The Attentional Cost of Feature-based Inhibition:

When ignoring distraction impairs selection

By

Lucy Sarah Andrews

A thesis submitted to

The University of Birmingham

for the degree of

DOCTOR OF PHILOSOPHY

School of Psychology

The University of Birmingham

September 2010

Abstract

The thesis investigates the inhibitory processes of visual selection across time. While distractor inhibition can improve current selection, this mechanism can also impair later selection when the new and important information shares features with the old inhibited information. I extend previous preview-based research (Braithwaite & Humphreys, 2003) to more ecologically valid dynamic circumstances. This work reveals that the cost of feature sharing is greatly magnified when items move, compared to when items remain static. These findings implicate a flexible inhibitory weighting system, where the featural aspects of a display become more heavily weighted upon as spatial aspects become less reliable. This strongly implicates feature-based inhibition in real-world failures of visual awareness. In addition, I extend the negative priming effect to conditions far more complex than previous research has suggested is possible. This not only improves its ecological validity, but also reveals a strong similarity between negative priming and inhibitory carry-over effects of preview search. This finding questions previous claims that these paradigms recruit separate processes, implicating an overlapping inhibitory mechanism. In all, the current thesis places feature-based inhibitory processing in a far more central role of guidance, selection and failures of visual awareness than previous research has suggested.

Dedication

To Mum and Dad, thanks for not getting it the other way around.

Acknowledgements

I'd first like to say a huge thank you to my supervisor Jason Braithwaite for all your help and excellent advice over the years. You ensured I made the most of every opportunity to further myself and to get the most out of the time we've worked together. I owe you hugely for everything I have achieved. It was scary at the time, but thank you for throwing me in at the deep end! I'd also like to say thank you to Derrick Watson for your many great idea's and discussions, for the useful feedback, and also the much needed programming help. And to Johan Hulleman for your genius programming skills, I definitely could not have done it without you! Gratitude also goes to Glyn Humphreys, for all your insightful comments and thoughts. I must also say thank you to my friends and family for all your support, and for giving me an escape when I've needed it! Finally, thank you to the ESRC for giving me this opportunity and funding me throughout my postgraduate studies.

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INTRODUCTION

Visual Attention

Our experience and interpretation of the visual world around us does not depend merely on the sensory input that falls on our retina. It depends on what our brain chooses to become aware of and what our brain chooses to *attend* to, which is influenced by previous experiences, current demands, goals and intentions. Attention is a crucial aspect of survival, influencing how we interact with the environment and people around us. Therefore, understanding the interaction between vision and attention is of huge importance to so many aspects of our lives.

What is Attention?

Defining attention has long posed a problem for psychologists, and over the last century it has been used to describe a variety of psychological phenomena. Early 'Folk' psychologists, (e.g., James, 1890; Kulpe, 1902) relied on an intuitive theory of attention, proposing a set of ideas about how attention influences our experience of the world.

'Everyone knows what attention is…'

William James (1890), Principles of Psychology

It was assumed that attention was controlled by the self, was fundamental to conscious perception, and was of limited capacity. If attention were not given to a particular input, we would not become consciously aware of it. Focussing attention on a specific sensation or behaviour would enhance our awareness of this sensation or performance of this behaviour.

However, this would also reduce the availability of attention for other sensations and behaviours.

Example: Attention when driving.

When first learning to drive, this is a very effortful task, demanding a great deal of attention. We have to focus on the road ahead, remember to check the mirror, change gears and watch our speed all at the same time. Having the radio on or having a conversation with a passenger can be very distracting and we can easily forget to indicate or check our mirror before setting off because of such a distraction. To perform each task correctly, we must direct our attention towards it. However, once we become experienced drivers, practice enables us to indicate, change gears and check mirrors automatically, without having to draw upon our attentional resources. Once these behaviours have been learned, we can quite easily chat to the passenger and have the radio on in the background, and still notice a cat in the road up ahead. However, if the conversation became a heated argument, this would place an increased demand on attention and the availability of attentional resources for watching the road ahead would be depleted. Now, even an experienced driver may well fail to notice the sudden appearance of a cat in the road up ahead.

The example above illustrates some important aspects of attention and awareness that the current thesis intends to address:

- *How is attention sustained to important visual information over time?*
- *How do we ignore and filter irrelevant information from attention?*
- *What factors influence whether attention will be automatically controlled by the external environment, or internally controlled by the goals and intentions of the observer?*
- *What cause failures of awareness, where we fail to notice important visual events?*

All of these questions arise from the understanding that attention is of limited capacity, and must therefore be *selective*. The current thesis is particularly interested in how selective attention operates over time, how we are able to maintain our focus of attention on the most important information available to us, and how and why this process of selective attention can sometimes go wrong.

Selective Attention

Unfortunately our brain does not have the capacity to process everything available to us and must therefore be selective in what information is attended to and what is not. The imbalance between the visual input available to us and the amount of information our cognitive systems can handle has long been acknowledged (Broadbent, 1958; Neisser, 1976; Kahneman, 1973; Sperling, 1960). However, *when* selection occurs has been a matter of much debate.

Early vs Late Selection

Early selection models assume that selection is based on the physical features of the input. Selection occurs prior to any attentional processing. Therefore, the unselected ‘discarded’ information is only processed at the level of physical features, (e.g., Broadbent, 1958).

> ‘*What then happens to unattended information? In general nothing happens to it… We simply don’t pick it up’*.
>
> *Neisser (1976, p. 87)*

However, there is a great deal of evidence to suggest that processing of unselected information is not always limited to physical characteristics. For example, in dichotic listening tasks, semantically relevant words from an ignored message can break through to consciousness (Moray, 1959; Treisman, 1960, 1964) and produce galvanic skin responses (Corteen & Wood, 1972). Similarly, the extent to which irrelevant distractors interfere with target responses in a visual selection task is dependent on the semantic relationship between the target and the distractors, (Eriksen & Schultz, 1979; Shaffer & LaBerge, 1979; Underwood, 1976). If distractors were not processed beyond perceptual features interference should be unaffected by their semantic properties.

In contrast, late selection theories assume that all information is fully processed before the most relevant information is then selected for awareness (Deutsch & Deutsch, 1963). However, the problem with this account is that unselected items are not *always* fully processed at the semantic level. As Treisman (1960) pointed out, breakthroughs in the dichotic listening task are actually very rare, and she found that on only 6% of trials did unattended words break through to consciousness.

Perceptual Load Theory

Research over the past few decades is most consistent with a flexible selection model, in that the extent to which unselected information is processed is dependent on the current attentional demands. In line with this, Lavie (1995) put forward Perceptual Load Theory, arguing that unselected information only receives additional processing when the task of selection does not require a high level of attention. When attention must focus on selection of a stimulus, there is no 'spare' attention left over to process other, less relevant information. Therefore, she proposed that selection is late under conditions of low perceptual demand and early under conditions of high perceptual demand. Consistent with this notion, Underwood (1974) found that awareness of the unattended message in dichotic listening is improved with practice, and Wilson, McLeod & Muroi (2008) showed that interference from irrelevant distractors in a visual search task is also reduced with practice, suggesting that distractors are only processed when the task is made easier, and requires less attention.

Inhibition and Selection

In the past, theories of attention have tended to think of attention as being guided by excitatory processes, where attention goes to the location, object or feature with the highest level of activation. For example, attention has been described as a metaphoric spotlight (Broadbent, 1982, Posner, 1980) or zoom lens (Eriksen & St. James, 1986). However, more recently a great deal of interest has been given to the idea that attentive processing of the relevant information may be achieved, in part, by mechanisms that inhibit the processing of irrelevant information, (Neill, 1977; Neill & Westbury, 1987; Tipper, 1985; Tipper & Cranston, 1985). Most current theories of attention now posit that information is selected and attended to by (i) excitatory processing of the relevant information, and (ii) inhibitory processing of the irrelevant information. In *preventing* the irrelevant information from being selected, this in turn facilitates selection of the relevant information, (Houghton & Tipper, 1994; Neill, 1977; Tipper, 1985).

