographs.

8.4.1.3 Apparatus and Stimuli:

There were always nine characters in the letter search task and they were placed within an invisible 9x9 grid depending on the orientation of the search. In the vertical search the letters were arranged down the centre of the screen (subtending 26.27 degrees), letters in the horizontal search were arranged across the centre of the screen (subtending 24.45 degrees), and in the random search letters were arranged randomly across the screen (subtending a maximum of 35.14 x 28.07 degrees). The letters were always presented in black on a white background, in Verdana font, size 18 and measured 0.95 x 0.95 degrees. In every search there were either 5 consonants and 4 vowels or 6 consonants and 3 vowels, and letters could be shown in upper or lowercase. Stimuli also included 180 road photographs taken from a driver's perspective. Sixty of these were photographs of rural roads, 60 were suburban roads and 60 were urban roads. The resolution of the photographs was 800 x 600 pixels (measuring 35.14 x 28.07 degrees); and they were shown in full colour. Eye movements were recorded using a Sensorimotoric Remote Eyetacking Device (SMI RED), which recorded eye movements from the right eye. The minimum fixation duration was set to 100ms, with a sampling rate of 50Hz and a fixation dispersion threshold of 100 pixels.

8.4.1.4 Procedure:

Full instructions were given on the screen followed by a calibration of eye movements. Each trial began with a letter search. Participants were asked to search through letter strings on the computer screen and decide whether there were 3 or 4 vowels shown in each string by pressing '3' or '4' on the keyboard. They could take as long as necessary to make each decision and were only ever asked to search for the vowels A, E, O and U. The letter 'I' was not used due to its ambiguity with the lowercase letter 'l'. Following each response they were given visual feedback on their answer for 1500ms. In a single repetition trial (R1) a road picture was then shown for

2000ms and participants were told to scan this photograph as carefully as possible in preparation for a memory test later. If the trial contained two (R2) or three (R3) repetitions a further one or two letter searches were given (letters in the same orientation) before the road picture was shown. Immediately after the road picture the next trial began. See figure 8.2 (page 250) for the sequence of events in each trial.

There were 180 trials in total, 60 for each orientation of the search task and 20 of each repetition for each orientation. Half the trials in each condition showed 3 vowels and half showed 4. All trials were presented randomly. Road images were selected at random[24]. Participants were given no information about the conditions being tested, they were simply told that they would have to search for vowels among consonants, and road photographs would appear at random intervals throughout the experiment. At the end of the experiment participants were told that they would not be given a memory test.

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[24] As the road images were selected at random there was no control over the number of each road-type which was shown in each condition. However, analysis of eye movements to the road pictures comparing rural, suburban and urban roads showed no differences between the search of each road-type.

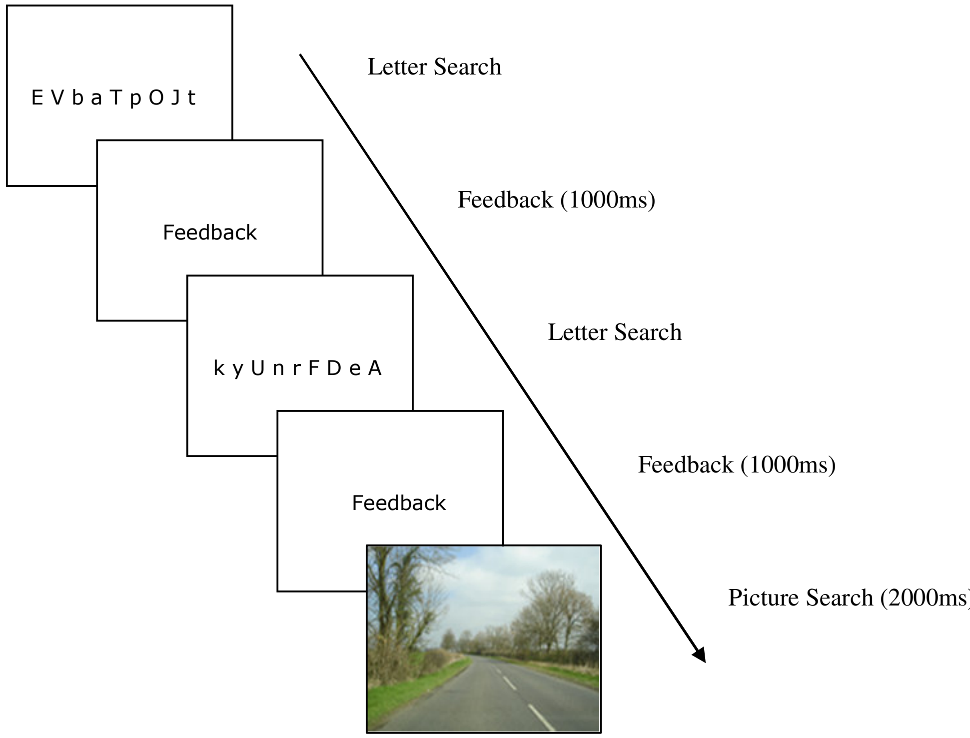

Figure 8.2: The layout of a trial in Experiments Eleven and Twelve. The items in the letter search task were arranged in one of 3 orientations and 1, 2, or 3 letter searches were completed before a road picture was presented. In the example shown the letters are arranged horizontally with two repetitions of the task.

8.4.2 Results

Prior to compiling the eye tracking data from the road pictures, accuracy and RT in the letter search task were analysed. This analysis consisted of two 3x3 ANOVAs using the two variables of *orientation* and *repetition* of the letter search, followed by planned contrasts. Helmert contrasts were used to compare the vertical and horizontal conditions, and then compare the random condition with the mean of the horizontal and vertical conditions. Simple contrasts were used to compare R1 to R3 and R2 to R3. Only the letter search immediately prior to the picture search was analysed (the single search in R1, the second search in R2, and the third search in R3), however these searches were only analysed if the preceding searches in each trial had been responded to correctly. Where sphericity was an issue the Huynh-Feldt correction was used, however the corrected degrees of freedom are only quoted if this correction changed the level of statistical significance. Preliminary analysis on the eye data revealed that one participant was more than two and a half standard deviations from the mean on more than one eye movement measure, therefore this participants' data was removed from all analyses.

For letter search accuracy the data showed a significant effect of *orientation* ($F(2,36) = 5.572$, $MSE = 33.222$, $p<0.01$), with a random search resulting in significantly fewer correct responses ($\bar{x}$ = 89%) than a horizontal or vertical search ($\bar{x}$ = 92%; $F(1,18) = 7.813$, $MSE = 20.331$, $p<0.05$), see figure 8.3a on page 252. There was no effect of *repetition*. In terms of RTs there were significant effects of *orientation* ($F(2,36) = 23.961$, $MSE = 0.075$, $p<0.001$) and *repetition* ($F(2,36) = 22.167$, $MSE = 0.048$, $p<0.001$), see figure 8.3b on page 252. Correct responses were significantly faster to a horizontal search ($\bar{x}$ = 2.6 seconds) compared to a vertical search ($\bar{x}$ = 2.95 seconds; $F(1,18) = 38.248$, $MSE = 0.062$, $p=0.001$). Responses to R1 ($\bar{x}$ = 2.95 seconds) proved to be significantly slower than responses to R3 ($\bar{x}$ = 2.7 seconds; $F(1,18) = 21.574$, $MSE = 0.047$, $p<0.001$). Mean response time to R2 was the same as to R3 ($\bar{x}$ = 2.7 seconds).

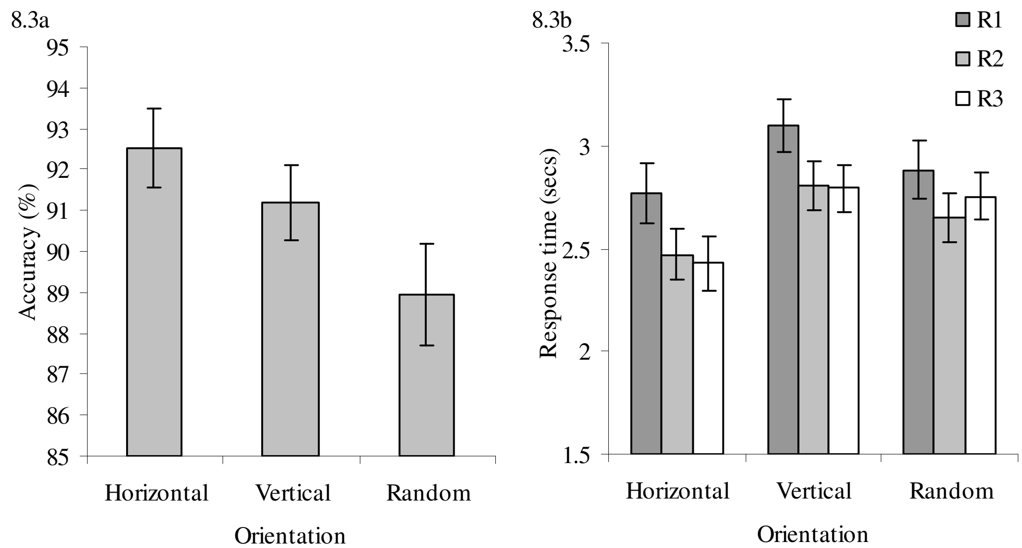

Figure 8.3: Accuracy (a) and response times (b) to the letter search task. A horizontal search is easier than a vertical and random search.

Analysis of eye movements was only conducted on trials in which the letter search task(s) had been completed accurately; any incorrect trials were removed from the analysis (this accounted for 8% of all trials completed, and 15% of all fixations made). To determine the scanning behaviour in the picture search following each letter search the standard deviation of fixations in the horizontal axis and the standard deviation of fixations in the vertical axis was measured. Although no predictions were made regarding the carry-over of other search characteristics this was explored by recording the mean number of fixations, mean fixation duration, and saccadic amplitude. Analysis therefore consisted of five 3x3 ANOVAs followed by the same contrasts used in the letter search task.

The *orientation* and *repetition* of the letter search had no influence over the standard deviation of fixations along the horizontal axis in the picture task. However for the standard deviations of fixations along the vertical axis there was a main effect of *orientation* (F (1.060,19.077) = 5.449, *MSE* = 2.105, p<0.05). Planned contrasts showed that the spread of search in the vertical axis in the picture search was significantly greater following a vertical letter search ($\bar{x}$ = 2.8°) compared to a horizontal letter search ($\bar{x}$ = 2.2°; F (1,18) = 6.766, *MSE* = 1.046, p<0.05). There was also an interaction between *orientation* and *repetition* (F (3.690,66.417) = 2.481, *MSE* = 0.110, p=0.057). The spread of search in the vertical axis following a vertical or horizontal letter search did not vary with regard to the number of repetitions of each search; however three repetitions of a random letter search increased the subsequent spread of search in this axis compared to a single repetition (F (1,18) = 7.448, *MSE* = 0.325, p<0.05), see figure 8.4.

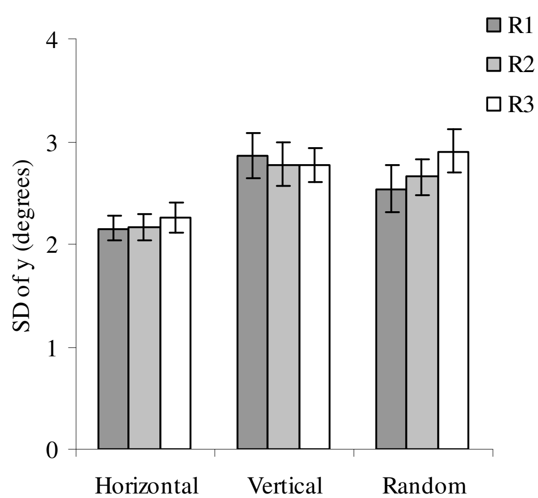

Figure 8.4: Spread of search along the vertical axis in the picture search task as measured through the standard deviation of 'y' coordinates of fixations.

The letter search task had no influence on the number of fixations or the mean duration of fixations given to the picture search task. It did however influence the saccadic amplitude in the picture search, showing an interaction between *orientation* and *repetition* (F (3.118,56.120) = 2.714, *MSE* = 0.561, p=0.051). The saccadic amplitude in the picture search following a horizontal or vertical letter search did not vary greatly across repetitions, however following a random search the saccadic amplitude in the picture search increased with more repetitions; from a mean of 6.3° at R1 to a mean of 7.1° at R3 (F (1,18) = 5.941, *MSE* = 1.727, p<0.05). See figure 8.5.

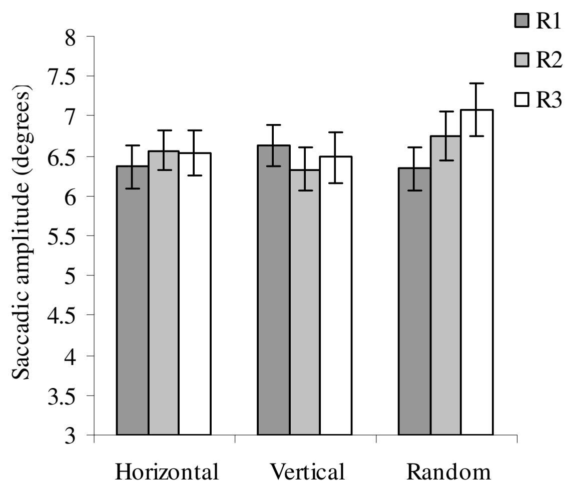

Figure 8.5: Saccadic amplitude in the picture search task. Whilst this did not differ following a horizontal or vertical letter search, more repetitions of a random letter search increased saccadic amplitude.

To ensure that the variations in saccadic amplitude were due to carry-over the saccadic amplitude of fixations in the letter search task were analysed. This showed a main effect of *orientation* (F (2,36) = 46.170, *MSE* = 5.214, p<0.001). The saccadic amplitude in a random letter search ($\bar{x}$ = 8.7°) was significantly larger than in a horizontal ($\bar{x}$ = 6.6°) or vertical search ($\bar{x}$ = 6.3°), (F (1,18) = 184.900, *MSE* = 1.097, p<0.001).

8.4.3 Discussion

The first experiment in this chapter showed that a completely unrelated visual search task could influence the spread of search on subsequent road pictures. However, the transference of search strategy from the letter search to the picture search was not found consistently across all measures taken. Only the vertical spread of search and the saccadic amplitude in the picture search task was affected by the previous letter search, and scanning of the pictures only appeared to be influenced by a previous letter search when the letters were arranged vertically or randomly.

The carry-over effects found support the theory of Bundesen (1990) that relevant objects and areas of space are assigned attentional weights which bias attentional selection to these areas and away from irrelevant areas. In the letter search task participants would have allocated attention to the locations of the letters, and any bias towards these locations then persisted to the picture search task because participants were used to making eye movements in this area. Yet why did the strategy from a horizontal letter search fail to carry-over? One possible reason is that because attention is usually distributed across the horizontal axis in the driving task (e.g., Crundall & Underwood, 1998) horizontal scanning in the picture task would be high regardless of the orientation of letters in the preceding search. This explanation is strengthened by the finding that although a vertical letter search did carry-over it only served to increase attention along the vertical axis, it did not reduce the spread of search given to the horizontal axis (this illustrates that participants were not simply looking back to where they had searched in the previous letter search task). It may be the case that due to experience of viewing natural scenes the horizontal axis is already biased for attentional selection and this cannot be overridden by the strategy from the letter search task.

An alternative explanation for the disproportionate carry-over between the horizontal and vertical conditions may be that the level of resources one invests in the task will influence the persistence of the task strategy. The results show that a horizontal letter search is easier than a vertical or random search, with faster RTs and higher accuracy. This is not particularly surprising considering that all participants were based in the United Kingdom and were accustomed to reading books in which the text ran from left to right. As a consequence of the simplicity of this condition participants may have invested fewer processing resources into the establishment of the strategy, allowing it to be abandoned with ease when the picture search ensued. This is consistent with the conclusions made following the individual differences of AB magnitude and carry-over in the AB experiments, and the differential carry-over of shape and colour in Experiment Eight.