Negative Priming

Neill (1977) provided an early demonstration of inhibition during selection in an adapted Stroop Task. Participants were required to name the colour of the ink in which the word was written, while ignoring the meaning of the word. He found that responses were slowed when the correct response to the ink colour matched the word meaning in the previous trial. This interference effect suggests that inhibition is applied to the irrelevant aspect of the display (i.e. the word meaning), to improve selection of the relevant aspect (i.e. the ink colour), and this inhibition carries over time. Therefore, inhibition of the word ‘RED’ results in a subsequent response of ‘red’ being impaired.

The slowed response to a stimulus that is the same as, or shares characteristics with a previously ignored stimulus has since been termed the *Negative Priming Effect* (see Fox, 1995; May, Kane & Hasher, 1995; Tipper, 2001, for reviews), and has been extensively covered in the literature over the past three decades to provide strong evidence of an inhibitory component of selection. Negative Priming experiments typically involve presentation of 2 displays. First a ‘prime’ display is presented and then a ‘probe’ display is presented, and both of these contain a target that requires a response and a distractor that simply needs to be ignored. When the probe target is the same or similar to the prime distractor, probe responses are slowed (Neill, 1977; Neill & Westbury, 1987; Tipper, 1985; Tipper & Cranston, 1985), compared with when the probe target is a completely new item, not related to the preceding prime display, (see Figure 1.1. for an example of a negative priming task). This effect has been found when the probe target and prime distractor share the same spatial location (Tipper, Brehaut & Driver, 1990), colour (Tipper, Weaver & Houghton, 1994), shape (DeShepper & Treisman, 1996), size, (Tipper, Weaver & Milliken, 1995), semantic meaning (Lowe, 1979; Neill, 1977; Tipper & Driver, 1988), or are from the same semantic category (Allport, Tipper & Chmiel, 1985; Tipper, 1985).

It has been proposed that during selection of the target stimulus, the internal representation associated with the distractor stimulus is inhibited. This inhibition spreads over time to associated representations, slowing later responses to these representations (Tipper, 1985; Tipper & Cranston, 1985), a notion analogous to the spreading activation account of positive priming, where responses are facilitated for information that is the same as, or shares similarities with information that has recently been selected, (Anderson, 1983).

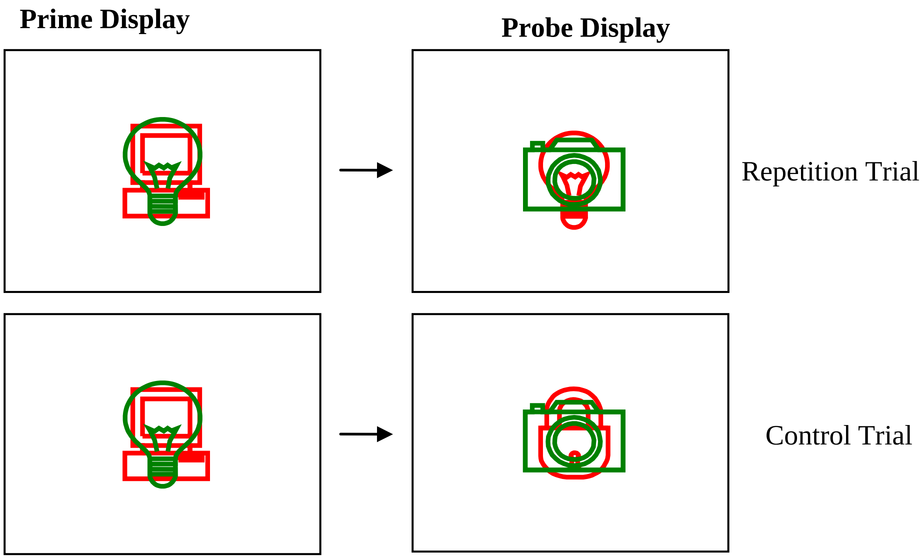


Figure 1.1. An illustration of the displays used in a typical negative priming experiment. In each trial, two displays are presented in succession – a prime display then a probe display. In this example (taken from Tipper, 1985), participants respond by naming the red object in each display. In control trials, the stimuli within the prime and the probe display are different. In repetition trials, the probe target is the same object as the prime distractor. The Negative Priming Effect demonstrates that probe responses are slowed in the repetition condition, compared to the control condition.

Selection & Awareness

Implicit measures of attention and selection have shown that attentional processing does not necessarily lead to awareness. In negative priming experiments, for example, participants do not notice any relationship between the prime and the probe display, suggesting the distractor is not consciously processed. Yet these items clearly have a significant influence on later processing, (Driver & Tipper, 1989; Neumann & DeShepper, 1991, 1992). Similarly, irrelevant onset items can often impair search performance of a central selection task, suggesting that they automatically attract attention away from the target, yet participants are not consciously aware of their occurrence (Yantis & Johnson, 1990).

Explicit measures have also revealed that salient visual information can often fail awareness. Would you notice a gorilla walk across the middle of the television screen whilst watching a game of basketball? Well demonstrations of *Inattentional Blindness* suggest that perhaps you would not. In fact, these failures of awareness are surprisingly common, and studies show that it is often more common for participants to completely miss such salient events than for participants to notice them (Neisser & Becklen, 1975; Simons, 2000; Simons & Chabris, 1999).

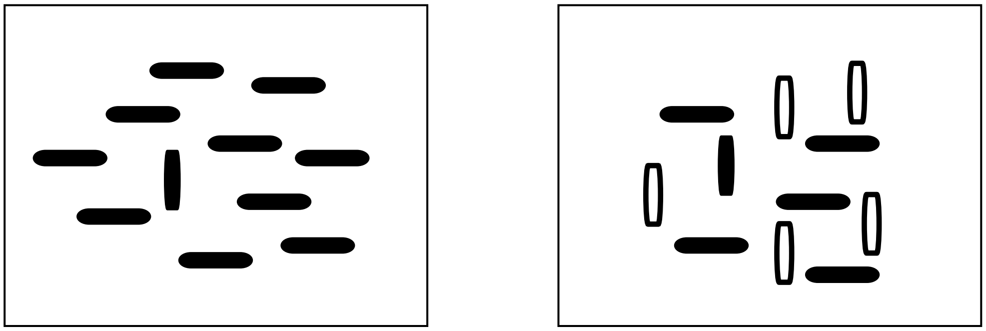
Inattentional blindness

Inattentional blindness refers to instances in which a salient but unexpected new item goes completely unnoticed by the observer (see Simons, 2000, for a review). In one of the first demonstrations of this, Mack & Rock (1998) found that around 75% of participants failed to notice an unexpected item appearing at fixation when attention was focussed on a peripheral location. Experiments have since been extended to more realistic visual experience, such as video footage of sports games to demonstrate these striking failures of awareness, (Becklen & Cervone, 1983; Neisser & Becklen, 1975; Simons & Chabris, 1999). For example, Simons & Chabris, (1999) found that participants commonly failed to notice a gorilla walk across the middle of a basketball game, when focussed attention was used to count the number of passes made between one of the teams. These ‘Selective Looking Tasks’ have also been carried out under more controlled, computer-generated visual tasks. Most et al (2001) used a multiple object tracking task, where participants were required to count the number of bounces made between 4 of the 8 items presented on the screen, during which, an unexpected cross moving across the centre of the screen often went unnoticed.

These investigations show that we are not as skilled at noticing salient and important visual events as we might expect to be. However, while these failures of awareness have been widely documented and illustrate the complex interaction between bottom-up and top-down processing in visual perception and awareness, a functional account of such failures of awareness has yet to be developed. This is a shortcoming the current thesis intends to address.

Visual Search

The visual search paradigm has been developed to examine how visual attention is guided to items within a visual display, when observers are required to locate a pre-specified item based on its distinguishing features. Two different types of search tasks have been used to develop an understanding of how feature and spatial information is used by attention to perform such tasks - easy ‘single-feature’ search, and difficult ‘conjunction’ search, (see Figure 1.2 for an illustration of each type of search task). In single feature search the target holds a different feature from all other items, (for example, the target could be a red item and the distractors could all be green items). Under these conditions search is fast and is not affected by how many distractors are present within the display, suggesting that the salient target ‘pops out’ of the display and attention is guided straight to the target without visiting the other items first. In conjunction search, all items within the displays share some features with the target. For example, the target could be a red X, and the distractors could be red A’s and green X’s. Under these conditions, search becomes slower as more distractors are added to the display, which suggests that attention must visit each item to locate the target, a process which becomes more demanding as more items must be searched.