A further finding lends support to this suggestion; whilst the number of repetitions of the letter search did not influence the carry-over of a vertical search strategy, a random search only persisted following three repetitions of the letter task. In a vertical letter search the spatial locations of the letters displayed was constant in every trial and in every repetition (even though the letters changed each time). This means that high attentional weights can be allocated to vertical locations in a single repetition of a vertical search because the locations are fixed. These weights then persist to the picture task regardless of the number of repetitions of the letter search. In the random letter search the spatial location of the letters varies on every repetition therefore allocating attentional weights to the locations from the first search (R1) would actually impair performance in subsequent searches (R2 and R3). Weights may therefore be allocated to the very top and very bottom of the display to ensure that attention is always directed to these areas (weights will be less necessary to the extreme left and right of the screen as these are locations usually associated with reading text). This will bias attention in the vertical axis in the picture search, but as the strategy is less controlled it may require time for it to reveal itself in the picture search task. This also fits with previous findings from the AB chapters that a set is more likely to persist as it becomes more controlled.

The carry-over of saccadic amplitude from a random letter search followed the same pattern, with an increase in saccadic amplitude in the picture task only when it was preceded by three random letter searches. As the letters in a random search are arranged further apart it encourages larger saccades in order to complete the task. This scanning then appears to carry over to the picture search, leading to larger saccades in the picture search as eye movements in the previous letter search task were less constrained. Experience with a random letter search enhances this carry-over, lending support to the notion that observers base their visual search on information built up through experience (Shinoda et al. 2001).

The fact that the orientation of letters influenced scanning in the picture task (albeit to a lesser extent than was predicted) shows that a set was established to complete the task, which then persisted to the pictures. This provides strong evidence of a location-based attentional set which biases attention to specific locations within the visual field using the knowledge that these locations will contain task-relevant stimuli. These biases remain, and serve to direct attention in a succeeding task despite the salience of the stimuli in the second task.

Although Experiment Eleven provided evidence to support two of the predictions made regarding the carry-over of search behaviour from a letter search task to an unrelated picture search task there was a drawback to the study. As there was no memory test it is difficult to claim that participants were actually viewing the pictures in a suitable way to process them effectively (as would happen in the real world). The transference of search behaviour from the letter search to the picture search could merely indicate that participants were moving their eyes in a similar manner to how they were moving them previously. Although this would also show that the letter search influences scanning in the picture search, this effect would have little real-world significance as completing a real-world task would require definite processing of any stimuli presented. As such the top-down task demands in a real-world task may overshadow any carry-over that occurs, meaning that carry-over will not be an issue of concern. In an effort to determine whether the pictures are being processed fully, the study was completed again with a memory test. By measuring eye movements to this memory test it would also be possible to establish any lasting effects of the carry-over, and determine the possible time limits of the effect.

8.5 Experiment Twelve: Carry-over of visual search in natural scenes (2)

8.5.1 Method

The methodology for the second experiment in this chapter was identical to that of the first, with the addition of a memory test. Twenty participants (9 males and 11 females), aged between 18 and 39, with a mean age of 22.5 years completed the experiment for a payment of £5. Participants were a mixture of undergraduate and postgraduate students at the University of Nottingham. Following completion of the procedure outlined in Experiment Eleven all participants were given a five minute break. They were then presented with all 180 road pictures again, randomly mixed with 90 new road images (30 rural, 30 suburban and 30 urban roads). Each picture was shown for 2000ms and then participants were prompted to press ‘y’ or ‘n’ to state if they had seen the picture in the previous stage of the experiment (yes or no).

8.5.2 Results

Analysis of this experiment consisted of the same ANOVAs and planned contrasts as the previous experiment. Two participants were removed from the analysis due to their performance on several eye movement measures falling more than 2.5 standard deviations from the mean.

In terms of accuracy to the letter task there was a main effect of *repetition* ($F(2,34) = 48.306$, $MSE = 38.016$, $p<0.001$), with participants performing better in R3 than R1 ($F(1,17) = 52.507$, $MSE = 44.707$, $p<0.001$) and R2 ($F(1,17) = 15.582$, $MSE = 15.453$, $p=0.001$). There was no effect of *orientation*. For RT there was a main effect of *orientation* ($F(2,34) = 67.264$, $MSE = 0.037$, $p<0.001$) and a main effect of *repetition* ($F(2,34) = 30.834$, $MSE = 0.021$, $p<0.001$). Participants took longer to correctly identify the number of vowels when the letters were presented vertically compared to horizontally ($F(1,17) = 113.509$, $MSE = 0.029$, $p<0.001$). Participants also took longer to complete a single repetition of a letter search than a third repetition ($\bar{x} = 2.8$ seconds vs. $\bar{x} = 2.6$ seconds respectively; $F(1,17) = 35.148$, $MSE = 0.016$, $p<0.001$). R2 and R3 were not significantly different. Taken together the accuracy and RT data show that a vertical search is difficult and participants improved at the letter search following more consecutive repetitions of the task.

As before, analysis on the eye tracking data was only conducted on trials in which the letter task had been completed correctly. Incorrect trials were removed, accounting for 11% of all trials completed and 13% of all fixations made. Analysis of the standard deviation of fixations in the horizontal axis showed similar findings to

Experiment Eleven, with no main effect of *orientation* or *repetition*. However there was an interaction between the two variables ($F(4,68) = 4.731$, $MSE = 0.452$, $p<0.01$). Following three repetitions with the letter search task, a horizontal letter search increased the standard deviation of fixations along the horizontal axis in the picture task. However, as expected the same finding was not seen following a vertical search, with little difference across repetitions ($F(1,17) = 13.663$, $MSE = 1.808$, $p<0.01$). In addition, whilst three repetitions of a horizontal letter search increased the spread of search in the pictures along the horizontal axis, the spread of search in this area did not alter with more repetitions of a random letter search ($F(1,17) = 4.361$, $MSE = 0.796$, $p = 0.052$). See figure 8.6a (page 261) for these effects.

For the standard deviation of fixations in the vertical axis in the picture search there was a main effect of *orientation* ($F(2,34) = 13.845$, $MSE = 0.213$, $p<0.001$). The planned contrasts revealed a significantly greater spread of search along this axis following a vertical letter search compared to a horizontal letter search ($F(1,17) = 30.356$, $MSE = 0.113$, $p<0.001$). Similar to Experiment Eleven there was an interaction between *orientation* and *repetition* ($F(4,68) = 2.948$, $MSE = 0.110$, $p<0.05$). Following three repetitions of a random letter search, participants increased their search along the vertical axis in the subsequent road pictures. Whereas fixations along the horizontal axis and the vertical axis did not change across repetitions, greater repetitions of a random letter search led to a wider vertical search ($F(1,17) = 8.434$, $MSE = 0.238$, $p=0.01$). See figure 8.6b (page 261) for these effects.

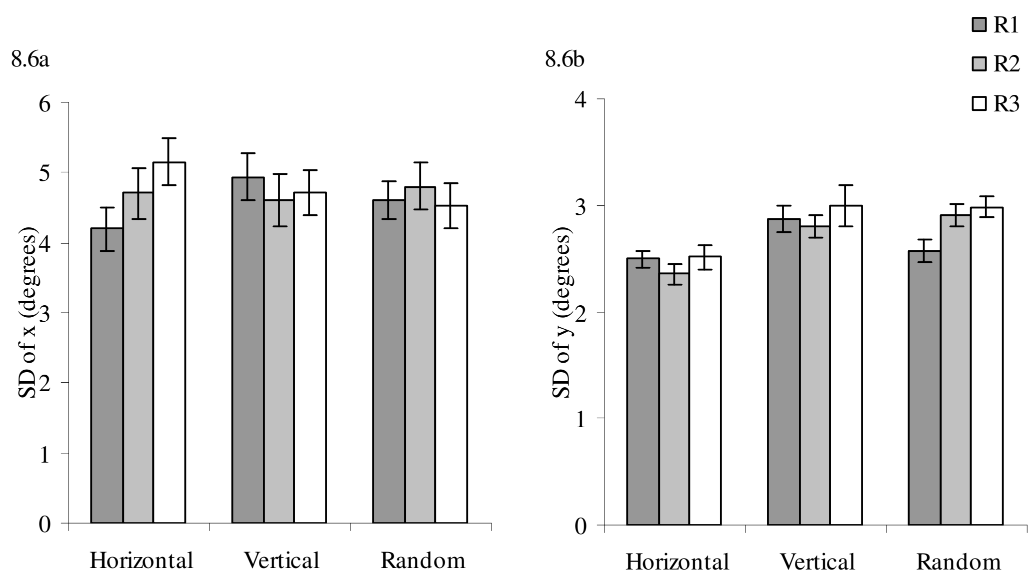

Figure 8.6: The standard deviation of the position of fixations in the 'x' (a) and 'y' (b) axis of the road photographs.

There was no difference between each *orientation* and *repetition* of the letter search for mean fixation duration or the number of fixations made to the road pictures. There was however an effect of the letter search on the saccadic amplitude in the pictures, but this was only due to the varying repetitions of the letter search ($F(2,34) = 3.263$, $MSE = 0.443$, $p=0.05$). Saccadic amplitude was greater following three repetitions of the letter search ($\bar{x} = 6.5°$) compared to just one repetition ($\bar{x} = 6.2°$; $F(1,17) = 4.228$, $MSE = 0.451$, $p=0.55$). However, unlike in the previous experiment, this effect occurred following all letter search types, not just a random letter search.

Accuracy to the memory test was very low, with participants only scoring an average of 57% correct. This did not vary according to the letter search which preceded each of the pictures viewed in the previous set of trials. The eye movement measures taken from the memory test (i.e., when participants viewed the same pictures for a second time) showed that the letter search had little effect on how participants viewed the images a second time around. However, there was a significant interaction between *orientation* and *repetition* for the standard deviation of fixations in the horizontal axis ($F(2.815, 47.863) = 3.958$, $MSE = 0.582$, $p<0.05$). Following one repetition of a horizontal letter search the standard deviation of fixations along the horizontal axis in the following road pictures when viewed in the memory test was low ($\bar{x} = 4.7°$), but after three repetitions this standard deviation increased to a mean of 5.2°. Conversely, following one repetition of a vertical letter search participants showed increased scanning along the horizontal axis when shown the same pictures in the memory test ($\bar{x} = 5.1°$), but this standard deviation decreased following three repetitions of a vertical letter search ($\bar{x} = 4.7°$). In addition, standard deviation of fixations along the horizontal axis in the memory test was high when the picture was preceded by a single random search in the first part of the experiment in comparison to a vertical and horizontal letter search ($F(1,17) = 11.794$, $MSE = 0.441$, $p<0.01$) but decreased when the picture was preceded by three random letter searches ($F(1,17) = 5.624$, $MSE = 1.811$, $p<0.05$). This again shows that the random letter search requires practice before it will persist to a further task. See figure 8.7 on page 263 for these effects. The data from the memory test shows that not only does the letter search transfer to a second task, influencing subsequent scanning along the horizontal axis in the picture search, this carry-over of search persists to a third task, revealing a robust effect with substantial staying power.

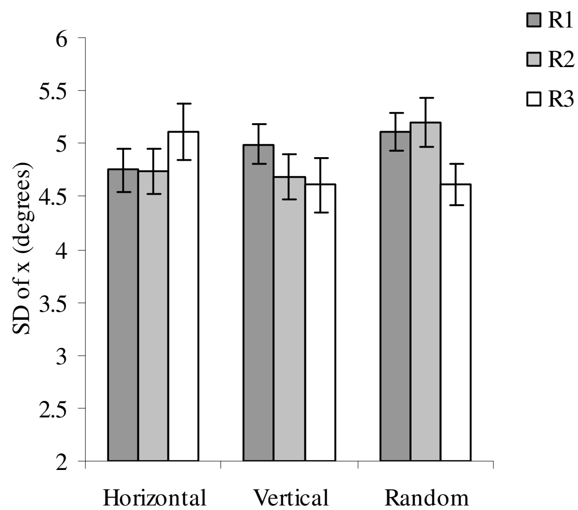

Figure 8.7: The standard deviation of fixations in the memory search task, based on the type of letter search preceding the picture in the main part of the experiment.

8.5.3 Discussion

This experiment was completed with the aim of replicating the findings of Experiment Eleven, whilst introducing a memory test to check that participants were processing the road pictures. Although the results found were slightly different to those found previously, the main effect of carry-over was replicated, and extended. Similar to the previous experiment the spread of search along the vertical axis in the road pictures increased following a vertical letter search. In addition to this findings also showed that a horizontal letter search increased the spread of search along the horizontal axis in the picture search. This gives more substantial evidence to show that the letter search influences the spread of search in the picture task, despite having no relevance to this task. Note however that this effect only revealed itself following three repetitions of the horizontal letter search task. This again suggests that some strategies take time to become established to such an extent that they will intrude upon another task.

The transference of search from a horizontal letter task to the picture task was not found in Experiment Eleven. One of the possible reasons proposed to account for this null effect in the previous experiment was that a horizontal search may not carry-over because people show a predominance of search along the horizontal axis when driving, and the letter search will have little influence over this pre-established effect. The fact that this experiment has shown an influence of the horizontal search suggests that this may not be the case. Although individuals are more likely to search along the horizontal axis, in the current study a preceding task which encouraged horizontal scanning served to heighten this effect, making participants even more likely to search in this direction.

Based on past research showing differences in search behaviour of drivers with varying levels of experience, the different results found across the two experiments could be attributed to participant differences. For instance, as experienced drivers show more horizontal scanning than novice drivers (Crundall & Underwood, 1998), a horizontal letter search might have little effect on their subsequent scanning of a road picture. However, as novice drivers do not have such a pre-defined spread of search because they have less experience to base their search upon (Shinoda et al. 2001), the horizontal letter search may have an effect on subsequent scanning. It is therefore predicted that the first experiment involved a greater number of experienced drivers than the second experiment. Information regarding whether participants had passed their driving test, and if so how long they had been driving for, was not collected for the present two experiments, therefore this prediction cannot be confirmed; however this is an avenue for future research.

Whilst the first experiment showed greater saccadic amplitude in the road pictures following more repetitions of a random letter search, the second experiment showed greater saccadic amplitude following more repetitions with all letter searches. As novice drivers fail to alter their spread of search in relation to demand (Crundall & Underwood, 1998), it may be suggested that their attentional set for relevant locations is not fully established and controlled. Consequently the set is more at risk from interference in comparison to that of an experienced driver. This also provides evidence for more experienced drivers in the first experiment; who are only influenced by specific aspects of the letter task due to a more controlled attentional set in the picture task.

Two explanations were proposed to account for the lack of horizontal carry-over in Experiment Eleven; the first was that a horizontal strategy did not carry-over because attention is biased to this area in road pictures anyway, the second was that it did not carry-over because fewer resources were required for a horizontal letter search meaning that it was easily abandoned when the task changed. As the present experiment has found carry-over from the horizontal letter search task it is difficult to conclude between these two alternatives, and instead it is suggested that the differences between the two studies are due to participant differences.