Single Feature Search **Conjunction Search**

Figure 1.2. An example of a single feature and a conjunction search task. In single feature search the target ‘jumps out regardless of how many distractors are present. In conjunction search the task becomes progressively harder as distractors are added.

To account for these differences between single feature and conjunction search, several theories of attention have been put forward. Particularly relevant to the current thesis are the Feature Integration Theory (Treisman & Gelade, 1980; Treisman & Sato, 1990), the Guided Search Model (Wolfe, 1994), and the Attentional Engagement Hypothesis, (Duncan & Humphreys, 1989, 1992). Although these models were originally developed to be set against each other, I suggest that all provide insight into guidance and selection in a variety of different visual attention tasks, and something can be taken from all of these frameworks when interpreting the findings of the current thesis.

Feature Integration Theory

The Feature Integration theory, (FIT: Treisman & Gelade, 1980) assumes that perceptual features, such as location, colour and size, are extracted and processed in parallel and independent of attention. However, to combine these features into objects, attention is required. By focussing attention on a specific location, the features associated with that location can be integrated to form an object file. This model can account for why single feature search is very fast and the search slope is flat across display size, as the target can be located by parallel extraction of the features. Whereas conjunction search is slow and the search slope increases as display size is increased, because serial search is required. Attention must visit each location, binding features into objects to eventually locate the target.

In a revised version of this model Treisman & Sato, (1990) have added an inhibitory component, suggesting that inhibitory connectors between the feature-based representation and the space-based representation enable any locations containing non target features to be inhibited. For example, if the task was to locate a red X, then all locations associated with activation of a non red colour-map would be inhibited and removed from selection. The current thesis provides support for this notion of feature-map suppression, suggesting that, under certain conditions of selection, multiple irrelevant items can be inhibited and rejected from selection by inhibiting the shared feature-map in which they all appear.

Guided Search Model

Providing a more flexible alternative to the Feature Integration Theory, the Guided Search Model (Wolfe, 1994, 1998) replaced the idea of serial and parallel processing with the notion of search *efficiency*, where performance falls somewhere on the continuum of very efficient search (where reaction times are flat over display size) and very inefficient search (where reaction times increase considerably with display size). They proposed that features are extracted by pre-attentive processes, and the level of activation is then used to guide attention to the likely targets. For example, if the display contains two colour groups, parallel extraction of features enables the display to be separated into two colour groups, and attention can then be directed towards the more relevant colour group. Attention is guided to the location with the highest activation level, which is determined by both bottom-up salience and top-down goals. The flexibility of this model can explain why some conjunction searches are easier than others, falling at different places along the continuum of search efficiency. As the signal to noise ratio is increased, and the target activation becomes less salient, guidance towards this item will become less efficient, (Wolfe, 1994; Wolfe et al., 1989). The notion of search efficiency is an important component of selection for the current thesis, which examines the factors that influence how efficient, or inefficient, search for salient targets will be.

Attentional Engagement

The Attentional Engagement Theory (Duncan & Humphreys, 1989) places less emphasis on feature activations within a location-based spatial-map, and a greater emphasis on the role of features in grouping items into objects. They found that search was more efficient when two distractor sets were similar to each other, than when the two distractor sets were very different, (Duncan & Humphreys, 1989). To account for why search efficiency is not only dependent on target-distractor similarity, but also distractor-distractor similarity, they proposed that perceptual grouping enables multiple objects to either be selected or rejected in parallel. Therefore, if the target is a feature singleton, it will be selected alone and selection will be fast. Similarly, if distractors share common features with each other and can be grouped accordingly, they will be rejected in parallel. They also suggest that suppression spreads throughout a rejected feature group. Therefore, when all distractors appear within the same feature group, all will be suppressed and excluded from selection. In the current thesis I find evidence to support this notion of suppression spreading throughout a group of distractors which have been grouped by a common feature (in the current case a common colour). Furthermore, the current thesis suggests that suppression also spreads across time to new items also appearing within this group.

Object-based Attention

The Feature Integration Theory and Guided Search Model are both *space-based* models of attention, where selection operates on areas of space. This has been described as an attentional spotlight, (Broadbent, 1982; Posner, Snyder & Davidson, 1980), a zoom lens, (Eriksen & St. James, 1986), and a gradient (LaBerge & Brown, 1989). In contrast, the Attentional Engagement Hypothesis is an *object-based* model of attention, where selection operates on later representations, where features have already been grouped into objects or perceptual ‘chunks’. Evidence for fast acting perceptual grouping of features and object-based processing has been widely documented in the literature, (Baylis & Driver, 1992; Driver et al., 1992; Duncan, 1995; Duncan & Humphreys, 1989; Kahneman et al., 1992; Lamy & Tsal, 2000; Neisser, 1967). I will therefore limit this discussion to the research most relevant to the current body of work – that of multiple object tracking (Pylyshyn & Storm, 1988), and object-based inhibition (Muller & Von Muhlenen, 2000; Owaga, Watanabe & Yagi, 2002; Tipper, Driver & Weaver, 1991).

Multiple Object Tracking

Multiple Object Tracking tasks (MOT: see Cavanagh & Alvarez, 2005, for a review) show that attention can operate effectively, to some degree at least, independent of a stable spatial representation. In these experiments, observers are presented with a display of identical, randomly moving items, and must selectively track a subset of these for a sustained length of time (typically around 5-10 seconds). Pylyshyn & Storm (1988) developed the FINST index to account for MOT, positing that a limited number of indexes (4-5) can be allocated to objects in parallel. This index can then stay 'glued' to the object as it moves around, independent of spatial location. More recent research suggests that the number of objects we can tag at one time is dependent on a number of factors, such as speed and size of stimuli, and display size and density (Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009; Horowitz et al., 2007), ranging from 2 objects up to 8 objects in some cases.

Object-based Inhibition

Investigations of Inhibition of Return and Inhibitory Tagging reveal that we can not only track moving items in an excitatory manner, we can also attach inhibition to a number of objects as they move through space. Inhibition of Return was originally proposed as the passive guidance away from a previously visited *location* (Posner & Cohen, 1984). When a target is immediately preceded by a spatial cue indicating its location, this improves selection, suggesting that attention is directed to the location in which the cue appears (Posner, 1980). However, when the time interval between the cue and the target is extended to around 300ms, the cue actually slows responses to the target, compared with when a cue is presented in a non-valid location. To account for this finding, Posner & Cohen (1984) proposed the mechanism of Inhibition of Return, suggesting that once the initial activation of an attended location has decayed, this is replaced by suppression. This was proposed as an adaptive process, designed to prevent attention from returning to a location that has recently been visited, which would save valuable time when scanning the area for prey or predators (Klein, 1988). More recently, research has shown that this effect is not limited to previously attended locations, and also applies to previously attended objects. For example, Tipper et al. (1991) found that IOR is preserved when the previously attended object is moved to a new location, suggesting that inhibition is tied to the object rather than the location in space occupied by that object (see also Jordan & Tipper, 1998).

Similarly, visual search studies suggest that inhibition can be applied both to locations and objects. Klein (1988) first coined the term ‘inhibitory tagging’ in a visual search study in which 50% of trials were followed by a dot-probe detection task, where the probe could either appear in a location occupied by one of the distractors from the search task, or it could appear in a new, unoccupied location. He found that probes were harder to detect when appearing on a distractor compared with background space. From this, it was suggested that when a location has been attended to, inhibition is attached to that location to prevent attention from returning to a previously rejected distractor.

Later research has suggested this inhibition is attached to the object at that location, rather than the location itself. This was first suggested because the cost for probes falling at the locations of previously rejected search items no longer occurs if the search items are removed prior to the probe-detection task, (Muller & Von Mühlenen, 2000; Takeda & Yagi, 2000). Furthermore, this cost for probes on rejected search items has been shown when visual search items are moving randomly and probes are presented at the end of the search task when items stop moving, and this cost is roughly doubled on target absent trials, compared with target present trials (Ogawa, Takeda & Yagi, 2002). Similar findings have also been obtained in multiple object tracking tasks, (Pylyshyn, 2006), suggesting that a number of irrelevant moving items can be successfully tracked and inhibited to remove these objects from attention and improving attentional tracking of other task-relevant objects.