Further evidence for the carry-over of a search strategy comes from the eye movements given to the road pictures in the memory test. Given the nature of the experiment, with different letter searches shown randomly, the carry-over of search strategy from the letter search is expected to be short-lived. In every trial participants complete at least one letter search and one picture search. However, as the subsequent trial may show letters in a different orientation, the carry-over is only expected to last until a new letter search is presented. Therefore, at the end of the main experiment, prior to the memory test, participants should have abandoned any strategy they have adopted previously. Despite this, when viewing the road pictures a second time in the memory test, participants were still influenced by the orientation of the letter search they were given immediately before they viewed the picture the first time. Specifically, greater horizontal scanning of road pictures was found in the memory test when these pictures had been preceded by this letter search type in the first part of the experiment. Road pictures which had been preceded by a vertical letter search in the first part of the experiment reduced horizontal scanning in the memory test. Therefore, when viewing the pictures for a second time, participants were moving their eyes to the same extent as before. If attentional weights are allocated to these images (Bundesen, 1990), and these weights are influenced by a preceding task, it is reasonable to infer that the preceding task will also influence the spread of search on later viewings of the same picture. This means that the strategy used to complete a visual search has the potential to influence subsequent search behaviour for a substantial period of time following its completion. As the pictures were fully randomised across the course of the experiment this effect has nothing to do with the characteristics of the road pictures. This also means that top-down processing which persists to a visual search of natural scenes will influence the allocation of attention in these scenes, overshadowing the automatic capture of attention by highly salient parts of the scene. This finding is also consistent with studies showing a similarity between scan paths made in an initial viewing of a natural scene and subsequent imagery of that scene (e.g., Brandt & Stark, 1997; Laeng & Teodorescu, 2002), and a similarity between scan paths made in an initial and subsequent viewing of a natural scene (e.g., Foulsham & Underwood, 2008).

Again there was a drawback to the findings and this was due to performance in the memory test. This second experiment aimed to show that participants were effectively processing the road images (and therefore should remember them) and not just moving their eyes across the same general areas as they did in the previous letter search. However accuracy in the memory test was very low with participants performing slightly better than chance. This does imply that they were not processing the pictures, possibly showing that in a real-world task carry-over would not be an issue because top-down task demands would overshadow the persistence of set from a previous task. It is worth noting however that the memory test was very difficult, participants saw 270 road pictures in total, all highly similar. The similarity between the image content and layout of each picture means that the task could have been too difficult. For instance, Simons and Levin (1997) have found that memory for the gist of a natural scene is good but memory for specific features is poor. In the driving images the gist and meaning of all pictures is very similar, therefore this may be one of the reasons why memory performance was so low. This would account for the low performance and also suggest that the carry-over effect may occur in real-world tasks.

8.6 Discussion of Experiments Eleven and Twelve

8.6.1 Further evidence for the carry-over of attentional set

The initial reason for completing the final two experiments was to determine whether the carry-over effect is limited to tasks in which the stimuli are highly similar, and search is confined to objects and features. The collection of experiments in Chapters 2-7 show clear evidence for the carry-over effect, yet in every experiment the attentional set persists from one task, to a second task which incorporates identical stimuli to the first (with the exception of Experiment Nine). To improve the applicability of these results it was therefore essential to test carry-over under conditions in which the stimuli differs between the two tasks. The two experiments in this chapter show that despite very distinct stimuli and task demands in the two tasks participants fail to switch set between task one (letter search) and task two (picture search).

The findings therefore reveal that the way in which an observer approaches one task can directly influence the way they approach a succeeding task, regardless of any relevancy between the task demands and stimuli involved, other than that they are both part of a single experiment. Leber and Egeth (2006) suggest that an attentional set persists to a new task because people fail to evaluate the set when the task demands change. Changing set requires resources and if the detriment to performance caused by the old set does not outweigh the resources required to change the set to one which would improve performance, the original set will persist as there is no motivation to change set. In the experiments presented here participants approach the letter search task by choosing the most efficient strategy for that particular search. A change in task to the picture search should elicit a change in strategy, however due to the nature of the task (simply viewing the road pictures for a later memory test), the strategy may not appear to cause any detriment to performance, and therefore there is no motivation to change strategy. This is particularly the case since participants received no feedback regarding their performance in the picture task, therefore were unaware if the way in which they were viewing and processing the road pictures was appropriate for the task.

8.6.2 Persistence of attentional set in the real world

In addition to using naturalistic scenes in the experiment to ensure that the second search task incorporated different stimuli to the first search task, naturalistic stimuli were also used to give some indication of whether the carry-over effect could be found in real-world tasks. Driving stimuli were used because there is already a body of research showing that drivers have pre-defined visual search strategies which are based upon experience with the task and the expectancies a driver has regarding the locations of important driving information (e.g., Crundall & Underwood, 1998; Shinoda et al., 2001; Trick et al., 2004).

Both experiments showed that the visual search of a driving image could be influenced by an unrelated preceding visual search task. This has implications for the driving task as the search given to a secondary task (such as a road sign or in-car display) may carry-over to the primary driving task. It must be noted however that the task of searching road photographs used in Experiments Eleven and Twelve is far removed from the actual driving task. Are the current findings applicable to real-world driving? Of some consequence to this is that researchers have shown that static driving stimuli and real road driving elicit a similar spread of search, with a predominance of horizontal scanning (Hughes & Cole, 1986). This adds weight to the findings and shows that they do have the potential to extend to real world tasks. Additionally the results not only apply to the visual search given to driving scenes, they also have some relevance to the literature regarding visual search in all natural images.

Studies of visual search in natural, complex images show that attention and eye movements are not distributed randomly across a natural scene (Buswell, 1935) and instead there appear to be patterns in the search of these scenes. Saliency models (e.g., Itti & Koch, 2000) state that eye movements and attention are driven by the attributes of stimuli within a scene, with attention allocated to regions of space and objects based on saliency. This means that the most salient areas will be fixated first, regardless of task demands or individual differences between observers. However a large number of studies have shown that there is a role for top-down processing when viewing a real-world scene. Mackworth and Morandi (1967) and Loftus and Mackworth (1978) provide evidence that attention is guided by the information contained within a scene, with participants looking at more informative areas and objects sooner, for longer, and more often than uninformative areas and objects. Brockmole and Henderson (2006) claim that as natural scenes have a particular structure, with standard spatial relationships between objects (e.g., the chair is next to the table), observers will use contextual cues (Chun & Jiang, 1998) to guide their visual search. This supports the view that visual search strategies are built up through experience and search is not purely guided by the attributes of the scene (Gilchrist & Harvey, 2006).

One distinctive characteristic of visual search in natural scenes is that observers make more horizontal saccades than vertical saccades and tend to focus their search along the horizon (e.g., Gilchrist and Harvey, 2006). As this is the same search strategy used when driving and when viewing driving images the present findings can be extended beyond the driving literature.

8.6.3 The influence of experience

Leber and Egeth (2006) have found that an attentional set will only persist to a second task if the participant has had sufficient experience with this set. When they gave participants 320 training trials the set carried over to a new task, however when they gave participants 40 training trials carry-over of the attentional set was not found. They attribute this to the amount of resources the participants invest in the training trials; if an attentional set is fully established it seems wasteful to change set, if fewer resources have been invested in the set the costs associated with switching set are low. In the current studies 'experience with the attentional set' was manipulated using the factor of repetition. However varying the number of repetitions from one to three in no way allows for the level of training given by Leber and Egeth, or by this author in the AB studies. Yet repetition of the letter search did serve to increase carry-over to the picture task. If anything one would expect that the motivation to change set in the current two studies would be high due to the differences between the two tasks (similar to the effects of variable mapping vs. consistent mapping; Shiffrin & Schneider, 1977), the small amount of experience with the letter search task, and the various top-down and bottom-up influences inherent in the picture search. The fact that these influences failed to overshadow the carry-over effect shows that the effect is fairly robust.

In addition to the findings that experience with the initial attentional set influences the carry-over of that set, the present results provide evidence that experience with the *second* attentional set influences carry-over. Due to the differences in 'horizontal' carry-over between the two experiments it has been predicted that participants in the first study had more experience with the driving task; this resulted in less carry-over because they had more top-down control in the picture search task. In the second experiment it is predicted that there were more novice drivers who suffered from carry-over to a greater extent because they had less top-down control over their search of the driving images.

Although this prediction cannot be tested without further investigation, it does support previous findings from the AB studies that individuals may differ in the level of control they have over a top-down attentional set. Results from Experiments Three and Four in this thesis suggest that the level of control over the initial attentional set will affect carry-over of this set. Now there is evidence, from a post-hoc explanation of the findings, that the carry-over effect will also be influenced by top-down control over the set in the second task. As experienced drivers have more top-down control over attention to driving stimuli they will suffer from carry-over to a lesser extent.

The fact that repetition had an effect on the level of carry-over also provides evidence for differing strengths of attentional set. Whilst the vertical letter search strategy persisted to the picture search after one repetition, a random letter search strategy required three repetitions before it persisted. A vertical search took longer than a random search, supporting the findings from the change detection experiments that when more resources have been invested into the strategy it is more likely to persist.

8.6.4 Evidence for a location-based attentional set.

One final reason for completing these two experiments was to explore the idea that attention can be directed to spatial locations on the basis of an attentional set, and that this ‘location-based’ attentional set would carry-over to a second task in a similar way to a feature-value- or feature-based attentional set. The letter search was designed to encourage participants to adopt a search strategy which allowed them to selectively attend to specific locations to search for target letters amongst distracter letters. The orientations changed across trials to ensure that different strategies would be required in different conditions. It was predicted that if participants did use a set to allocate attention to certain areas in the display this set may persist to a second search task and influence the spread of search in this second task. Findings from both experiments supported this showing an increase in vertical scanning after a vertical letter search and an increase in horizontal scanning after a horizontal search.

8.6.5 Drawbacks of Experiments Eleven and Twelve

Despite the fact that predictions have been made regarding possible individual differences between participants in the two experiments, no solid conclusions can be drawn due to the fact that levels of driving experience were not recorded. In hindsight this would have been a very useful measure to take, however this would also have required a between-groups design, which comes with its own problems. The differences between the findings of the two experiments have prompted a number of interesting hypotheses and there is scope to take this work forward in the future.

In addition to this, it has been brought to the author's attention that providing a horizontally presented feedback to the participants after each letter search could in itself force participants to allocate attention horizontally in the picture task (representing a further source of carry-over). Any concerns about this could be resolved by providing participants with feedback in the form of a blank green or red screen (correct or incorrect). However, given the time that the feedback was presented for (1000ms), and the fact that vertical carry-over was more evident that horizontal carry-over, it is proposed that the presentation of the feedback had little influence on the data.

A further issue with the studies is that there was no 'control' condition in which participants viewed the driving pictures with no accompanying letter search task. This would have given a baseline measure of visual search on the road pictures with which to compare the visual search of road pictures that followed the different letter searches. However, although the letter search task was not particularly demanding, the resources required to complete it would have had an influence over processing of the road pictures. Even with no carry-over of the location-based attentional set there would inevitably have been some level of carry-over whereby the picture search would have been influenced by the letter search. A control condition without a letter search task would therefore not be completely comparable to the experimental condition.

8.6.6 Conclusion

Although the two experiments in this chapter represent a departure from the other studies in this thesis there were strong theoretical reasons why they should be conducted. The studies were designed to satisfy three separate issues:

- Will the carry-over effect extend to situations in which the two successive tasks involve very different stimuli?
- Is the carry-over effect applicable to naturalistic situations or limited to controlled laboratory environments?
- Can attention be allocated using a location-based attentional set, and will this set persist to a succeeding task and influence the spread of search in this second task?

The experiments have been successful by providing an answer to all three questions, and the answer has been positive on all three counts. The results have therefore increased the applicability of the other findings in this thesis, and they have expanded upon the theoretical assumptions that have so far been suggested. The collection of findings from this thesis can now be applied to more varied situations, and the results are applicable to more real-world tasks.

Chapter Nine: General Discussion – The characteristics of top-down attentional control

9.1 Review of the research aims and objectives

The primary aim of the work contained in this thesis was to investigate the persistence of top-down attentional set. In particular the intention was to determine whether an attentional set can carry-over from a task in which it is relevant to a task in which it is no longer relevant, what influences this carry-over, and what ultimately causes the carry-over. Related to this, the work also aimed to verify the importance of top-down attentional control, and reveal some of the characteristics of attentional control by exploring the carry-over effect.

These aims were achieved through the use of three different methodologies; the Attentional Blink (AB) paradigm, a change detection task paired with a visual search task, and visual search of natural scenes. This chapter contains a discussion of the findings from each of the methodologies employed. First the main findings of carry-over will be reviewed. Due to the fact that the evidence for carry-over had implications for the top-down control of attention the collection of results motivated the development of a model to describe the workings of an attentional set. This model will be described in relation to what the experiments revealed about the mechanisms of top-down control, and key findings from the literature will be discussed in relation to the model. The chapter will then end with a short conclusion to evaluate the success of the work completed.

9.2 Summary of the findings of carry-over

9.2.1 Persistence of attentional set in the RSVP paradigm

In a rapid serial visual presentation task (RSVP) participants are asked to search through a stream of stimuli and respond to one target (T2) and ignore another target (T1; single target RSVP), or to respond to both targets (T1 and T2; dual target RSVP). All items are usually shown to the same spatial location and T1 precedes T2 by a ‘temporal lag’. The temporal lag varies and studies show that whilst T2 accuracy in a single target RSVP remains constant (and high) across all lags, T2 accuracy in a dual target block follows a bimodal pattern; accuracy is high if T2 is shown immediately after T1 (lag 1) but decreases between lags 2 to 5 (around 200-500ms SOA), before rising again at later lags. The deficit at intermediate lags is referred to as the attentional blink (AB; e.g., Broadbent & Broadbent, 1987; Chun & Potter, 1995; Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Ghorashi et al., 2003; Raymond et al., 1992; Shapiro et al., 1994; Visser et al., 1999; Weichselgartner & Sperling, 1987) and represents the detriment caused when an individual has to respond to two items in close temporal proximity.

When completing a RSVP participants will establish an attentional set to selectively attend to targets and inhibit distracters, but this set will differ according to whether they have to respond to both T1 and T2, or just T2. In the latter instance participants should ignore T1 and the (irrelevant) target will not be represented in the set. If participants complete a single target block after a dual target block they should switch attentional set from one which allocates resources to T1 and T2 to one which allocates resources to T2 and inhibits T1. It was reasoned that if they fail to switch set and the set from the dual target block persists they will continue to show a U-shaped pattern of performance in the single target block. Providing that T1 does not capture attention automatically in a single target block on the basis of sharing similarities with T2 (contingent capture; Folk et al., 1992), the only reason for such a pattern of performance in the single target block would be that participants are still allocating attention using the attentional set from the preceding dual target block (despite T1 being irrelevant and causing a detriment to performance).

Following the completion of two pilot studies to ensure that the experimental design and the stimuli selected were suitable for measuring the AB in a dual target block and to check that performance did not vary in relation to lag in a standard single target block (no prior experience of responding to T1), three RSVP experiments were conducted to investigate the carry-over of attentional set. In each experiment participants were separated into two groups; one group had no experience of a task-relevant T1 and only ever responded to T2 (no-set-priming) and the other group completed a single target block after having experience with responding to both T1 and T2 in a dual target block (set-priming). The comparison between the final single target block completed by each group was the most pertinent to the hypothesis as this would show whether participants in the set-priming group were continuing to allocate attention to T1, despite its irrelevance, due to the carry-over of attentional set. Only the final experiment (Experiment Five) showed definitive evidence of an AB effect in the final block completed by the set-priming group (compared to the no-set-priming group). In this experiment set-priming participants completed three dual target blocks before the single target block, whereas in the initial two experiments (Experiments Three and Four) set-priming participants completed one dual target block before the single target block. This shows that an attentional set is more likely to persist to a second task when it is more practiced. This is consistent with the notion that as a set becomes more practiced it becomes less controlled and more automatic (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Although Experiments Three and Four did not show a clear effect of carry-over after the initial analysis, the removal of participants who suffered from the AB to a lesser extent in the dual target block (nonblinkers) revealed an AB in the single target block completed by the remaining set-priming participants (blinkers). This was an unexpected finding as the size of the blink was deemed to be unimportant to the overall hypothesis of carry-over ("the precise blink magnitude is not critical" [Chapter Three, pp. 77]), yet blink magnitude had a direct influence on carry-over. Participants who suffered from a large blink in the dual target block continued to use the set in the single target block, whereas those who showed a smaller blink in the first block appeared to switch set between the two blocks.

Given that blink magnitude is related to cognitive control (Taatgen et al., 2007) and activity in the prefrontal cortex (Martens et al., 2006); and deficits in set switching have also been related to cognitive control (Dreisbach & Goschke, 2004) and activity in the prefrontal cortex (Milner [1964], as cited by Robbins & Rogers [2000]) it is predicted that participants who suffer from a smaller blink have a more flexible cognitive style. They can flexibly attend to both T1 and T2 (reducing the blink; Olivers & Nieuwenhuis, 2006) and they can flexibly switch set in accordance with a change in task demands. Participants who suffer from a large blink invest more resources into the identification of targets (Olivers et al., 2007). This means that the impairment on T2, due to the processing of T1, is more substantial because more effort is put into processing T1. It also means that participants are unable to change set when required because the set is more stable (less flexible) and the investment of resources has consolidated the set and increased the costs of switching set (relative to the benefits of switching set).

9.2.2 Carry-over from a visual search task to a change detection task

Although the AB studies did reveal a carry-over effect, this was limited in its applicability because spatial shifts of attention were not required in these experiments, and the dual target RSVP was very similar to the single target RSVP (task switching literature shows that a set is more likely to intrude upon a second task when the stimuli and task demands in both tasks are very similar [e.g., Lien et al., 2005; Monsell, 1996]). To increase the range of cognitive approaches that show carry-over the second methodology incorporated the requirement to move attention through different areas of space, and increased the difference between the two tasks (the task in which the set is initially adopted, and the task to which the set persists). This was achieved with the use of a change detection task and a visual search task.

In a change detection task participants are presented with two successive arrays that are identical except for a single change that has been made. Under normal circumstances this change is easy to detect because it elicits a motion transient (Smilek et al., 2000). However, if this transient is masked by an ISI the change becomes difficult to detect, resulting in 'change blindness' (e.g., Levin & Simons, 1997; Rensink et al., 1997; Rensink, 2002; Shapiro, 2000; Simons & Levin, 1998). Findings show that changes are easier to find if they occur in areas of 'central interest' (Rensink et al., 1997), or are more relevant to the situation portrayed in the scene (Velichkovsky et al., 2002). In the change detection experiments completed for the present thesis the top-down and bottom-up influences upon the visual array were controlled therefore participants were expected to adopt a serial search to find the change. However, before completing the change detection task in each trial participants had to search for a number of specifically coloured targets or a number of specifically shaped targets among a series of heterogenous distracters. Again, because the influences upon the change detection arrays were controlled there should be no difference between detection of different types of change, *unless* the attentional set from the visual search task persisted to the change detection task. This was explored by varying the congruence between the search feature and the change. The change was either congruent or incongruent to the *feature level* that was relevant in the preceding search (i.e., if searching for red shapes a congruent feature change would be a colour change to one of the items in the display [either a previous target or a previous distracter] and an incongruent change would be a shape change to one of the items in the display [previous target or distracter]). The change was also congruent or incongruent to the *feature value* that was relevant in the preceding search (i.e., if searching for red shapes a congruent change would be a change to a red shape [a change to a previous target] and an incongruent change would be a change to another coloured shape [a change to a previous distracter]). Note that these examples use the feature of colour but the experiments involved an equal number of shape and colour searches (with the exception of Experiment Nine) and an equal number of shape and colour changes.

The results of the experiments consistently showed that changes made to previous targets were detected faster than changes made to previous distracters. This was regardless of whether the targets remained in the same locations in the search task and the change detection task (Experiment Nine), and regardless of display size and search set size[25] (Experiment Ten). This clearly revealed the carry-over of a *feature-*

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[25] The number of feature values participants had to search for; either one or two.

value-based attentional set. Experiment Eight also showed that changes made to previous distracters were detected faster if the change was congruent to the preceding search feature (either shape or colour). This provided evidence for the persistence of a *feature-level-based* attentional set (this is referred to as a *feature-based* attentional set), however this effect was not replicated in the subsequent two experiments.

One further finding was that a search for shape appeared to carry-over to a greater extent than a search for colour (Experiment Eight). This was attributed to the processing time required to complete a shape search; a shape search is more difficult therefore the set would have to be stronger to complete the task (focusing on shape and inhibiting colour). A colour search is easier and can be completed via a 'passive' search (Wolfe, 1994) therefore it only necessitates a weaker set, which does not carry-over because it is easy to abandon when the task changes (Olivers & Nieuwenhuis, 2005). Experiment Ten attempted to test this theory but as the effect of feature congruence disappeared (changes made to the previous search feature are detected faster than changes made to the previous non-search feature), it could not be concluded. The evidence from Experiment Eight was however consistent with the data from the AB experiments in that a set is more likely to persist when more resources are invested in the task.

9.2.3 Carry-over of attentional set to natural scenes

The evidence from the AB experiments and the change detection experiments appeared to be consistent, showing the same influences upon carry-over when participants searched in the same spatial location throughout the task, and when they searched through different spatial locations. Additionally, varying the demands between the two tasks did not remove the carry-over effect, indicating that it is not based on similarity between the two tasks. However, both sets of experiments used relatively low-level stimuli, and the tasks were far removed from real-world scenarios. Furthermore, although the visual search task and the change detection task did involve a distinct task goal, the stimuli in both tasks were highly similar (if not identical).

In order to obtain further evidence for the carry-over effect, using more naturalistic stimuli and increasing the differences between the first and second tasks, two experiments were completed using a third methodology. Participants were required to search through a display of letters to detect targets, and then search through a photograph of a natural scene for a later memory test. The photographs all showed pictures of roads, taking advantage of the fact that when viewing a road drivers have pre-defined visual search patterns. In general drivers show a wider spread of search in the horizontal axis than the vertical axis (e.g., Crundall & Underwood, 1998; Hughes & Cole, 1986), and they tend to search in areas most likely to contain task-relevant information (e.g., Shinoda et al., 2001; Trick et al., 2004). The spatial layout of the letters in the initial task was manipulated to determine whether the search in this task persisted to the second task of searching the road photographs.

Both experiments showed a significant carry-over effect with spread of search in the vertical axis increasing following a vertical letter search (letters arranged down the centre of the screen) but not following a horizontal letter search (letters arranged from left to right across the screen). Experiment Eleven provided no evidence for the carry-over of a horizontal letter search; however in Experiment Twelve greater horizontal scanning was found following a horizontal letter search. It was concluded that the studies provided evidence for the carry-over of a *location-based* attentional set, and the variation in results across the two experiments was attributed to participant differences. Driving experience was not recorded but it was predicted that there were more experienced drivers in Experiment Eleven and more novice drivers in Experiment Twelve. With experience drivers are able to refine their visual search patterns and can modulate these patterns in relation to task demands (e.g., Crundall & Underwood, 1998), therefore it may be postulated that experience will consolidate (and strengthen) their ‘perceptual set’ (Trick et al., 2004) making it more resistant to interference from preceding task demands. As a result only participants in Experiment Twelve were influenced by the carry-over of the horizontal search because they have less driving experience, therefore a weaker perceptual set which is less resistant to the intrusion of a previous task.

A further important finding was that a random letter search (letters arranged randomly across the screen) also influenced scanning in the picture search task, inducing longer saccades and greater search in the vertical axis. Crucially, this search only persisted to the picture search task following three repetitions of a letter search (participants completed one, two, or three letter searches before a road photograph was presented), whereas carry-over of a horizontal and vertical letter search occurred after one repetition. Consistent with the difference between colour and shape carry-over in the change detection studies this finding provided evidence that some attentional sets are stronger than others. As a horizontal search is often used in real-world tasks it will be more robust, therefore more likely to carry-over. As a vertical search is more difficult, the effort required to complete the search will strengthen the set, making it more likely to carry-over. In a random search the locations of the letters in each search varied, whereas letters were located in the same places in each search for the horizontal and vertical conditions. The set used to complete the task would therefore be weaker, requiring more practice before it persisted to a second task.

9.2.4 Conclusions regarding the persistence of attentional set

9.2.4.1 The carry-over effect

The collection of experiments presented in this thesis provides strong evidence for the persistence of attentional set. The carry-over effect was found when all stimuli were presented to the same spatial location and it was also found when the tasks involved a search through different spatial locations. The effect remained regardless of whether the stimuli and goals in each task were very similar or substantially different, and carry-over was reliably found with low-level and more naturalistic stimuli. This clearly shows that in addition to being configured on the basis of current task demands, an attentional set is also influenced by previous experience. Three forms of carry-over were revealed; carry-over of a location-based attentional set, carry-over of a feature-based attentional set, and carry-over of a feature-value based attentional set. This has important implications for the top-down control of attention which will be addressed later.

9.2.4.2 Influences upon carry-over

Crucially the three different methods employed consistently showed the same influences upon the persistence of attentional set. The first was experience with the attentional set. Greater experience with the initial task will increase the chances of carry-over to a second task (Experiment Five), and greater experience of the second task (to which the set persists) will attenuate carry-over from the first task (Experiments Eleven and Twelve). The second influence was the 'strength' of the set; a more stable, stronger set is more likely to persist to a second task than a weaker set. Set strength can be manipulated by the amount of processing required in the task, with a more difficult task involving more resources and therefore carrying over to a greater extent than an easier task (Experiment Eight). It can also be manipulated by the amount of resources an individual will invest in the task; again, more resources will increase the chance of carry-over. This was shown through the individual differences in carry-over found in Experiments Three and Four. Although the difficulty of the task did not vary across the dual target block, participants who put more resources into target detection and distracter inhibition (leading to a larger blink) suffered from carry-over, whereas those who adopted a more passive search strategy were able to change set when the task demands changed. Experiments Eleven and Twelve also revealed that the strength of a set can be increased via practice, whereby a set that is initially weak will not intrude upon a second task unless it has been consolidated through repeated exposure.

9.2.4.3 Cause of the carry-over effect

It may be argued that these two influences (set strength and experience) can be encapsulated within the notion of cognitive control; the level of control an individual has over the task and the set will influence whether the set will persist to a second task. Importantly, experience and set strength each tap into the different levels of cognitive control that were outlined in Chapter One. The first is macro-control (so termed by this author) and this represents the level of control one has over the goal representation. The second is micro-control (again, termed by this author) which represents the top-down influence upon attentional control. The goal representation is based on the task demands and to ensure that the attentional set is meeting these demands performance must be monitored (Luks et al., 2002), and the set must be altered when necessary (macro-control). To ensure that task-relevant items are selected and task-irrelevant items are inhibited the set must be specific (micro-control).

When greater emphasis is placed on target selection and distracter inhibition the attentional set will be highly controlled (micro). This occurs when the task is more difficult (for example if targets require more processing and distracters require greater inhibition; Experiment Eight), or when an individual exerts more control over the set due to their own cognitive style (Experiments Three and Four). It is hypothesised that more top-down control over the task will consolidate the set, making it stronger. Thus, when a change in set is required more resources will be needed to reconfigure the processing system to a new task and inhibit any persisting activation of the original set. This means that an *increase* in micro-control will lead to carry-over because set switching will be too costly. This is consistent with the claims made by Leber and Egeth (2006) that a failure to switch set is due to the relative costs and benefits of switching, and also with task switching literature which outlines that switch costs occur due to persisting activation of the original set and a lack of top-down control over the new set (e.g., Allport et al., 1994; Dreisbach & Goschke, 2004).

In direct contrast to this it may be postulated that a *decrease* in macro-control will lead to carry-over. If experience with a task increases and if the stimuli present in the task are 'consistently mapped' onto the same responses, the set established to complete the task will become automatic, reducing the need for focused attention (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). This will mean that the stimuli will automatically trigger the set without top-down control. A lack of top-down control (micro-control) means that fewer resources have to be devoted to the task, however because the set is not 'controlled' it will automatically be activated by the related stimuli whenever these stimuli are encountered and will become 'habitual'

(Reason, 1984; Trick et al., 2004). If the set is not appropriate for a situation but the stimuli trigger the set macro-control is required to inhibit the habitual set and allow a new set to be configured (Mannell & Duthie, 1975; Posner & DiGirolamo, 1998). A lack of macro-control at this point will result in the intrusion of the habitual set. It is predicted that as an individual gains more experience with a task, not only will the set become automatic, the level of micro-control will be reduced because the task remains constant over a long period of time. As micro-control reduces, the requirement for macro-control is more evident; a lack of control at this executive level will therefore result in carry-over.

The findings from the experiments in this thesis therefore indicate that the persistence of attentional set is caused by cognitive control. Too much control over the task (an increase in micro-control) will lead to carry-over, but too little control over the set (a decrease in macro-control) will also lead to carry-over. This may suggest that the two levels of control are in a push-pull relationship. When micro-control increases, the level of macro-control decreases, whereas when macro-control increases, the level of micro-control decreases. Both are important for the control of attention and the control of the attentional set; and this can clearly be evidenced through the persistence of attentional set.

9.3 A model for the top-down control of attention

9.3.1 The impact of top-down control

The top-down control of attention is described as “the goal-driven allocation of attention toward the processing of task-appropriate stimuli and responses and away from distractions" (Luks et al., 2002; pp. 792). An attentional set helps to achieve this by biasing attention towards the 'task-appropriate' stimuli, allowing selective processing of relevant information without interference from irrelevant information (Kahneman & Treisman, 1984). Despite a consensus among researchers regarding the importance of selective attention, there is a difference of opinion regarding the importance of top-down control (Lavie, 1995); specifically whether attention can be oriented on the basis of top-down factors at a relatively low level of processing (e.g., Bundesen, 1990; Folk et al., 1992; Folk et al., 1994; Wolfe, 1994), or whether orientation at such levels is solely based on bottom-up influences (e.g. Koch & Ullman, 1985; Müller & Rabbitt, 1989; Theeuwes, 1991a, 1991b; Theeuwes & Burger, 1998). Investigating the carry-over of attentional set was not only expected to reveal how and why a set persists from one task to another, it was also expected to show how attention is allocated through the use of a top-down attentional set, and how this set can be characterised.

It has long been suggested that visual attention is allocated in two stages. The first 'preattentive' stage allows for an initial analysis of the scene (e.g., Ullman & Koch, 1984), further processing of specific items and locations then takes place at a limited capacity 'attentive' stage (Neisser, 1967). Preattentive analysis is completed on all sections of the display in parallel and the scene is represented on the basis of a set of pre-determined 'feature maps' (e.g., colour, motion, orientation, etc.; e.g., Wolfe, 1994). The selection of attention at the later stage is governed by the activation from the combination of all feature maps. The key difference between various models is that whilst earlier versions outline that processing at the preattentive stage is governed solely by stimulus properties and the salience of items and locations in relation to neighbouring items and locations (e.g., Broadbent, 1958; Koch & Ullman, 1985; Treisman & Gelade, 1980; Ullman, 1984) later versions allocate a role for top-down processing at this stage, stating that selection is influenced by whether an item or location matches the target-defining features (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Treisman & Sato, 1990; Wolfe, 1994).

Two-stage models are supported by the differences found between the efficiency of a simple search (search for a unique item among a series of homogenous items) and the efficiency of a conjunction search (search for an item which shares one feature with some distracters and another with other distracters). Whilst a simple search is efficient and does not vary with set size because the item can be found at the preattentive stage (parallel processing), a conjunction search must be completed in serial resulting in a search slope which increases with set size (e.g., Treisman & Gelade, 1980).