Attention Across Time

The current thesis is interested not only in how attention is guided across space, but also how attention is guided across time. The processes of onset capture and IOR show that new items tend to be automatically prioritised over old visual items, and observers require no top-down intention to do so, for these processes to take effect. However, the current thesis is mostly concerned with the higher level processes that become involved in guidance towards new information when observers *intend* to ignore the old and attend to the new. I will therefore briefly summarise automatic onset capture before moving on to the processes involved in the top-down prioritisation of new visual information.

Onset Capture

Numerous studies have shown that attention is automatically guided towards new luminance onsets (Yantis & Johnson, 1990; Yantis & Jonides, 1984) and new objects (Yantis & Hillstrom, 1994). Yantis & Jonides (1984) first showed the onset advantage by presenting visual search displays in which the target was defined by either a luminance onset or a luminance off set, and found that visual search was improved for onset targets. Similarly, during visual search, a completely irrelevant onset item interferes and slows down responses, suggesting that its presence automatically captures attention away from the search task (Theeuwes, 1991, 1994). Automatic onset capture appears to be highly robust, and only when attention is focussed on a different spatial location can it be overridden, (Yantis & Jonides, 1990; Theeuwes, 1991).

Like Inhibition of Return (discussed on page 17), automatic capture of new objects and events, and luminance changes to current information is an adaptive process beneficial to survival. However, onset capture and IOR only occur for around 4-5 items at one time, limiting the conditions in which they can operate (Snyder & Kingstone, 2000; Yantis & Jones, 1991). In contrast, when new information is task relevant, and sufficient time and attention is available for observers to *actively* prioritise the new items, the extent to which new items enjoy attentional priority is greatly increased, compared with that afforded by low-level processing alone (Watson & Humphreys, 1997; Watson et al., 2003).

Preview Search

The preview paradigm, originally developed by Watson & Humphreys (1997), examines attentional guidance and selection across space and time. In this visual search procedure, half of the distractors are presented earlier than the remaining distractors and the target. Staggering the onset of display items in this manner greatly improves search performance, relative to when all items are presented at the same time, and is more reflective of search when the second onset of items are presented alone. This effect, termed the Preview Benefit, suggests that the old irrelevant items can be excluded from search, enabling attention to be limited to the new relevant set of items. Figure 1.3 examples the displays and procedure used in a typical preview search task (e.g. Watson & Humphreys, 1997). Figure 1.4 illustrates the typical pattern of performance observed in a preview search task, compared with the half-set baseline (where the second set of items is presented alone) and the full-set baseline (where all items from both displays are presented together).

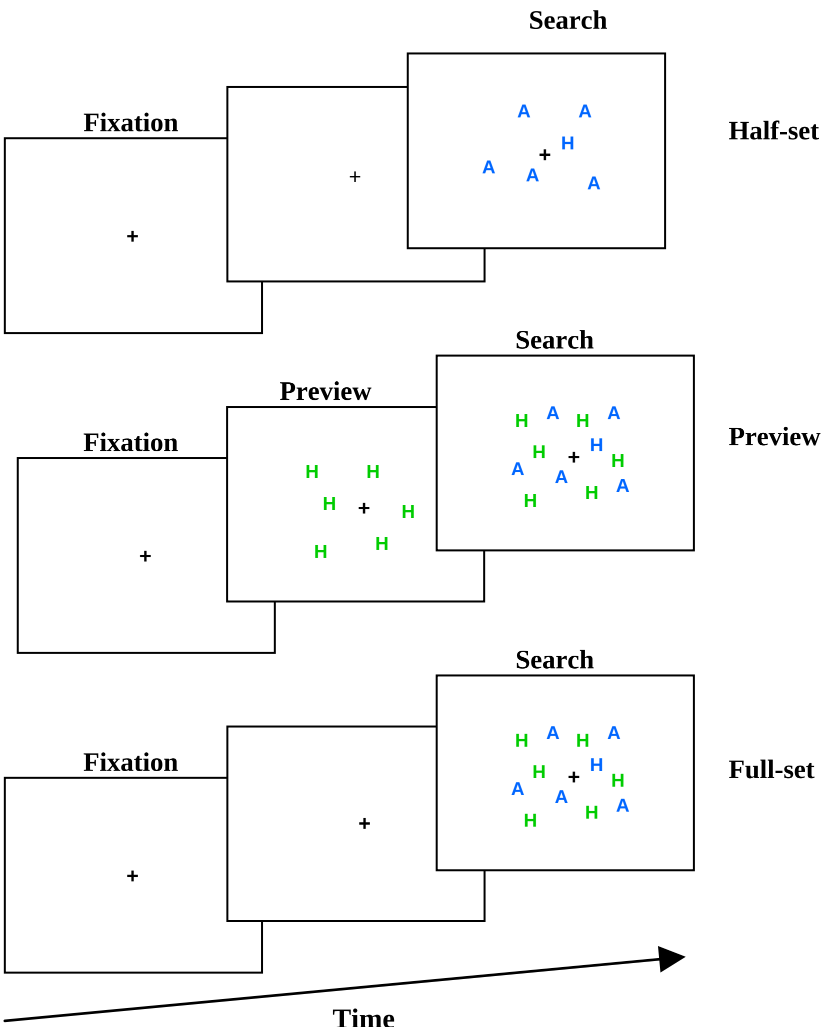


Figure 1.3. An illustration of the displays used by Watson & Humphreys (1997). In the preview condition, the preview display is first presented (Green H’s), before being joined by the search display. In the half-set baseline, the search display is presented alone. In the full-set baseline, the preview and search display are presented together.

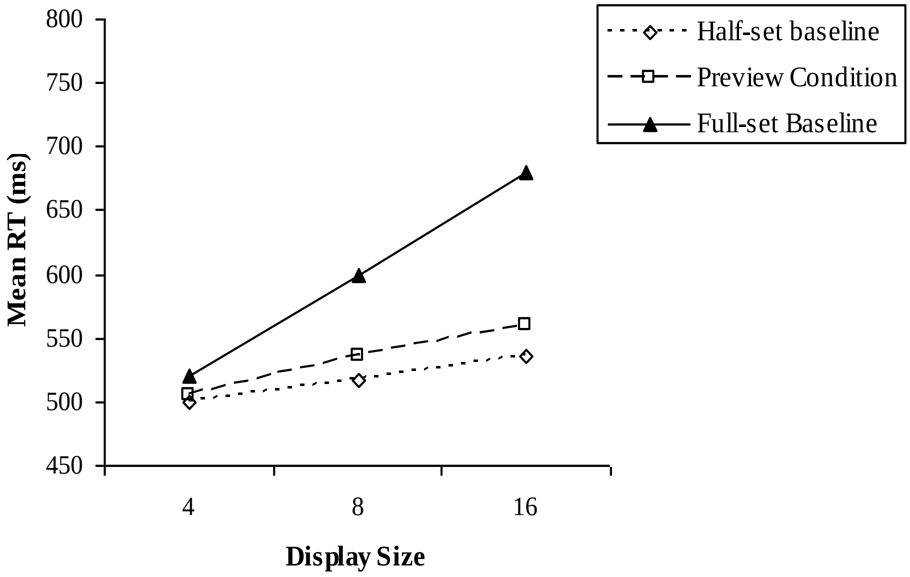


Figure 1.4. An example of the results typically found in preview search, compared to the half-set and full-set baseline conditions. The half-set baseline is an efficient search task, where the target is usually defined by colour or shape. Here, the number of distractors present has very little impact on search, and reaction times are flat across display size. The full-set baseline contains two sets of distractors and the target shares features with all items. This is an inefficient conjunction search task, where reaction times become longer as more distractors are added to the display. In preview search, the same items present during full-set baseline search are also present here. However, one set of distractors is presented earlier than the other set of distractors and the target. Here, search is efficient and comparable to the half-set baseline, despite there being a full display of conjunctive stimuli present during search. This suggests that search is limited to the second onset of stimuli, which is identical to the half-set baseline display and where the target is a feature pop-out item.

The Visual Marking Model

During their original investigations, Watson & Humphreys (1997) identified a number of important constraints to the preview benefit. Crucially, the benefit is disrupted by (i) reducing the time between the onset of the preview and search display below 350ms, (ii) performance of a secondary, attentionally demanding task during the preview period, and (iii) local luminance changes at the locations of the old items.

To explain these findings, they put forward the Visual Marking Model, proposing that the locations in which the old items fall are actively inhibited, enabling these irrelevant items to be filtered from attention and excluded from search. This top-down process was proposed to compliment low-level capture to afford the new, task-relevant items optimal attentional priority.

An inhibitory mechanism of preview search has received wide empirical support, and in particular from studies incorporating dot-probe detection into preview search tasks. Research shows that, when probes are presented briefly on a subset of trials, they are less likely to be detected when they fall on a preview item, than when they fall on a new search item (Olivers & Humphreys, 2002; Watson & Humphreys, 2000), or when they fall on empty background space (Humphreys, Jung-Stalman & Olivers, 2004). This later finding suggests that attention is not only guided towards the new locations, but it is also guided *away* from the old locations.

The inhibitory mechanism of preview search has been distinguished from the inhibitory mechanisms of Inhibition of Return (Posner & Cohen, 1984) and Negative Priming, (Tipper, Brehaut & Driver, 1990) for a number of reasons. Firstly, up to 15 old items can be inhibited in preview search (Theeuwes, Kramer & Atchley, 1998), whereas IOR is limited to 4 items at one time, (Snyder & Kingstone, 2000), and negative priming effects are strictly limited to displays containing just 2 items, (Houghton, Tipper, Weaver & Shore, 1996; Neumann & DeShepper, 1992). Secondly, while the preview benefit is disrupted by luminance changes occurring at the marked locations (Watson & Humphreys, 1997, 2002), both IOR and negative priming occurs when the initial item at that location is removed, and replaced by a new item. This suggests that inhibition in preview search is disrupted by such luminance changes, whereas IOR and negative priming is not. Finally, IOR occurs for previously *attended* locations, whereas in preview search participants are explicitly told not to search the preview items, and Olivers, Humphreys, Heinke & Cooper (2002) found that the preview benefit is completely abolished when participants are required to search through the preview items before the search display is presented.

The Role of Features in Preview Search

Preview-search investigations have used colour manipulations to show that performance is greatly influenced by the featural relations between the old and new items. When new targets share features with the preview items search is significantly impaired and the preview benefit to search is diminished (Braithwaite & Humphreys, 2003, 2007; Braithwaite, Humphreys & Hodsoll, 2003, 2004; Braithwaite, Humphreys & Hulleman, 2005; Braithwaite, Humphreys, Hulleman & Watson, 2007). This effect, termed the negative colour-based carry-over effect, is argued to reflect the spread of inhibition across time, and strongly implicates a feature-based component of inhibition in preview search, (Braithwaite & Humphreys, 2003).

Detailed investigations have been carried out to show that these carry-over effects do not merely reflect low-level colour grouping, (Braithwaite et al., 2003, 2007; Braithwaite & Humphreys, 2003, 2007; Olivers & Humphreys, 2003). For example, when the preview duration is reduced to just 150ms, both the preview benefit and carry-over are abolished

(Braithwaite et al., 2003, 2007), suggesting that time is required for an inhibitory attentional-set to become established. Preview benefits and carry-over effects are also contingent on the old items being irrelevant to the task. When the target is just as likely to, or more likely to fall in the preview display as the new display, both of these effects are abolished, suggesting an active bias against the old items is required (Braithwaite et al., 2005, 2007; Braithwaite & Humphreys, 2007; Olivers & Humphreys, 2002; Watson & Humphreys, 2000). Finally, the carry-over cost for new items sharing the original preview colour remains even when the old items change colour (Braithwaite et al., 2003, 2004, 2005) or are completely removed (Olivers & Humphreys, 2003) when the new items appear. These findings go against a bottom-up grouping or capture account of preview benefits and costs. If the carry-over effect merely reflected a reduced onset signal for new items sharing the colour of the old items (i.e. the background colour), this would not require time, would not depend on attentional set, and would be abolished if the background colour was no longer present. Instead, the findings implicate a higher-level, inhibitory filtering mechanism based on the shared features within the display. This enables old items to be inhibited but carries over time resulting in a cost for new items also sharing this feature.

Dynamic Preview Search

The research discussed above has examined preview search through static visual displays. However, preview benefits can also occur when display items move, (Kunar, Humphreys & Smith, 2003; Olivers, Watson & Humphreys, 1999; Watson & Humphreys, 1998; Watson, 2001). Under these dynamic conditions, feature coding appears to be more central to preview benefits than in static conditions, where location-based coding is also possible. For example, static preview benefits occur for achromatic stimuli, whereas dynamic preview benefits do not (Olivers et al., 1999; Theeuwes et al., 1998). Similarly, a colour change to the preview items disrupts the dynamic preview benefit but not the static preview benefit, (Kunar et al., 2003; Watson & Humphreys, 2002). To explain these differences, it has been suggested that, in static preview search, inhibition occurs predominantly via the old locations, (Watson & Humphreys, 1997, 2000, 2002) and features are used to aid grouping and guidance of attention away from these old locations, (Braithwaite & Humphreys, 2003), whereas in dynamic preview search, it has been suggested that old items may be inhibited via their shared feature-map representation, (Kunar et al., 2003; Watson & Humphreys, 1998). However, to date there has been no formal investigation into the role of colour in dynamic preview search. It is unclear from the previous research findings whether the increased role for colour in dynamic preview search reflects an increased role for low-level segmentation processes, or an increased role for colour-based inhibition. This ambiguity is a problem the current thesis intends to address.

Overview of the Current Thesis

The current thesis investigates feature-based inhibitory processes under dynamic preview search conditions (Chapters 2 & 3) and in the negative priming paradigm (Chapter 4). Both of these paradigms examine attentional guidance across time, and both have been used to evidence distractor inhibition during selection. While this suppression improves current target selection, it also carries over time, resulting in a cost for new stimuli sharing similarities with old distractors. It is this inadvertent attentional cost that is of primary interest to the current body of work.

The work carried out here addresses two main weaknesses of the research carried out to date. Firstly, demonstrations of carry-over effects in preview search are limited to static-based investigations. However, real world selection rarely involves a completely static environment. Therefore, the current work extends these investigations to more ecologically valid dynamic circumstances, to more reliably understand the role of inhibitory guidance and selection.

Secondly, although inhibitory carry-over effects in preview search and negative priming share a great deal of similarity, these paradigms are presumed to draw upon different inhibitory processes. This assumption has been based largely upon their capacity differences. By examining the literature, I have noticed an important confound between the types of stimuli used to examine negative priming capacity and preview search investigations. Extending the negative priming effect to more complex and realistic conditions of selection would not only implicate an overlap between negative priming and the inhibitory mechanisms involved in complex search and selection across time (i.e. preview search), but it would also considerably improve the ecological validity of the negative priming effect, which at present is limited to selection involving just two stimuli.

Chapter 2

Chapter 2 compares preview benefits and colour-based carry-over effects under both static and dynamic preview search conditions. Previous research has suggested that features may be more heavily relied upon under dynamic conditions, when location-based visual marking is not possible. If this is indeed the case, and the role of colour is not equivalent for static and dynamic stimuli, then the effects of feature sharing may also be different. Real visual experience is in a constant state of flux, as we move around the environment and the environment moves around us. Therefore, it is important to understand the mechanisms of selection across time for moving displays, in order to more reliably infer real world selection from laboratory findings.

In Chapter 2, I ask:

- *Will a colour-based carry-over effect occur under more ecologically valid dynamic search conditions?*

And,

- *If so, will this cost of feature sharing be increased under dynamic search conditions (where features are more heavily relied upon) than static stimuli (where location-based inhibition is proposed to dominate)?*

Chapter 3

Chapter 3 extends this investigation further, by comparing preview-based carry-over effects under two different types of dynamic conditions. In the common motion search conditions (also used in Chapter 2) items move together in a uniform manner. This is most representative of local motion, as observers move around a stable and structured visual environment. In the new random motion search conditions, items moved in different and unpredictable directions.