The present studies were not completed with the intention of providing support for or against two-stage models and the tasks involved in the experiments completed did not incorporate a simple search or a conjunction search. Instead, the aim of the work was to focus on goal-driven selection, rather than trying to determine the relative influence of endogenous and exogenous orienting. However, it may be argued that the results (and conclusions) are more in-line with an alternative model of attentional selection developed by Di Lollo and colleagues (Di Lollo, Kawahara, Zuvic, & Visser, 2001; Di Lollo, Smilek, Kawahara, & Ghorashi, 2005; Visser, Bischof, & Di Lollo, 1999), as opposed to a two-stage model of selection. They posit that rather than visual search (and the related deployment of attention) operating via two-stages, it is instead completed through the configuration of a set of *input filters*. These filters are not pre-determined like the different 'feature maps' proposed by the two-stage models, and their configuration depends entirely on the task demands. In their view, search efficiency is not determined by the level at which the search can be completed (preattentive or attentive); it is dependent on whether the input filters are suitably configured for the task at hand. As the input filters can be configured at a single level for a simple search the search slope elicited is flat, however because a conjunction search involves configuration at two levels (therefore requiring 'reconfiguration' of the filters) the search takes longer. The time taken to complete a search is therefore related to whether the task involves a switch in attentional set.

Di Lollo et al (2001) support their model with the results of experiments completed by Joseph, Chun, and Nakayama (1997) who gave participants a task of searching for a unique item among distracters based on the orientation of grating patterns. They found that the search yielded a flat search slope unless it was completed after another task (part of a dual task) in which case the search slope was steep. In addition, when the search was part of a dual task, efficiency increased when the interval between the two tasks was increased. Di Lollo et al. (2001) state that this is indicative of 'set reconfiguration'. In a single task the input filters are configured at one level and that level is suitable for the task, in a dual task the filters must be reconfigured after the initial task in order to be suitable for the second task, this takes time (Monsell, 1996) therefore reducing the efficiency of the search when it follows a preceding task. Increasing the time between the two tasks allows more time for reconfiguration, consequently increasing search efficiency again. They therefore claim that "efficient processing depends on the adequacy of the preparatory set" (pp.490).

Importantly Di Lollo and colleagues state that selective attention is the consequence of top-down control; they do not account for any bottom-up influences in their model. Any evidence for stimulus-driven capture is attributed to the input filters being incorrectly configured for the task, allowing task-irrelevant stimuli through to processing. Although the current experiments do not measure bottom-up capture (with the exception of the first AB pilot study which explored the extent to which an irrelevant T1 would capture attention in a single target block; Experiment One) they do indicate a strong role for top-down control over selective attention, similar to Di Lollo et al. Moreover, they illustrate what happens when the system is not suitably reconfigured for the task at hand; attention will be allocated to previously relevant stimuli because the system is still working to the original configuration.

Di Lollo and colleagues suggest that selective attention via a two-stage process is not flexible enough to deal with the wide range of tasks and stimuli that will be encountered. The current findings appear to agree with this suggestion because they show that (1) configuration of the orienting system is not limited to a set of basic features such as colour and orientation. For example participants can effectively search for specific categories of alphanumeric characters among highly similar alphanumeric characters with no contingent capture of task-irrelevant stimuli, and a high level of search accuracy overall (AB Experiments). (2) That configuration can occur at a variety of levels dependent upon the task requirements, for instance if the search feature remains constant throughout the task this feature will not be used to allocate attention (Experiment Nine). (3) Configuration can occur at more than one level at any one time meaning that attention can be initially directed at a ‘general’ level and then be directed at a more ‘specific’ level (Experiment Eight).

Obviously these conclusions are based on the findings of carry-over, rather than the direct influence of the set when it is relevant; however allocation of attention to a second task can infer how attention was allocated in a preceding task. These conclusions have resulted in the development of a model to account for top-down control which will now be described and explained (see figure 9.1 on page 294). The model is similar to that proposed by Di Lollo and colleagues; however the findings revealed by the carry-over effect have also been incorporated into the model.

9.3.2 G-MAS (General Model of Attentional Set)

When undertaking a task requiring visual attention, the starting point is the initiation of a *goal state*. This is based on the task demands and the aims and intentions of the observer. Importantly, the goal state is monitored and maintained by macro-control. The goal state establishes an *attentional set* to meet the task demands, and within the attentional set there are three distinct components. Each one relates to a different aspect of any visual scene, and each is given a *set point*, based on its importance and relevance to the task. Set points range from 0 to 100, with a higher set point indicating higher priority of a component over the allocation of attention. Set points relate to the strength of the set; the higher the point the stronger the set.

The components of the attentional set are arranged in a hierarchy with the most influential at the top; this is the allocation of attention based on a *location filter*. The work contained within this thesis does not show that location-based selection has priority (equally it does not show that location-based selection does not have priority), but the position of location in the hierarchy is due to the assumptions made in the literature. For example, Tsal and Lavie (1988) and Soto and Blanco (2004) suggest that location-based selection has a primary role in the allocation of attention. The allocation of a set point to this filter is heavily influenced by any known feature location. Under certain circumstances (for example in the AB experiments) observers will only be presented with stimuli in one location, in which case the location filter

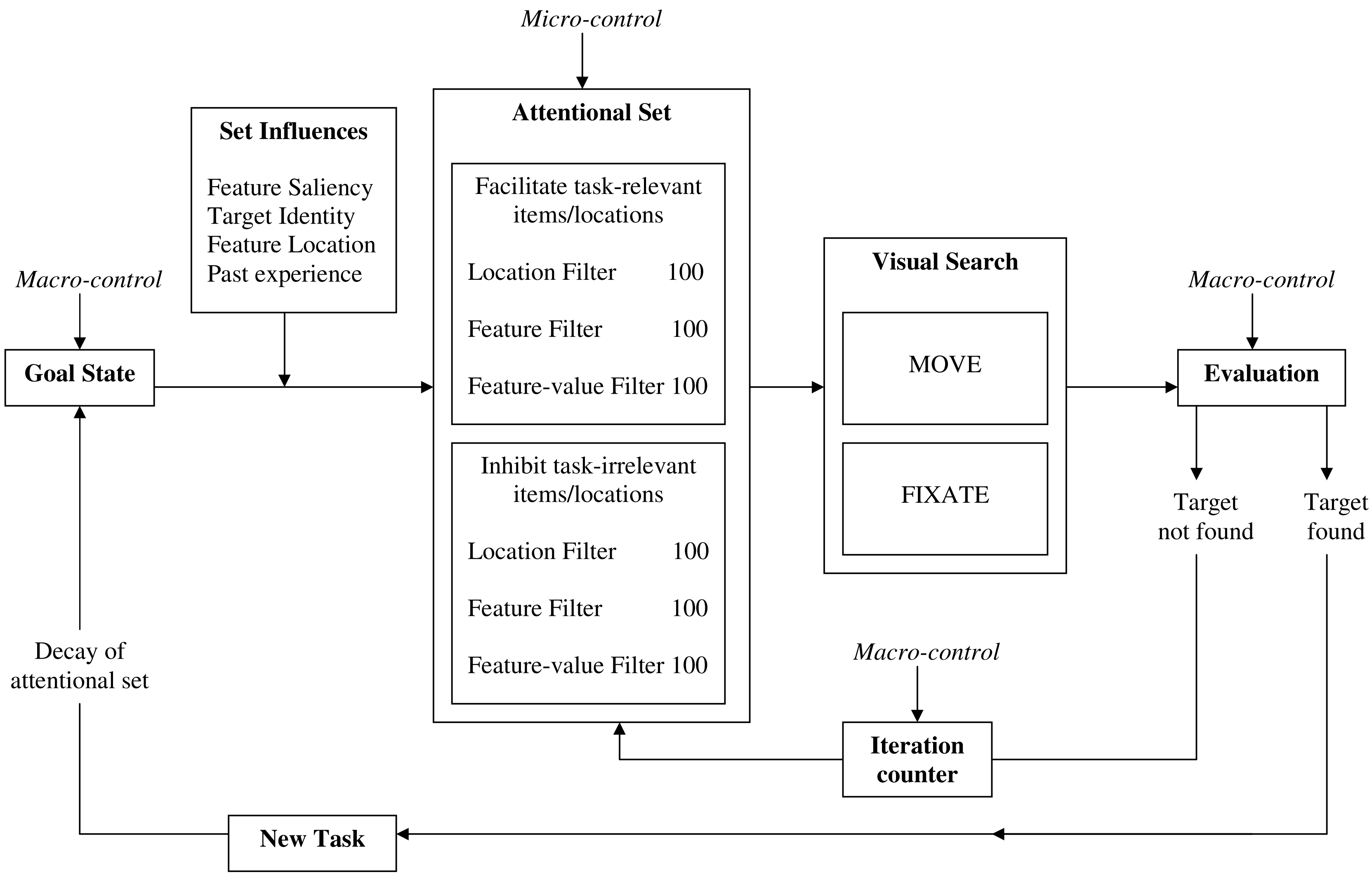

Figure 9.1: A General Model of Attentional Set (G-MAS)

may have a high set point (putting all resources into the one known location), or the filter may not be given a set point in an effort to preserve resources.

The second component of the attentional set is the *feature-filter*. The feature filter relates to the overall category of the items to which attention should be allocated. For example, if an observer is searching for blue shapes amongst differently coloured shapes the feature filter is set to search for ‘colour’ rather than shape (which is the task-irrelevant feature category in this instance). The set point given to the feature filter is affected by the saliency of the target feature, and the saliency of any other features within the scene (*feature saliency*). As colour is easier to search for than shape (evidenced from the SVT tasks in Experiments Eight to Ten), a search for colour would result in a very low set point for the feature filter. Alternatively, if the search is for shape, the set point given to the feature filter would be high as the set would have to give more resources to concentrating attention on shape and inhibiting the pop-out of colour (e.g., Fanini et al., 2006). It has been suggested that this is the reason why there was greater carry-over for shape than for colour in Experiment Eight; shape has a greater set strength and is more likely to persist to a second task because the feature of shape is more difficult to process and the feature of colour is more difficult to inhibit.

Like the location filter, the feature filter is also influenced by the task constraints; if an individual searches for one particular feature consistently, without having to change to searching for a different feature the feature filter may not be given a high point (or may not be given any points) because the filter is less likely to benefit the search in this instance. This is consistent with the assumptions of Wolfe (1994). It can also explain the lack of any feature congruency effect in Experiment Nine; participants did not have to switch between a search for shape and a search for colour in the SVT therefore the feature filter was less important in the allocation of attention and was consequently given a lower set point. Note that although the examples used here are the features of shape and colour, it is suggested that the feature filter is not limited to ‘basic features’ in the same way that two-stage models are. Instead, following from Di Lollo and colleagues the feature filter will encompass any category of item (e.g., letters, numbers, colours, shapes, etc.).

The final level of configuration of the orienting system is the *feature-value filter*. This relates to the actual target of the search, so a search for blue shapes may be defined by the *feature* of ‘colour’, but the *feature value* would be ‘blue’. Again, the set point given to this filter depends heavily upon the saliency of the feature. Whilst a search for colour would have a low set point for feature filter because colour pops out, the set point given to the feature-value filter may be higher to ensure inhibition of the irrelevant colours. However, as a search for a particular shape may necessitate a high set point for feature filter (due to processing demands), the set point given to the feature-value filter may be lower, as in this case the inhibition of colour (accounted for by the feature filter) is more difficult than the inhibition of non-target shapes. Again, this would explain why the feature of shape carries over to a greater extent than the feature of colour in Experiment Eight (the feature filter is given a higher set point for shape than for colour and therefore takes longer to decay), and why the carry-over of a shape feature value did not differ from the carry-over of a colour feature value (the points given to the respective feature value filters may have been relatively equal).

The hierarchy of the system is very similar to that proposed by Folk et al. (1992), with the specificity of the set increasing down the hierarchy. In particular, the feature-based set would be configuration at a general level, and the feature-value-based set would be configuration at a more specific level. This also corresponds with the singleton detection and feature search modes outlined by Bacon and Egeth (1994).

The attentional set is also separated into a *facilitation* component and an *inhibition* component, and all three filters are represented within each component. The notion that the set can be both excitatory and inhibitory follows research in the literature which provides evidence for selective attention through both forms. For example, the visual marking effect shows that locations (Watson & Humphreys, 1997) objects (Watson & Humphreys, 1998), and features (Olivers & Humphreys, 2001) are inhibited to benefit visual search, whereas Folk et al. (1992) promote an excitatory set. More recently, Fanini et al. (2006) have found that when one feature of a multi-dimensional object is relevant it is activated and therefore detection of this feature is facilitated, yet this is also paired with suppression of the irrelevant feature (again to facilitate detection of the relevant feature). The AB experiments and Experiments Eleven and Twelve would support the notion of an excitatory set; attention is allocated to the task-relevant items in the RSVP task and is allocated to task-relevant locations in the letter search task, this biases attention to these items/locations in a subsequent task due to carry-over. The findings from the visual search – change detection experiments demonstrate that the set can be both excitatory and inhibitory. Experiments Eight and Nine support an inhibitory account (irrelevant items and features are actively inhibited), as revealed through impaired change detection of previously irrelevant items; and Experiment Ten provides evidence for inhibition and activation (similar to Fanini et al., 2006), showing facilitation of previously relevant targets in conjunction with inhibition of previously irrelevant distracters.

Again, it should be reiterated that the present experiments lend support to the respective sets on the basis of the carry-over effects; a proposed inhibitory set results in prolonged RTs to previously irrelevant stimuli, and a proposed excitatory set results in faster RTs to previously relevant stimuli. It may be postulated that inhibition and facilitation may be relative depending upon the task demands and the stimulus properties. For example, if the irrelevant items and features are more salient than the relevant items and features, the set points given to the inhibitory set will have to be higher than the points given to the excitatory set. This is consistent with the claims made by Bundesen (1990) that attentional weights are based on the amount to which items match the top-down control settings, and also on the similarity between the relevant and irrelevant items. However, a key difference between this model and Bundesen's theory is that here the 'weights' (points) are given to the attentional set, whereas Bundesen proposes that weights are allocated to items in the visual display on the basis that they match the attentional set.

Once the attentional set has been established, and the set points have been allocated to the relevant filters based on the *set influences* attention will be deployed to items and locations which match the configuration of the filters. In the *visual search* attention is allocated to items and locations that match the filters (and therefore match the top-down control settings). When attention is directed to one region of space it will *fixate* here in order to process the stimuli in that region. Attention will remain at this location until processing is complete, or until another region of the visual field attracts attention, at which time it will *move* to a new location.

The *fixate* and *move* centres will have different influences acting upon them, and the strongest will win out. To illustrate this with an example, a search for a single target identity would mean that the target is easier to process once it has been found, taking less time to process as a consequence. This would lead to lower activation in the fixate centre because the attentional spotlight can be larger, allowing for the capture of attention by items in the periphery. If the task is more difficult and involves a search for several target identities the processing time of each target will take longer, this creates a greater foveal load, reducing the spotlight and so reducing the possibility of items in the peripheral field capturing attention. This would be represented through greater activation in the fixate centre.

Following the *visual search* task-performance is *evaluated* in relation to the aims of the observer (namely, have they been successful in finding the target?). If the target has not been found further steps need to be taken to complete the task. This leads to a loop back through the attentional set, and a further fixation or shift of attention, followed by another evaluation. This continues until the target has been found, looping back through after each shift of attention, or fixation. The *iteration counter* counts each time the observer has to go back through the system, and the author proposes that if this count reaches a certain level and the target has not been found, the set points will be altered to allow a more successful visual search to be conducted, presumably because the set points were not accurate initially. This means that task performance must be monitored by macro-control to ensure that the set is altered if necessary (e.g., Luks et al., 2002). Evidence for this comes from studies in the literature, for example Theeuwes and Burger (1998) and Turatto and Galfano (2001) have found that when the colours of targets and distracters remain constant across the course of an experiment the distracters will initially capture attention but after a time they fail to capture attention. It may be suggested that participants initially begin the task by configuring the system at a general level, but as performance is monitored the set can be altered to facilitate search (prevent exogenous capture) due to updated knowledge regarding the identity of targets and distracters.

It is hypothesised that carry-over is also influenced by the number of times the iteration counter is activated. Looping through the system a number of times will increase the set points (to improve task performance) and higher points will take longer to decay. This is why shape carried over to a greater extent than colour in Experiment Eight; it took longer to complete a shape search so presumably the iteration counter was activated more often. It also accounts for the finding that a random letter search, which did not influence spread of search in the picture search initially, resulted in carry-over following repetition of the task (Experiments Eleven and Twelve).

Once the target has been found a *new task* can begin. As the goal state of this new task is being initiated the attentional set from the previous task begins to *decay*. If the set is stronger (higher set points) the decay takes more time, leading to persistence of the set if the benefits of switching do not outweigh the costs of switching (Leber & Egeth, 2006). This is revealed in Experiments Three and Four; more investment (control) in the task increases the set points making the set more costly to inhibit when the task changes. Monitoring the number of iterations through the system, and modulating the attentional set should be under macro-control. However, Posner and DiGirolamo (1998) have predicted that executive control is not necessary in all situations. Crucially, a set switch will be required when a new task begins, but if this switch does not occur (potentially due to the automaticity of the set following enhanced experience; Experiment Five) a lack of macro-control will fail to determine that the set (the previously relevant set) is no longer meeting the task requirements and the set will not be reconfigured.

9.3.3 Suitability of the G-MAS in accounting for findings in the literature

Like the model proposed by Di Lollo et al. (2001), the G-MAS can effectively explain the findings of contingent capture (Folk et al., 1992; Folk et al., 1994). Anything matching the top-down control settings (the filters) will capture attention, therefore if a task-irrelevant item shares a defining feature with the target it will capture attention. Crucially, the model can also account for the findings which suggest that attention can be captured purely on the basis of bottom-up influences (e.g., Schreij et al., 2008; Theeuwes, 1991b; Theeuwes & Burger, 1998; Turatto & Galfano, 2001;). When accounting for these findings using a two-stage model with pre-determined features (such as colour and orientation) one would assume that the irrelevant singletons used in these experiments should not capture attention because they do not match the top-down set. It is presumed that the top-down set would be a set for a basic search feature (e.g., colour, orientation) even if the search was for a target which could be defined by a different feature (e.g., an alphanumeric character) as according to the two-stage models only basic features which can be defined preattentively. The finding that an irrelevant singleton captures attention therefore indicates automatic capture. However, if one was to assume that a top-down set can be configured for a greater range of features, these findings would provide support for contingent capture. Take for example the study completed by Theeuwes and Burger (1998). Participants searched for a specific target letter (E or R) among a set of homogenously coloured distracter letters and a uniquely coloured singleton captured attention. The authors attribute this capture to the salience of the singleton, indicating that attention is allocated on the basis of bottom-up factors. Yet this singleton was also the letter E or R, therefore if participants completed the task by searching for the target letter (not possible in the two-stage models), the capture of attention by the singleton occurred because the singleton matched the target-defining features. The G-MAS allows for the filters to be configured for any feature dimension and is not constrained by a limited set of basic features, therefore the findings that were classed as originating from bottom-up capture can instead be explained in terms of top-down control.

The notion that the orienting system may be configured for a greater range of feature dimensions, and is more flexible was introduced in Chapter One. The results from this thesis provide evidence for the existence of a location-based, feature-based, and feature-value-based attentional set and therefore it does not seem unreasonable to propose a more flexible account of top-down control, similar to that suggested by Di Lollo and colleagues. By underestimating the level at which the orienting system can be configured researchers claim evidence for bottom-up capture, however this author proposes that this capture is always contingent upon the top-down control settings.

9.4 Conclusion

In the words of Leber and Egeth (2006) "Efforts to further explore how past experience influences attentional set may succeed not only in reconciling inconsistent findings in the attention capture literature, but in facilitating a broader understanding of the properties of attentional control" (pp. 581). The collection of work conducted by this author and presented in the current thesis has achieved this. The initial aim was to measure the carry-over of an attentional set from a task in which it is relevant to a subsequent task in which it is no longer relevant. This investigation has helped to clarify the cause of the carry-over effect and has also determined some of the influences upon carry-over. Additionally the work has provided evidence to show how the orientating system is configured to allow for selective attention and efficient task performance. This has outlined some of the characteristics of top-down attentional control. Finally, in specifying the properties of attentional control the research has been successful in providing an explanation for attentional selection which can effectively account for the findings of contingent capture, and the findings which have previously been attributed to pure stimulus-driven capture. In conclusion, this thesis has shown the importance of top-down control; revealing not only the implications of this control, but also the flexibility of control. Goal-driven attention has therefore been revealed as more multi-faceted than previously imagined.

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Appendix One: Analysis of variance tables

Experiment One: Piloting the single target RSVP

Percentage accuracy to T2

	df	SS	MS	F-value	p-value
Demand	1	18050	18050	12.120	.010
Position of T1	1	78.125	78.125	.288	.608
Lag	3	12434.375	4144.792	14.409	.0001
Demand * position	1	612.500	612.500	3.854	.090
Demand * lag	3	49.000	1633.333	9.333	.0001
Position * lag	3	1009.375	336.458	2.305	.106
Demand * position * lag	3	437.5	145.833	.788	.514

Experiment Two: Establishing the blink

Comparison of performance in first blocks completed by DSS group and SDS groups (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	893.994	297.998	.939	.425
Group	1	3380.931	3380.931	32.913	.0001
Lag * group	3	2041.125	680.375	2.145	.101

Planned contrasts for the first blocks completed by DSS and SDS

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	1.252	1.252	.003	.959
	2 vs. mean	1	6.540	6.540	.046	.832
	3 vs. mean	1	520.188	520.188	2.439	.130
Lag * group	1 vs. mean	1	134.949	134.949	.284	.599
	2 vs. mean	1	1448.971	1448.971	10.171	.003
	3 vs. mean	1	422.456	422.456	1.981	.170

Comparison of the dual target block and the first single target block completed by DSS (% T2 accuracy)

	df	SS	MS	F-value	p-value
Block	1	14059.727	14059.727	50.942	.0001
Lag	3	527.374	175.791	.253	.859
Block * lag	3	1403.161	467.720	3.649	.020

Planned contrasts for the first two blocks completed by DSS

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	269.266	269.266	.212	.652
	2 vs. mean	1	46.233	46.233	.165	.691
	3 vs. mean	1	193.408	193.408	.780	.392
Lag * block	1 vs. mean	1	13.497	13.497	.109	.746
	2 vs. mean	1	824.173	824.173	9.658	.008
	3 vs. mean	1	135.798	135.798	1.444	.249

Comparison of the dual target block and the second single target block completed by SDS (% T2 accuracy)

	df	SS	MS	F-value	p-value
Block	1	4453.618	4453.618	30.101	.0001
Lag (GG)	3 1.360	4359.803	1453.268 3205.039	3.302	.029 .070
Block * lag	3	1380.837	460.279	4.050	.013

Planned contrasts for the second two blocks completed by SDS

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	2742.621	2742.621	3.348	.089
	2 vs. mean	1	628.994	628.994	5.524	.034
	3 vs. mean	1	972.962	972.962	6.613	.022
Lag * block	1 vs. mean	1	132.962	132.962	1.221	.288
	2 vs. mean	1	254.463	254.463	7.528	.016
	3 vs. mean	1	1018.679	1018.679	.199	.662

Comparison of the final block completed by DSS and SDS (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	8025	2675	8.279	.0001
Group	1	13.333	13.333	.088	.769
Lag * group	3	658.333	219.444	.679	.567

Planned contrasts for the final block completed by DSS and SDS

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	4949.833	4949.833	9.599	.004
	2 vs. mean	1	30	30	.170	.684
	3 vs. mean	1	2253.333	2253.333	17.467	.0001
Lag * group	1 vs. mean	1	40.833	40.833	.079	.780
	2 vs. mean	1	213.333	213.333	1.207	.281
	3 vs. mean	1	403.333	403.333	3.127	.088

Experiment Three: Carry-over of attentional set using the AB paradigm

Performance in the negative lags between the four blocks completed (% T2 accuracy)

	df	SS	MS	F-value	p-value
Block	3	1062.052	354.017	1.426	.245

Comparison of the first block completed by the set-priming and no-set-priming groups (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	2235.243	778.414	5.803	.001
Set priming	1	735.199	735.199	3.221	.083
Lag * set priming	3	1420.566	473.522	3.530	.018

Planned contrasts for the first block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	119.271	119.271	.967	.332
	2 vs. mean	1	943.238	943.238	7.587	.010
	3 vs. mean	1	43.134	43.134	.687	.414
Lag * set priming	1 vs. mean	1	4.947	4.947	.040	.842
	2 vs. mean	1	855.655	855.655	6.883	.014
	3 vs. mean	1	13.297	13.297	.212	.649

Comparison of the final block completed by the set-priming and no-set-priming groups (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	698	232.667	2.592	.058
Set priming	1	252.300	252.300	1.067	.310
Lag * set priming	3	301.200	100.400	1.118	.346

Planned contrasts for the final block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	.033	.033	.0001	.984
	2 vs. mean	1	313.633	313.633	4.591	.041
	3 vs. mean	1	381.633	381.633	6.456	.017
Lag * set priming	1 vs. mean	1	7.500	7.500	.092	.764
	2 vs. mean	1	218.700	218.700	3.202	.084
	3 vs. mean	1	24.300	24.300	.411	.527

Comparison of the first ten trials at each lag in the final block between groups

	df	SS	MS	F-value	p-value
Lag	3	1246.667	415.556	2.431	.071
Set priming	1	270.00	270.00	.957	.336
Lag * set priming	3	393.333	131.111	.767	.516

Comparison of the last ten trials at each lag in the final block between groups

	df	SS	MS	F-value	p-value
Lag	3	309.167	103.056	.422	.738
Set priming	1	91.875	91.875	.333	.569
Lag * set priming	3	542.500	180.833	.740	.531

Comparison of the first block completed by the set-priming and no-set-priming groups after removal of data from one participant on the basis of a low blink magnitude (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	2656.621	885.450	6.658	.0001
Set priming	1	1075.547	1075.547	5.486	.027
Lag * set priming	3	1674.160	558.053	4.196	.008

Comparison of the final block completed by the set-priming and no-set-priming groups after removal of data from one participant on the basis of a low blink magnitude (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	637.620	212.540	2.359	.078
Set priming	1	371.431	371.431	1.610	.215
Lag * set priming	3	293.344	97.781	1.085	.360

Experiment Four: Individual differences in the control of attentional set

Performance in the negative lags between the three groups - field dependents, field independents, and no-set-priming group from Experiment Three (% T2 accuracy)

	df	SS	MS	F-value	p-value
Group (block 1)	2	827.116	413.558	1.854	.169
Group (block 2)	2	758.800	379.400	3.253	.049

Post-hoc Bonferroni contrasts on negative lags in Block 2

Group	Standard Error	Mean difference	p-value
SS vs. FD	3.94325	2.2	1.000
SS vs. FI	″	-7.4	.203
FD vs. SS	″	-2.2	1.000
FD vs. FI	″	-9.6	.058
FI vs. SS	″	7.4	.203
FI vs. FD	″	9.6	.058

Block one compared between the three groups (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	9915.280	3305.093	24.028	.0001
Group	2	2621.658	1310.829	2.223	.121
Lag * group	6	4662.135	777.022	5.649	.0001

Planned contrasts for the first block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	245.677	245.677	2.238	.142
	2 vs. mean	1	6486.602	6486.602	50.497	.0001
	3 vs. mean	1	84.694	84.694	1.115	.297
Lag * group	1 vs. mean	2	607.166	303.583	2.765	.074
	2 vs. mean	2	3105.660	1552.830	12.088	.0001
	3 vs. mean	2	40.865	20.433	.269	.765

Comparison of performance in block one between no-set priming-group, FDs, and FIs (K-matrix)

	Standard Error	Contrast Estimate	p-value
No-set-priming vs. FD	4.434	-8.929	.050
No-set-priming vs. FI	4.434	-2.067	.644

Block two compared between the three groups (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	1335.733	445.244	5.573	.001
Group	2	973.378	486.689	3.574	.037
Lag * group	6	922.133	153.689	1.924	.082

Planned contrasts for the second block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	235.756	235.756	3.940	.054
	2 vs. mean	1	970.689	970.689	14.975	.0001
	3 vs. mean	1	41.089	41.089	.819	.371
Lag * group	1 vs. mean	2	229.991	114.956	1.921	.159
	2 vs. mean	2	381.911	190.956	2.946	.063
	3 vs. mean	2	71.511	35.756	.713	.496

Comparison of performance in block two between no-set-priming group, FDs, and FIs (K-matrix)

	Standard Error	Contrast Estimate	p-value
No-set-priming vs. FD	4.261	-2.933	.495
No-set-priming vs. FI	4.261	8.067	.065

t-test comparing blink magnitude of FDs and FIs

	df	Mean	Standard Error	t-value	p-value
FD vs. FI	28	6.05169	6.34259	.954	.176

Comparison of first block completed by no-set-priming group, "blinkers", and "nonblinkers" (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	9915.288	3305.093	25.811	.0001
Group	2	2291.434	1145.717	10.561	.0001
Lag * group	6	5859.296	976.549	7.626	.0001

Planned contrasts for the first block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	254.677	245.677	2.213	.144
	2 vs. mean	1	6486.602	6486.602	52.339	.0001
	3 vs. mean	1	84.694	84.694	1.266	.267
Lag * group	1 vs. mean	2	554.336	277.168	2.496	.095
	2 vs. mean	2	3295.520	1647.760	13.295	.0001
	3 vs. mean	2	421.909	210.955	3.155	.053

Comparison of performance in block one between blinkers, nonblinkers and no-set-priming group (K-matrix)

	Standard Error	Contrast Estimate	p-value
No-set-priming vs. blinkers	3.803	16.286	.0001
No-set-priming vs. nonblinkers	3.803	13.641	.001

Comparison of second block completed by no-set-priming group, blinkers, and nonblinkers (% T2 accuracy)

	df	SS	MS	F-value	p-value
Lag	3	1335.733	445.244	5.604	.001
Group	2	766.711	383.356	2.717	.078
Lag * group	6	976.533	162.756	2.048	.064

Planned contrasts for the first block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	235.756	235.756	3.884	.055
	2 vs. mean	1	970.689	970.689	15.458	.0001
	3 vs. mean	1	41.089	41.089	.818	.371
Lag * group	1 vs. mean	2	193.911	95.956	1.597	.214
	2 vs. mean	2	466.978	233.489	3.718	.033
	3 vs. mean	2	67.511	33.756	.672	.516

Comparison of performance in block two between blinkers, nonblinkers and no-set-priming group (K-matrix)

	Standard Error	Contrast Estimate	p-value
No-set-priming vs. blinkers	4.338	9.667	.031
No-set-priming vs. nonblinkers	4.338	2.267	.604

Experiment Five: Persistence of attentional set in a RSVP task

Analysis of negative lags (% T2 correct)

	df	SS	MS	F-value	p-value
No-set-priming	3	834.583	278.194	2.062	.116
Set-priming	3	1595.616	531.872	5.395	.002

Post-hoc Bonferroni comparisons of negative lags

No-set-priming	Standard Error	Mean difference	p-value
Block 1 vs. Block 2	4.24103	-5.6	1.000
Block 1 vs. Block 3	″	-9.46667	.178
Block 1 vs. Block 4	″	-8.73333	.265
Block 2 vs. Block 1	″	5.6	1.000
Block 2 vs. Block 3	″	-3.86667	1.000
Block 2 vs. Block 4	″	3.13333	1.000
Block 3 vs. Block 1	″	9.46667	.178
Block 3 vs. Block 2	″	3.86667	1.000
Block 3 vs. Block 4	″	.73333	1.000
Block 4 vs. Block 1	″	8.73333	.265
Block 4 vs. Block 3	″	3.13333	1.000
Block 4 vs. Block 4	″	-.73333	1.000
Set-priming			
Block 1 vs. Block 2	3.62547	-5.05267	1.000
Block 1 vs. Block 3	″	-13.51267	.003
Block 1 vs. Block 4	″	-10.37467	.035
Block 2 vs. Block 1	″	5.05267	1.000
Block 2 vs. Block 3	″	-8.46000	.139
Block 2 vs. Block 4	″	-5.32200	.886
Block 3 vs. Block 1	″	13.51267	.003
Block 3 vs. Block 2	″	8.46000	.139
Block 3 vs. Block 4	″	3.13800	1.000
Block 4 vs. Block 1	″	10.37467	.035
Block 4 vs. Block 3	″	5.32200	.886
Block 4 vs. Block 4	″	-3.13800	1.000