This is most representative of external motion, as the environment moves around us in an unsystematic manner.

In Chapter Three I ask:

- *Does a stable configuration contribute towards inhibitory guidance through a dynamic visual environment?*

And,

- *If so, will the cost of feature sharing be increased more so for unpredictable, randomly moving stimuli than uniformly moving arrays?*

Together, these investigations reveal that the colour-based carry-over is greatly increased when items move (for both types of dynamic displays), compared with when they remain static. This strongly suggests that the reliance on feature-based inhibition is increased when location-based inhibition is not possible. This magnified dynamic carry-over effect also suggests that, in the real dynamic visual world, new information can suffer a severe attentional cost through sharing features with old irrelevant information. I also find that the dynamic carry-over effect is increased even more so when items move randomly than when items move together. This suggests that new and unpredictable moving stimuli suffer a greater attentional cost than new moving stimuli which form part of a stable configuration.

The findings also highlight a strong similarity between feature-based carry-over effects in preview search and instances of feature-based inattentional blindness, where unexpected items are far more likely to go unnoticed when they share features with items currently being ignored (Most et al., 2001, 2005; Simons & Chabris, 1999). I therefore suggest that the feature-based inhibitory mechanism of preview search may play a role in these instances of sustained inattentional blindness. The severe attentional cost found in the current thesis strongly implicates feature-based inhibition in real world failures of visual awareness.

Chapter 4

Chapter 4 examined whether feature-based carry-over effects in preview search may reflect a form of feature-based negative priming. Although previous research has drawn a distinction between the inhibitory processes of preview search and negative priming, (Olivers et al., 1999; Watson & Humphreys, 1997), these investigations have been primarily concerned with location-based inhibition. However, more recent demonstrations of feature-based inhibitory carry-over effects in preview search (Braithwaite & Humphreys, 2003) share a close resemblance with feature-based negative priming effects. I propose that these developments in the literature demand the case be re-opened as to whether these paradigms recruit the same, or at least overlapping, inhibitory mechanisms of selection.

One of the major distinctions between preview search and negative priming is that in preview search, carry-over effects emerge when up to 12 items must be inhibited (Braithwaite et al., 2003), whereas negative priming is abolished when more than 1 distractor must be inhibited at one time (Houghton et al., 1996; Neumann & DeShepper, 1992). In an effort to bridge the gap between inhibition in preview search and negative priming, I examine whether negative priming can be extended to conditions more representative of preview search by addressing a crucial confound of the literature. In preview search, old distractors typically share a common feature, such as colour or shape (Braithwaite & Humphreys, 2003; Olivers & Humphreys, 2003; Watson & Humphreys, 1997, 2000, 2002), and this shared feature contributes towards inhibitory filtering (Braithwaite & Humphreys, 2003; Olivers & Humphreys, 2003). However, in negative priming experiments, this is not the case. Previous investigations into capacity limits have used displays in which all distractors hold different shapes and different colours, (Houghton et al., 1996; Neumann & DeShepper, 1992). Therefore, a reliable comparison of capacity is not possible from the data obtained from previous research. I address this confound by examining whether negative priming will occur when distractors share a common feature with which to be grouped and encoded.

In Chapter 4 I ask:

- *Will a shared feature amongst distractors extend the negative priming effect to conditions of selection involving more than just 2 stimuli?*

And,

- *Can negative priming effects be obtained in an inefficient visual search task?*

> The study revealed that when the confound between the number of distractors and the number of distractor types is controlled for, negative priming effects occur (i) when selection involves multiple distractors, and (ii) when inefficient visual search for the target is required. These findings question the previous assumption that the inhibitory process of negative priming is isolated from inhibitory filtering during preview search, strongly implicating an overlap between the mechanisms of preview search and negative priming effects.

The format of this thesis varies from convention, as each experimental chapter is based on a separate, self-contained journal article. Therefore, each experimental chapter includes its own introduction and general discussion and some repetition has been unavoidable.

CHAPTER 2

AN INCREASED RELIANCE ON FEATURE-BASED INHIBITION UNDER DYNAMIC VISUAL SEARCH CONDITIONS LEADS TO MAGNIFIED IMPAIRMENTS OF SELECTION

Synopsis

Evidence for inhibitory processes in visual search comes from studies using preview conditions, where half of the distractors are presented early, (Watson & Humphreys, 1997). I examined whether inhibition was applied in the same manner for static and moving displays, or whether the inhibitory weighting applied to different features varied with their utility for the search task. I did this by examining negative carry-over effects under the ecologically valid conditions of dynamic visual search, revealing that the cost of feature sharing was significantly exaggerated with moving displays compared with static displays. Collectively, the findings suggest that feature-based inhibition contributes strongly to preview search through dynamic displays and this leads to an amplified attentional-blindness to new targets. (This chapter is based on a paper accepted for publication in the Journal of Experimental Psychology: Human Perception & Performance).

Introduction

The human brain is constantly being bombarded with information which makes up our visual environment, providing a constant flow of dynamic visual information. However, the capacity of the nervous system is far exceeded by such a rich, detailed and continuous source of information (Broadbent, 1958; Neisser, 1967). As a consequence of these limitations, certain items, objects and events must be selected at the expense of others, in order to guide appropriate behaviour and action. To ensure this, attentional mechanisms are required to select stimuli that are relevant to the current goals and reject stimuli that are irrelevant and distracting. Visual search tasks have been used extensively to study visual selection over the past three decades or so, measuring search efficiency to ascertain the ease of selection (Wolfe, 1998). Typically, visual search studies have investigated how attention is guided across space (Treisman & Gormican, 1988; Wolfe, 1998). However, to develop a comprehensive understanding of real-world selection, it is also important to investigate how attention is guided across time.

Preview Studies of Visual Search and Selection

The Preview Paradigm (Watson & Humphreys, 1997) has been developed as one way to examine attentional guidance and selection across both space and time. This procedure demonstrates that the efficiency of visual search performance can be greatly improved if observers are given an initial preview of half of the distractor items, before the remaining distractors and the target item are added (Watson & Humphreys, 1997). Under these ‘preview’ conditions search is improved compared to when all items are presented at the same time, suggesting that search is restricted to the new relevant items. As a consequence of the preview (and the psychological processes recruited in that period), the initial distractors do not compete strongly for selection. This improvement on search performance has been termed the *'preview benefit'* (see Watson et al., 2003).

To account for this preview benefit on search, Watson and Humphreys (1997) proposed the mechanism of *'visual marking'*. They proposed that goal directed top-down inhibitory filtering of the locations occupied by old irrelevant distractors enables old items to be effectively filtered from search, allowing new items to be prioritized for selection. This inhibitory marking mechanism was cast as a complementary process that worked in concert with onset-capture mechanisms, particularly in situations where the capacity of capture mechanisms had been far exceeded (Watson & Humphreys, 1997; Watson et al., 2003). Therefore, the existences of these inhibitory processes were not being proposed instead of capture mechanisms, but in addition to such low-level processes.

There are a number of findings which support the contention that visual-marking is an active, top-down attentionally-demanding process. Firstly, if the preview duration is reduced below that of around 350ms – then preview benefits to search efficiency are severely attenuated or even abolished (Humphreys et al., 2004, 2006; Watson & Humphreys, 1997). This suggests that sufficient time is required for the inhibitory bias directed towards the irrelevant items to accrue – it does not occur passively or merely as a result of staggering the displays. Indeed, by current estimates 60ms is sufficient for two temporally distinct events to be perceived as separate and 350ms is far beyond the time frame of fast-acting low level processes (Leonards, Singer & Fahle, 1996; Yantis & Gibson, 1994). Secondly, the preview benefit is also abolished if participants are given an attentionally demanding dual-task to complete during the preview period – consistent with the idea that this new task competes for limited resources and removes them from the inhibitory process (Braithwaite et al., 2005; Olivers & Humphreys, 2002; Watson & Humphreys, 1997). As a consequence the irrelevant items continue to compete for selection and search becomes inefficient.

Thirdly, studies which have incorporated a probe-detection task into preview search have shown that probes are harder to detect when they fall at the location of a preview item compared to when they fall at the location of a new item (Braithwaite et al., 2005; Braithwaite & Humphreys, 2007; Olivers & Humphreys, 2002; Watson & Humphreys, 2000), and compared to when they fall in an unoccupied background location (Humphreys et al., 2004). However, this selective cost to probes falling on preview items is greatly reduced when these old items are no longer irrelevant to the primary task (Braithwaite & Humphreys, 2007; Olivers & Humphreys, 2002; Watson & Humphreys, 2000), consistent with the preview benefit being dependent on the top-down intentions of participants to ignore the old irrelevant items, rather than being due to automatic bottom-up attentional prioritisation of the new items (Yantis & Jonides, 1984; Yantis & Hillstrom, 1994).

An important component of the original visual-marking account was that, for static items, the preview display items were inhibited on the basis of their locations and not their featural attributes (Watson & Humphreys, 1997, 2000). Features played no part in this process. As such, inhibitory filtering was argued to be ‘feature-blind’. This notion is not without some support. Preview benefits for static items have been shown for up to 15 items even when all items are presented achromatically and there are no featural differences between the displays

(Theeuwes et al., 1998). In addition, Watson and Humphreys (2002) showed that isoluminant colour changes to the preview items when the search items were added had no effect on the preview benefit. If old items were inhibited via their colour properties then colour changes should ‘release’ the old items from suppression and attenuate the preview benefit. However, preview search remained efficient despite such colour changes. While this was taken as evidence that colour was not critical or involved in mediating preview benefits to search for static items, a growing number of more recent studies have substantially revised this position (discussed below).

Negative Feature-based Carry-over Effects in Static Preview Search

In the original preview study, Watson & Humphreys (1997) argued that the inhibitory mechanism of static preview search was a purely location-based, feature-blind process. More recently however, research has strongly implicated an additional feature-based component to the inhibitory mechanism by showing that preview benefits are dependent on the colour relation between old and new items. Numerous studies have now shown that, for static items, when the new target carries the colour of the previewed items search is significantly less efficient than when the target holds a different colour (Braithwaite & Humphreys, 2003, 2007, 2010; Braithwaite et al., 2003, 2004, 2005; Braithwaite, Hulleman, Andrews & Humphreys, 2010; Braithwaite, Watson, Andrews & Humphreys, 2010; Olivers & Humphreys, 2003). This impairment has been termed the *negative colour carry-over effect*, and is argued to reflect a form of sustained attentional-blindness to new items which carry the properties of items being ignored (Braithwaite et al., 2003). By this account, feature-based inhibition (perhaps akin to the inhibition of a whole feature-map: Treisman & Sato, 1990) spreads to new and important information if it carries the critical attribute currently being ignored.

These negative effects from successful inhibition have been shown for new groups of items carrying the old colour and even new singletons carrying the colour of the preview items and they occur despite the fact that colour itself was always irrelevant to the task and was not a useful or informative cue to guide search to the target (Braithwaite, et al., 2003; 2004; Olivers & Humphreys, 2003). The effect suggests that, in addition to any process of location-based inhibition (Watson & Humphreys, 1997), there is also inhibition of the colour of the old items (i.e., featural attributes). If this inhibition spreads and is applied to the new items carrying the same colour, then these items will become difficult to detect as they will receive a degree of de-prioritisation.

Interestingly, recent evidence has distinguished the temporal properties of these feature-based effects from location-based effects which are co-present and also mediating performance in static displays. Braithwaite, Hulleman, Andrews & Humphreys (2010) had situations where the preview period was fixed (at a standard 1000ms) but the target (either a new carry-over target or non carry-over target) could change colour into a new singleton (i.e., blue in colour) at varying time frames after the onset of the second search display. They found that optimal search performance for non carry-over targets occurred for colour changes occurring around 350ms and there were no additional benefits to search after that time period. In contrast, costs to search for carry-over targets emerged later, and continued to rise until it peaked at around 750ms. This suggests that the location-based inhibitory process contributing to the benefit for non carry-over targets enjoys a different time-scale to that mediating the feature-based effects impacting on carry-over targets. This result might also imply functionally separable inhibitory mechanisms mediating performance.

There are a number of findings which show that the colour-based carry-over effect cannot be explained merely by passive colour-grouping processes existing between the displays, or by attention being automatically captured by the new colour onset. Firstly, both the cost to carry-over targets and the benefits to non carry-over targets are abolished when the preview duration is reduced to around 150ms, (Braithwaite et al., 2003, 2007, 2010). Secondly, carry-over effects remain when the background preview items are removed (Olivers & Humphreys, 2003) or change into a new colour (Braithwaite et al 2004, 2005) and can no longer provide a context for the new items to passive sink into. Furthermore, these effects are contingent on the attentional-set of the observer. Only when the old items are deemed irrelevant to the task do preview benefits and colour-based carry-over effects emerge, (Braithwaite & Humphreys, 2007; Olivers et al., 2002). These findings are not consistent with a bottom-up grouping or capture account of the carry-over effect and are instead consistent with the suggestion that it reflects goal directed inhibition of the irrelevant preview items, which spreads across time to new items sharing the preview colour, (see Braithwaite & Humphreys, 2003; Braithwaite et al., 2003).

Onset Capture and Preview Search

Against the notion of a top-down inhibitory filtering mechanism, Donk and Theeuwes (2001) have proposed that preview benefits reflect automatic attentional capture of the new luminance onsets. By examining preview search when items either appear with abrupt luminance onsets or appear isoluminant to the background, Donk & Theeuwes (2001) showed that preview search was impaired when onset signals were removed either from the whole display or from the second search display alone. From this they argued that preview benefits reflect automatic attentional capture of the new luminance onsets and there was no need to assume additional inhibitory components (see also Belopolsky, Peterson, Kramer, 2005; Donk & Theeuwes, 2003; Peterson, Belopolsky, & Kramer, 2003).

In addition, Donk and Verburg (2004) showed that preview benefits to search can occur even when the preview duration is reduced to 50ms (thus arguing against the slow build up of inhibition). In this study the preview items were presented isoluminant to their background and only the second search display arrived with luminance onsets. Such situations produced, so these researchers argued, strong preview benefits to search without the need to recruit notions of inhibitory filtering.

However, recent evidence and a closer re-examination of these results question the idea that the preview benefit is due solely to the automatic capture of attention. For example, using similar isoluminant displays to those of Donk and Theeuwes (2001), Braithwaite, Humphreys, Watson and Hulleman (2005) found that preview benefits did indeed emerge when onset signals were selectively removed from the second search display and when (i) sufficient sample sizes were employed, and (ii) appropriate baseline conditions were included. This result should not have occurred if the preview benefit is driven solely by luminance onset signals alone. Indeed, as Braithwaite et al., (2005) noted in their critique, the critical comparison of the Donk and Theeuwes (2001) study may have produced a null effect (indicating no preview benefit to search when onsets were removed from the second display) but this was based on a p-value of .08, a sample of eight participants, and there were no full-set baseline conditions in that study. In addition, Braithwaite, Hulleman, Watson & Humphreys (2006) demonstrated that a preview benefit could also emerge even under more conservative conditions when all the items were isoluminant to their background, provided sufficient time was given for the isoluminant items to be coded and filtered.

In addition to the above, the arguments and findings put forward by Donk and Verburg (2004) are based on the fundamental and somewhat unsupported assumption, that isoluminant items compete for selection as strongly as luminant items – which is simply not the case (cf. Braithwaite et al., 2005; Livingstone & Hubel, 1984, 1987). To my mind, isoluminant items would be difficult to perceive and locate with a 50ms preview and would be practically invisible to the visual system, at least at the level at which later components of selection operate.