T1 accuracy in Blocks 1-3 for the set-priming group (% correct)

	df	SS	MS	F-value	p-value
Block	2	993.244	496.622	8.654	.001
Lag	3	140.800	46.933	1.759	.170
Block * lag	6	101.867	16.978	.580	.746

Comparison of performance between set-priming and no-set-priming groups in Block One (% T2 correct)

	df	SS	MS	F-value	p-value
Lag	3	5963.337	1987.779	13.627	.0001
Set priming	1	602.851	602.851	4.388	.045
Lag * set priming	3	5753.520	1917.840	13.148	.0001

Planned contrasts for the first block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	.589	.589	.005	.945
	2 vs. mean	1	2877.820	2877.820	19.841	.0001
	3 vs. mean	1	6.776	6.776	.063	.804
Lag * set priming	1 vs. mean	1	38.994	38.994	.322	.575
	2 vs. mean	1	3409.654	3409.654	23.508	.0001
	3 vs. mean	1	18.790	18.790	.175	.679

Comparison of performance between set-priming and no-set-priming groups in Block Two (% T2 correct)

	df	SS	MS	F-value	p-value
Lag	3	3065.110	1021.703	6.691	.0001
Set priming	1	720.717	720.717	5.507	.026
Lag * set priming	3	2520.135	840.045	5.501	.002

Planned contrasts for the second block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	1283.835	1283.835	12.457	.001
	2 vs. mean	1	1684.014	1684.014	10.557	.003
	3 vs. mean	1	14.950	14.950	.125	.727
Lag * set priming	1 vs. mean	1	498.189	498.189	4.834	.036
	2 vs. mean	1	1714.117	1714.117	10.746	.003
	3 vs. mean	1	2.595	2.595	.022	.884

Comparison of performance between the set-priming and no-set-priming groups in Block Three (% T2 correct)

	df	SS	MS	F-value	p-value
Lag	3	3065.356	1021.785	10.791	.0001
Set priming	1	710.193	710.193	5.269	.029
Lag * set priming	3	1606.514	535.505	5.656	.001

Planned contrasts for the third block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	312.438	312.438	2.939	.098
	2 vs. mean	1	1883.139	1883.139	34.009	.0001
	3 vs. mean	1	12.656	12.656	.183	.672
Lag * set priming	1 vs. mean	1	123.282	123.282	1.159	.291
	2 vs. mean	1	959.676	959.676	17.333	.0001
	3 vs. mean	1	7.993	7.993	.115	.737

Magnitude of the attentional blink effect in the first three blocks (% T2 correct)

	df	SS	MS	F-value	p-value
Block	2	1224.715	612.357	2.146	.130

Comparison of performance between set-priming and no-set-priming groups in Block Four (% T2 correct)

	df	SS	MS	F-value	p-value
Lag	3	402.667	134.222	2.562	.060
Set priming	1	154.133	154.133	1.713	.201
Lag * set priming	3	917.333	305.778	5.838	.001

Planned contrasts for the fourth block completed

	Lag	df	SS	MS	F-value	p-value
Lag	1 vs. mean	1	246.533	246.533	8.189	.008
	2 vs. mean	1	145.200	145.200	2.874	.101
	3 vs. mean	1	10.800	10.800	.280	.601
Lag * set priming	1 vs. mean	1	360.533	360.533	11.976	.002
	2 vs. mean	1	546.133	546.133	10.809	.003
	3 vs. mean	1	8.533	8.533	.222	.642

Average T2 accuracy across the four blocks

	df	SS	MS	F-value	p-value
Block	3	4292.251	1430.750	46.427	.0001
Set priming	1	511.459	511.459	5.107	.032
Block * set priming	3	141.969	47.323	1.536	.211

Comparison of performance across blocks with T2 accuracy in block four

	Lag	df	SS	MS	F-value	p-value
Block	1 vs. 4	1	7129.283	7129.283	111.409	.0001
	2 vs. 4	1	3308.340	3308.340	46.122	.0001
	3 vs. 4	1	388.584	388.584	7.383	.011
Block * set priming	1 vs. 4	1	147.275	147.275	2.301	.140
	2 vs. 4	1	208.244	208.244	2.903	.099
	3 vs. 4	1	202.644	202.644	3.850	.060

Experiment Six: Selecting a feature pair

A comparison of change detection accuracy between the three feature pairs

	df	SS	MS	F-value	p-value
Feature pair	2	.916	.458	.095	.910

A comparison of change detection RT between the three feature pairs

	df	SS	MS	F-value	p-value
Feature pair	2	139.709	69.854	31.570	.0001

Post-hoc Bonferroni comparisons of feature pairs (RT)

Feature pair	Standard Error	Mean difference	p-value
HW vs. CS	.52592	-.82258	.374
HW vs. SFO	″	-3.95956	.0001
CS vs. HW	″	.82258	.374
CS vs. SFO	″	-3.13698	.0001
SFO vs. HW	″	3.95956	.0001
SFO vs. CS	″	3.13698	.0001

t-tests to compare the two features within each feature pair (accuracy)

	df	Mean	Standard Error	t-value	p-value
Height vs. width	15	-.39125	.48340	-.809	.431
Colour vs. shape	15	.000	.98769	.000	1.000
Spatial frequency vs. orientation	15	-.58625	.76585	-.765	.456

t-tests to compare the two features within each feature pair (RT)

	df	Mean	Standard Error	t-value	p-value
Height vs. width	15	-.16117	.24180	-.667	.515
Colour vs. shape	15	-.62805	1.06657	-2.355	.033
Spatial frequency vs. orientation	15	-2.29928	1.94355	-4.732	.000

Experiment Seven: Piloting the detection of colour and shape changes

A comparison of change detection accuracy (%) for the variables of change feature (colour and shape) and array (static and jumbled)

	df	SS	MS	F-value	p-value
Change feature	1	46.643	46.643	12.519	.004
Array	1	44.643	44.643	13.702	.003
Change feature * array	1	31.500	31.500	7.951	.014

A comparison of change detection RT (secs) for the variables of change feature (colour and shape) and array (static and jumbled)

	df	SS	MS	F-value	p-value
Change feature	1	25.904	25.904	42.217	.0001
Array	1	.691	.691	1.797	.203
Change feature * array	1	.456	.456	1.279	.279

Experiment Eight: The influence of visual search on later change detection

t-test for accuracy to the SVT task (%)

	df	Mean	SD	t-value	p-value
Colour vs. shape	15	10.62500	5.54026	7.671	.0001

t-test for RT to the SVT task (secs)

	df	Mean	SD	t-value	p-value
Colour vs. shape	15	-2.07366	0.77025	-10.769	.0001

Accuracy in the change detection task (%)

	df	SS	MS	F-value	p-value
Search feature	1	243.958	243.958	17.360	.001
Target congruence	1	25.099	25.099	.335	.571
Feature congruence	1	71.730	71.730	1.521	.236
Search feature * target con	1	289.682	289.682	9.465	.008
Search feature * feature con	1	101.140	101.140	6.425	.023
Target con * feature con	1	1.584	1.584	.055	.818
Sfeature * target con * feature con	1	3.498	3.498	.172	.684

RT in the change detection task (secs)

	df	SS	MS	F-value	p-value
Search feature	1	44.341	44.341	29.816	.0001
Target congruence	1	79.751	79.751	11.744	.004
Feature congruence	1	4.041	4.041	6.277	.024
Search feature * target con	1	2.833	2.833	2.558	.131
Search feature * feature con	1	.737	.737	.567	.463
Target con * feature con	1	3.246	3.246	5.448	.034
Sfeature * target con * feature con	1	2.639	2.639	2.174	.161

Experiment Nine: The influence of visual search on later change detection when the visual stimuli differs across the two tasks

Accuracy in the change detection task (%)

	df	SS	MS	F-value	p-value
Target congruence	1	161.640	161.640	5.468	.034
Feature congruence	1	332.175	332.175	4.618	.048
Array	1	2.622	2.622	.073	.791
Target con * feature con	1	47.678	47.678	3.414	.084
Target con * array	1	35.280	35.280	1.819	.198
feature con * array	1	18.514	18.514	.631	.439
Target con * array * feature con	1	5.136	5.136	.135	.718

RT in the change detection task (secs)

	df	SS	MS	F-value	p-value
Target congruence	1	81.769	81.769	32.836	.0001
Feature congruence	1	44.505	44.505	20.199	.0001
Array	1	.124	.124	.094	.764
Target con * feature con	1	2.014	2.014	1.158	.299
Target con * array	1	2.062	2.062	1.824	.197
Feature con * array	1	4.281	4.281	6.503	.022
Target con * array * feature con	1	.471	.471	.335	.571

Experiment Ten: The influence of visual search difficulty on the carry-over of attentional set

Accuracy in the SVT (% correct)

	df	SS	MS	F-value	p-value
Search feature	1	1529.887	1529.887	16.746	.001
Search set size	1	1543.934	1543.934	17.747	.0001
Search feature * search set size	1	93.115	93.115	1.313	.266

RT in the SVT (secs)

	df	SS	MS	F-value	p-value
Search feature	1	129.793	129.793	132.655	.0001
Search set size	1	65.995	65.995	117.524	.0001
Search feature * search set size	1	3.837	3.837	13.035	.002

Accuracy in the change detection task (%)

	df	SS	MS	F-value	p-value
Search feature	1	122.723	122.723	1.343	.261
Search set size	1	75.107	75.107	1.842	.191
Target congruence	1	112.824	112.824	1.868	.188
Feature congruence	1	60.092	60.092	.692	.416
Search feature * search set size	1	1.160	1.160	.028	.868
Search feature * target congruence	1	4.378	4.378	.093	.763
Search feature * feature congruence	1	6.208	6.208	.153	.700
Search set size * target congruence	1	50.015	50.015	1.570	.225
Search set size * feature congruence	1	5.426	5.426	.125	.728
Target congruence * feature congruence	1	7.791	7.791	.186	.671
Search feature * set size * feature con	1	109.805	109.805	1.696	.208
Search feature * set size * target con	1	6.427	6.427	.300	.590
Search feature * Tcon * Fcon	1	185.547	185.547	3.912	.063
Set size * Tcon * Fcon	1	6.900	6.900	.213	.650
Sfeature * Tcon *Fcon * set size	1	.141	.141	.003	.958

RT in the change detection task (secs)

	df	SS	MS	F-value	p-value
Search feature	1	17.207	17.207	3.355	.083
Search set size	1	3.936	3.936	1.020	.325
Target congruence	1	260.908	260.908	15.281	.001
Feature congruence	1	.277	.277	.094	.762
Search feature * search set size	1	2.840	2.840	1.522	.232
Search feature * target congruence	1	10.477	10.477	2.481	.132
Search feature * feature congruence	1	5.913	5.913	1.718	.206
Search set size * target congruence	1	14.585	14.585	4.037	.059
Search set size * feature congruence	1	.214	.214	.090	.767
Target congruence * feature congruence	1	3.848	3.848	3.218	.089
Search feature * set size * feature con	1	8.271	8.271	1.569	.226
Search feature * set size * target con	1	.154	.154	.021	.888
Search feature * Tcon * Fcon	1	5.494	5.494	1.095	.308
Set size * Tcon * Fcon	1	.020	.020	.004	.951
Sfeature * Tcon *Fcon * set size	1	.0001	.0001	.0001	.990

t-tests to investigate interaction between change item and set size (RT)

	df	Mean	SD	t-value	p-value
Target change set size 1 vs. 2	19	-.64893	1.35537	-2.141	.045
Distracter change set size 1 vs. 2	19	.20533	1.37835	.666	.513

Experiment Eleven: Carry-over of visual search in natural scenes (1)

Letter search accuracy (%)

	df	SS	MS	F-value	p-value
Orientation	2	370.236	185.118	5.572	.008
Repetition	2	150.947	75.474	2.506	.096
Orientation * repetition	4	162.205	40.551	.814	.520

Planned contrasts for the letter search accuracy

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	35.026	35.026	2.038	.171
	mean of H & V vs. R		1	158.848	158.848	7.813	.021
Repetition	R1 vs. R3		1	72.288	72.288	3.176	.092
	R2 vs. R3		1	78.530	78.530	5.004	.038
Orientation * repetition	V vs. H	R1 vs. R3	1	.021	.021	.0001	.990
		R2 vs. R3	1	436.991	436.991	2.507	.131
	mean of H & V vs. R	R1 vs. R3	1	17.772	17.772	.119	.734
		R2 vs. R3	1	45.614	45.614	.231	.636

Response times to the letter search (secs)

	df	SS	MS	F-value	p-value
Orientation	2	3.580	1.790	23.961	.0001
Repetition	2	2.148	1.074	22.167	.0001
Orientation * repetition (HF)	4 3.300	.400 .400	.100 .121	2.487 2.487	.051 .064

Planned contrasts for RT in the letter search task

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	2.366	2.366	38.248	.0001
	mean of H & V vs. R		1	.016	.016	.562	.463
Repetition	R1 vs. R3		1	1.005	1.005	21.574	.0001
	R2 vs. R3		1	.004	.004	.278	.604
Orientation * repetition	V vs. H	R1 vs. R3	1	.023	.023	.126	.727
		R2 vs. R3	1	.003	.003	.029	.866
	mean of H & V vs. R	R1 vs. R3	1	1.182	1.182	13.540	.002
		R2 vs. R3	1	.306	.306	2.540	.128

Standard deviation of fixations along horizontal axis (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	6.397	3.198	1.707	.196
Repetition	2	.132	.066	.212	.810
Orientation * repetition	4	1.886	.471	.947	.442

Standard deviation of fixations along vertical axis (degrees)

	df	SS	MS	F-value	p-value
Orientation (HF)	2 1.060	12.159	6.079 11.472	5.449	.009 .029
Repetition	2	.542	.271	2.241	.121
Orientation * repetition (HF)	4 3.690	1.004	.251 .272	2.481	.051 .057

Planned contrasts for standard deviation of 'y'

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	7.079	7.079	6.766	.018
	mean of H & V vs. R		1	.770	.770	2.327	.145
Repetition	R1 vs. R3		1	.305	.305	2.953	.103
	R2 vs. R3		1	.233	.233	12.414	.002
Orientation *	V vs. H	R1 vs. R3	1	.754	.754	1.376	.256
repetition		R2 vs. R3	1	.204	.204	.544	.470
	mean of H & V vs. R	R1 vs. R3	1	2.417	2.417	7.448	.014
		R2 vs. R3	1	.853	.853	2.053	.169

Saccadic amplitude in the picture search task (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	2.113	1.056	.792	.461
Repetition	2	1.811	.905	2.503	.096
Orientation * repetition (HF)	4 3.118	4.743	1.186 1.521	2.714	.036 .051

Planned contrasts for saccadic amplitude in the picture search task

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	.002	.002	.004	.949
	mean of H & V vs. R		1	1.055	1.055	1.021	.326
Repetition	R1 vs. R3		1	1.195	1.195	5.700	.028
	R2 vs. R3		1	414	414	1.329	.264
Orientation * repetition	V vs. H	R1 vs. R3	1	1.983	1.983	.828	.375
		R2 vs. R3	1	.630	.630	.398	.536
	mean of H & V vs. R	R1 vs. R3	1	10.262	10.262	5.941	.025
		R2 vs. R3	1	1.392	1.392	.816	.378

Saccadic amplitude in the letter search task (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	412.779	206.390	46.170	.0001
Repetition	2	5.487	2.744	.843	.439
Orientation * repetition	4	1.959	.490	.230	.921

Planned contrasts for saccadic amplitude in the letter search task

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	4.749	4.749	1.058	.317
	mean of H & V vs. R		1	202.821	202.821	184.900	.0001
Repetition	R1 vs. R3		1	.149	.149	.130	.722
	R2 vs. R3		1	3.296	3.296	2.779	.113
Orientation * repetition	V vs. H	R1 vs. R3	1	.222	.222	.097	.759
		R2 vs. R3	1	6.849	6.849	.615	.443
	mean of H & V vs. R	R1 vs. R3	1	.040	.040	.003	.959
		R2 vs. R3	1	.005	.005	.002	.969

Experiment Twelve: Carry-over of visual search in natural scenes (2)

Letter search accuracy (%)

	df	SS	MS	F-value	p-value
Orientation	2	337.071	168.536	1.826	.176
Repetition	2	3672.754	1836.373	48.306	.0001
Orientation * repetition	4	42.044	10.511	.364	.833

Planned contrasts for the letter search accuracy

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	2.898	2.898	.042	.840
	mean of H & V vs. R		1	166.362	166.362	4.129	.058
Repetition	R1 vs. R3		1	2347.394	2347.394	52.507	.0001
	R2 vs. R3		1	240.779	240.779	15.582	.001
Orientation * repetition	V vs. H	R1 vs. R3	1	39.506	39.506	.283	.602
		R2 vs. R3	1	34.722	34.722	.413	.529
	mean of H & V vs. R	R1 vs. R3	1	61.728	61.728	.383	.544
		R2 vs. R3	1	.347	.347	.007	.936

Response times to the letter search (secs)

	df	SS	MS	F-value	p-value
Orientation	2	5.005	2.502	67.264	.0001
Repetition	2	1.309	.655	30.834	.0001
Orientation * repetition	4	.062	.015	1.119	.355

Planned contrasts for RT in the letter search task

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	3.291	3.291	113.509	.0001
	mean of H & V vs. R		1	.034	.034	2.220	.155
Repetition	R1 vs. R3		1	.579	.579	35.148	.0001
	R2 vs. R3		1	.008	.008	1.036	.323
Orientation * repetition	V vs. H	R1 vs. R3	1	.001	.001	.023	.882
		R2 vs. R3	1	.114	.114	1.092	.311
	mean of H & V vs. R	R1 vs. R3	1	.065	.065	2.868	.109
		R2 vs. R3	1	.058	.058	1.705	.209

Standard deviation of fixations along horizontal axis (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	.316	.158	.374	.691
Repetition	2	1.248	.624	2.224	.124
Orientation * repetition (HF)	4 3.177	8.559	2.140 2.694	4.731	.002 .005

Planned contrasts for standard deviation of 'x'

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	.086	.086	.447	.513
	mean of H & V vs. R		1	.094	.094	.336	.569
Repetition	R1 vs. R3		1	.825	.825	5.173	.036
	R2 vs. R3		1	.147	.147	.760	.395
Orientation * repetition	V vs. H	R1 vs. R3	1	24.705	24.705	13.663	.002
		R2 vs. R3	1	2.146	2.146	1.001	.331
	mean of H & V vs. R	R1 vs. R3	1	3.472	3.472	4.361	.052
		R2 vs. R3	1	5.463	5.463	2.758	.115

Standard deviation of fixations along vertical axis (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	5.904	2.952	13.845	.0001
Repetition	2	.982	.491	2.536	.094
Orientation * repetition	4	1.295	.324	2.948	.026

Planned contrasts for standard deviation of ‘y’

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	3.416	3.416	30.356	.0001
	mean of H & V vs. R		1	.390	.390	3.028	.100
Repetition	R1 vs. R3		1	.589	.589	4.541	.048
	R2 vs. R3		1	.367	.367	2.089	.167
Orientation * repetition	V vs. H	R1 vs. R3	1	.184	.184	.320	.579
		R2 vs. R3	1	.017	.017	.032	.861
	mean of H & V vs. R	R1 vs. R3	1	2.005	2.005	8.434	.010
		R2 vs. R3	1	.187	.187	.558	.465

Saccadic amplitude in the picture search task (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	.192	.096	.275	.761
Repetition	2	2.889	1.444	3.263	.051
Orientation * repetition	4	2.087	.522	1.756	.148

Planned contrasts for saccadic amplitude in the picture search task

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	.058	.058	.210	.652
	mean of H & V vs. R		1	.052	.052	.371	.551
Repetition	R1 vs. R3		1	1.906	1.906	4.228	.055
	R2 vs. R3		1	.659	.659	3.430	.081
Orientation * repetition	V vs. H	R1 vs. R3	1	4.908	4.908	5.192	.036
		R2 vs. R3	1	3.702	3.702	2.486	.133
	mean of H & V vs. R	R1 vs. R3	1	.172	.172	.170	.686
		R2 vs. R3	1	1.822	1.822	2.456	.136

Accuracy in the memory test (% correct)

	df	SS	MS	F-value	p-value
Orientation	2	15.123	7.562	.060	.942
Repetition	2	52.160	26.080	.267	.767
Orientation * repetition	4	626.543	156.636	1.337	.265

RT in the memory test (seconds)

	df	SS	MS	F-value	p-value
Orientation	2	.001	.001	.084	.920
Repetition	2	.0001	.0001	.024	.976
Orientation * repetition	4	.026	.006	.631	.642

Standard deviation of fixations along horizontal axis in the memory test (degrees)

	df	SS	MS	F-value	p-value
Orientation	2	.891	.445	.856	.434
Repetition	2	.463	.232	.828	.446
Orientation * repetition	4	6.490	1.623	3.958	.006

Planned contrasts for standard deviation of ‘x’ in the memory test

			df	SS	MS	F-value	p-value
Orientation	V vs. H		1	.057	.057	.147	.706
	mean of H & V vs. R		1	.403	.403	1.756	.203
Repetition	R1 vs. R3		1	.308	.308	1.914	.184
	R2 vs. R3		1	.095	.095	.488	.494
Orientation * repetition	V vs. H	R1 vs. R3	1	11.492	11.492	4.682	.045
		R2 vs. R3	1	3.615	3.615	2.987	.102
	mean of H & V vs. R	R1 vs. R3	1	5.200	5.200	11.794	.003
		R2 vs. R3	1	10.183	10.183	5.624	.030

Appendix Two: Instructions to participants[26]

Experiment One: Piloting the single target RSVP [27]

This experiment is separated into two blocks, each block is identical but one takes 8 minutes to complete and the other takes 20 minutes to complete. During each experimental trial you will see a series of consonants flash up in the centre of the screen, your task is to attend to these letters carefully to see if a vowel is shown. There will only ever be one vowel in each trial and some trials will have no vowel. At the end of each trial you will be asked if you saw a vowel, if you did see a vowel press the key marked 'Y' at the bottom of the keyboard, if you did not see a vowel press the key marked 'N'. Once you have made this choice you will be asked which vowel (if any) you saw, if you did not see a vowel and answered 'N' to the previous question press the spacebar, if you did see a vowel please indicate which vowel it was by pressing one of the marked keys at the top left of the keyboard (‘A’, ‘E’, ‘I’, ‘O’, or ‘U’). You will then be given feedback so you know if your answer was correct or incorrect; following this the next trial will begin. During each trial a diamond shape will also appear, this is for the purpose of a different version of this experiment in which we are testing participants' responses to the diamond. You are in the control group and so will not carry out this version of the experiment, therefore the diamond shape is irrelevant to you and you do not need to make any response to it.

[26] In every experiment participants completed a consent form and were assured that they were free to leave the experiment at any time, without having to give a reason.
[27] In each RSVP experiment participants were also told that they would be given a short practice with the experimental procedure, and were informed that the presentation of stimuli involved a pronounced flicker effect.

Experiment Two: Establishing the blink

Participants were given instructions at the beginning of each block. These instructions all began with the following:

During the following set of experimental trials you will see a series of letters flash up in the centre of the screen. Most of the letters will be consonants, however a vowel will be shown at a random point in each trial. Your task is to attend to these letters carefully to find the vowel amongst them. At the end of each trial you will be asked which vowel you saw, please indicate which vowel it was by saying ‘A’, ‘E’, ‘I’, ‘O’, or ‘U’ to the experimenter who will record your response. You will then be given feedback so you know if your answer was correct or incorrect and following this the next trial will begin.

In a single target block participants then saw these instructions:

In some trials a shape may also appear, this is for the purpose of a different version of this experiment in which we are testing participants' responses to these shapes. This is the control session and you will not be asked to make any response to these shapes, as they hold no relevance to this experimental session.

In a dual target block participants saw these instructions:

During each trial one of four shapes will also appear prior to any vowel appearing. Before being questioned about any vowel you saw you will be asked to identify which of the four shapes you saw, a triangle, a diamond, a square or a hexagon. To make your response simply say the name of the shape you saw and this will be recorded by the experimenter.

Experiment Three: Carry-over of attentional set using the AB paradigm

The instructions for Experiment Three were identical to those used for Experiment Two, with the following exceptions:

In both blocks:

A vowel can be shown at any point in the letter string and in some trials more than one vowel will be shown. When this happens please respond by saying the *last* vowel that you saw.

After being notified of the task to search for vowels, in a single target block participants were provided with the following instructions:

In some trials a number may also appear, this is for the purpose of a different version of this experiment in which we are testing participants' responses to these numbers. This is the control session and you will not be asked to make any response to these numbers, as they hold no relevance to this experimental session.

In a dual target block participants were provided with the instructions shown below:

During each trial one of five numbers (2, 3, 4, 5, 6) will also appear prior to any vowel appearing. Before being questioned about any vowel you saw you will be asked to identify which of the five numbers you saw. To make your response simply say the name of the number you saw and this will be recorded by the experimenter.

Experiment Four: Individual differences in the control of attentional set

The instructions provided for the RSVP task were identical to those from Experiment Two with the addition of the ‘dual target’ instructions from Experiment Three. Before completing the EFT participants were provided with the instructions that were taken from the EFT manual (Witkin, Oltman, Raskin & Karp, 1971).

Experiment Five: Persistence of attentional set in a RSVP task

Participants in Experiment Five were provided with the initial instructions from Experiment Two regarding the search for T2 (vowel) and were then given the instructions outlined in Experiment Three regarding the search for T1 (number). Again, the instructions for T1 differed depending upon whether the participant was completing a dual target or single target block.

Experiment Six: Selecting a feature pair [28]

Participants were provided with the following instructions at the beginning of each block. The instructions presented in italics varied across the three blocks and the alternatives are shown on the next page.

In this experiment you will be shown an image which contains blue and purple triangles and diamonds. Please look at this image. After three seconds the screen will go blank before the image appears again for a short period of time. The screen will go blank again and will then be replaced by a second image. This will be identical to the first image that you saw but one item will have changed. *This change could be to one of the shapes (e.g., a diamond changing to a triangle) or to one of the colours (e.g., a blue shape changing to a purple shape).* You task is to try and find the change within the display. The first and second images will continue to alternate on the screen one after the other, separated by the blank screen until you have found the change. Once you think you have found it please determine which row (out of 5 possible rows) of the display the changing item is located and then press the spacebar. You will then be asked to state which location you think the change occurred in. To make your response press one of the five keys, 1, 2, 3, 4 or 5 on the keyboard. Once you have made your response the next trial will begin. Please note, the time it takes you to find the change will be recorded so try to find it as quickly as possible and press the spacebar as soon as you find it. If you wish to take a break at any time you can do so after you have pressed the spacebar when you will have as long as necessary to state where the change was located.

[28] Prior to completing Experiments 6-10 participants were informed that the study involved a pronounced flicker effect and they were asked to tell the experimenter if this was a problem.

Height-width:

In this experiment you will be shown an image which contains black rectangles of different sizes.

This change could be to the width of one of the rectangles (e.g., a wide rectangle becomes a narrow rectangle) or to the height of one of the rectangles (e.g., a tall rectangle becomes a short rectangle).

Spatial frequency-orientation:

In this experiment you will be shown an image which contains small circles. Each circle will be filled with black and white bars and these bars will differ in their width, and the direction they are oriented.

This change could be to the width of the bars of one circle (e.g., bars that were wide may become narrow) or to the orientation of the bars of one circle (e.g., bars that slant to the left may slant to the right).

Experiment Seven: Piloting the detection of colour and shape changes

Instructions for this experiment were identical to the colour-shape instructions shown for Experiment Six, with the exception of the first sentence, which read:

In this experiment you will be shown an image which contains coloured shapes; the shapes are circles, squares, triangles, diamonds, and pentagons, and these shapes can be blue, yellow, green, red, or purple).

Experiment Eight: The influence of visual search on later change detection

In this experiment you will be asked to complete two tasks. Each task will require you to make a decision about a visual array containing a series of coloured shapes. Within each array you will see five possible shapes (circle, square, triangle, diamond, pentagon) in five possible colours (blue, yellow, green, red, purple). Before being shown an array you will see a statement concerning the number of shapes or colours the following array will hold. For example "There are four circles". The statements will only involve three of four targets and your first task is to search the array and decide if the statement is true or false. Please make your decision by pressing 'T' or 'F' on the keyboard. Try to make each response fast and accurate. Following your response to the visual array the screen will go blank. A green blank screen indicates that your answer was correct; a red blank screen means that your answer was incorrect. Then you will see a second array followed by a blue blank screen. You will then see this second array with one item changed. The change could be made to a colour (e.g., a shape changes from blue to red) or to a shape (e.g., a red triangle changes to a red circle). Your second task is to find the change and determine which row of the array the changing item is on. This change will not be related to the previous search. As soon as you have seen the change press the spacebar as quickly as possible. You will then be asked to state which location you think the change occurred in. To make your response press one of the five keys, 1, 2, 3, 4, or 5 on the keyboard. You will be given feedback on your answer before the next trial. The original array and the changed array will continue to alternate until you have found and responded to the change.

Experiment Nine: The influence of visual search on later change detection when the visual stimuli differs across the two tasks

These instructions were identical to those used for Experiment Eight; however any references to a SVT involving colour were removed.

Experiment Ten: The influence of visual search difficulty on the carry-over of attentional set

The instructions used for this experiment was also identical to those provided in Experiment Eight. Exceptions to this are shown below:

In each image you will see eight possible shapes (star, square, pentagon, moon, heart, cross, circle, triangle) in eight possible colours (yellow, red, purple, pink, orange, green, brown, blue).

For the first task you will need to search each image for one or two specific shapes or colours. A search for one shape/colour would be "there are 3 green items", a search for two shapes/colours would be "there are 4 stars and squares". In both searches (one or two) you will only ever be searching for 3 or 4 items in the display. This means that if you are asked to search for 4 stars and squares there could be 3 stars and 1 square, 1 star and 3 squares, or 2 stars and 2 squares. Remember, this does not mean you are searching for 4 stars *and* 4 squares. Please ask the experimenter to clarify this if you are in doubt.

Experiment Eleven: Carry-over of visual search in natural scenes (1)

In this study you will be shown a series of random letters consisting of vowels and consonants. Your task is to respond to the number of vowels. There will either be 3 or 4 vowels, if you see 3 press '3', if you see 4 press '4'. Please respond as quickly and as accurately as possible. It is important to note that you will only be responding to the vowels A, E, O and U, and not the letter I. In addition to this you will also see photographs of roads throughout the experiment. Each time you see a road photo you need to study it as carefully as possible as you will be asked to take part in a memory test following the experiment which will test your recall of these photographs.
At the end of the experiment participants were told that they would not be given a memory test.

Experiment Twelve: Carry-over of visual search in natural scenes (2)

Instructions were the same as Experiment Eleven. After completing the main block participants were then given instructions to the memory test:
You will now see a series of photographs, some you will have seen in the first part of the experiment and some will be new. After each picture has been shown you will be asked whether you have seen the picture before or not. If you remember the picture please press 'Y'. If you do not think you saw the picture before please press 'N'.