The idea that the preview benefit can be explained solely by onset-capture also fails to explain several other findings in the literature. For example it struggles to account for (i) costs in probe-detection performance relative to neutral locations and variations in probe-detection performance as a function of attentional-set (Braithwaite et al., 2005; 2010; Humphreys et al., 2004; Watson & Humphreys, 2000); (ii) the fact that preview search is disrupted when a secondary task is introduced during the preview period (Humphreys, Watson & Jolicoeur, 2002; Watson & Humphreys, 1997) and that (iii) search for a target carrying the featural attributes of the inhibited items is severely impaired – but only when observers are set against those irrelevant items (Braithwaite & Humphreys, 2003; 2007; Braithwaite et al., 2003; 2005). If attention capture by the new onsets was sufficient, then the colour relations between the new and old items should not matter – or even if they did – then search should be guided to colour singletons in the new display. However, the exact opposite occurs (Olivers & Humphreys, 2003; Braithwaite et al., 2004). Collectively, these findings argue against the automatic capture of attention being the sole mechanism mediating preview benefits to visual search efficiency.

Temporal Segmentation and Preview Search

Another non-inhibitory account of preview search, the Temporal Segregation Hypothesis, has been proposed by Jiang, Chun & Marks (2002). They argued that segmentation based on temporal onset enabled attention to be directed towards which ever group was relevant to the current goals, without the need for any inhibition to be directed towards the irrelevant temporal group. However, this account fails in many of the ways the onset-capture account does. Again, variations in probe-detection performance, the abolishment of preview benefits with short preview durations (which are still more than sufficient to support temporal-segmentation) and the existence of specific colour-based effects are difficult to explain via an account positing that the temporal discontinuity between the displays is sufficient on its own for the prioritization of relevant information.

Preview Benefits under Dynamic Preview Search Conditions

Although preview benefits to search efficiency have also been demonstrated for dynamic moving stimuli, only four studies are currently published which have investigated the performance and mechanisms of preview search in these circumstances (Kunar et al., 2003;

Olivers et al., 1999; Watson & Humphreys, 1998; Watson, 2001). In static preview search, both location-based (Watson & Humphreys, 1997, 2000, 2002), and feature-based (Braithwaite & Humphreys, 2003; 2007; Braithwaite et al., 2003, 2004; 2005) inhibitory processes are thought to contribute to and mediate performance

In dynamic preview search, however, stable location-based processing is not possible (as the locations of the items are constantly changing). It is also unlikely that individual object-based inhibition can operate efficiently in dynamic preview search. While Multiple Object Tracking (MOT) research does suggest that inhibition can be tagged to a number of individual moving objects, this is typically limited to 4-5 items at one time, (Doran & Hoffman, 2010; Pylyshyn, 2004, 2006; Pylyshyn, Haladjian, King & Reilly, 2008), whereas in preview search, up to 8 moving items can be inhibited during search through another 8 items (Kunar et al., 2003; Watson, 2001; Watson & Humphreys, 1998).

Instead, it has been suggested that features play an important role in tagging, marking and filtering the activations associated with irrelevant items under dynamic preview conditions (Watson & Humphreys, 1998). By this account, inhibition is argued to be applied to whole feature-maps which are selectively activated by and represent the irrelevant items (cf. Treisman & Sato, 1990). There are a number of findings that support this notion. For example, in static preview search a preview benefit occurs even when colour differences are removed from display items (from both the preview display and the search display), and items are presented achromatically (Olivers et al., 1999; Theeuwes et al., 1998). Colour differences are not necessary under static conditions. As already discussed above, such benefits are likely due, at least in part, to a stable location-based representation being computed to which inhibition can be applied (Watson et al., 2003). However, when display items are moving a preview benefit is *only* obtained when the old and new displays are defined by different colours, (Olivers et al., 1999). Additional evidence comes from Kunar et al (2003) in demonstrating that, when items moved in different directions (along vertical or horizontal trajectories), a colour change to the preview display removed the preview benefit, whereas this manipulation has been found to have no detrimental effect on static preview benefits, (Braithwaite et al., 2003, 2004, 2005).

The Present Study

In order to assess whether inhibitory processes in search, specifically, differentially weight visual features according to the search context, I examined the negative carry-over effect under preview conditions and contrasted preview search with static and dynamic (moving) displays. The new and old distractors always had different colours, but the target in the new display could carry the colour of the old items or the colour of the new items equally. With static displays, targets are difficult to detect if they have the same colour as the preview (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2005, 2007). In Experiment 1, I evaluated whether this negative carry-over effect was larger with dynamic than static displays – indicating a stronger role of feature-based inhibition under dynamic circumstances. In Experiments 2a and 2b, I tested and rejected the possibility that the stronger colour carry-over effects for moving displays reflect an increased role for pre-attentive colour grouping rather than selective inhibition of colour.

When the target had the same colour as the old items in the current experiments, it differed in colour from the new stimuli – that is, it was a colour singleton. This also enables me to test alternative, non-inhibitory accounts of preview search, which propose that the preview benefit reflects the automatic capture of attention by the sudden onsets of the new stimuli (Donk & Theeuwes, 2001, 2003), or the temporal segmentation of old and new stimuli (Jiang, Chun & Marks, 2002). Both of these accounts predict that there should be easy detection of a singleton target in the new display, contrasting with the prediction from an inhibitory account that such targets should be difficult to detect.

Experiment 2.1: The Colour Carry-over Effect with Static and Dynamic Displays

Here, I present the first empirical investigation of feature-based carry-over effects under dynamic preview search conditions. Experiment 1 compared colour-based carry over effects in preview search with moving and stationary displays. I presented the preview items in one colour (e.g., red[1]) and the distractors in the search display in a different colour (e.g., green). The target could carry either the colour of the old items or the colour of the other new stimuli (see Figure 2.1). With both static and dynamic displays, the preview condition was compared with a full-set baseline condition, which had exactly the same displays except that all of the stimuli appeared simultaneously. The full-set conditions provide baselines against which to measure the benefits from preview search. I reasoned that if colour-based inhibition is especially important for de-prioritizing old items in moving displays, compared with stationary displays, then a larger colour carry over effect should be obtained with moving stimuli

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[1] Note – the actual colour combinations were counter-balanced across participants (R+RG / G+RG). I refer to old red and new green distractors here for clarity and conciseness.

(indicated by a greater degree of attentional blindness for new targets carrying the inhibited colour).

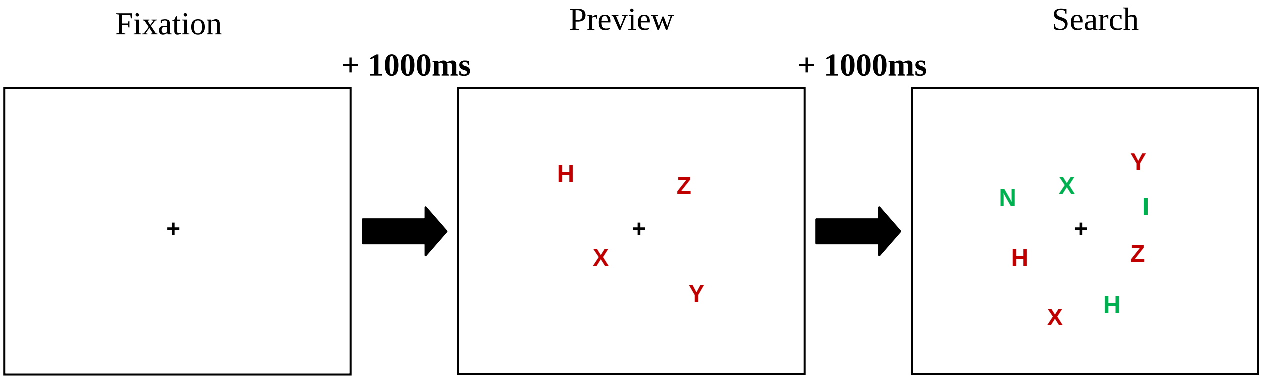

Figure 2.1. An illustration of the displays used under the preview conditions of the present study. The preview display (red items) appeared for 1000ms followed by the search display (green distractors and the target which could be either red or green). The target was the letter ‘N’ and the response was whether it fell in the left or right visual field. Final displays were made up of mixed red and green items. Baseline conditions consisted of simultaneous presentation of both the preview and the second, search display. Under dynamic conditions, the preview items immediately began scrolling down the screen upon arrival via common motion. Under static search conditions, preview items remained in the spatial position in which they were initially presented and never moved.

Method

Participants

Twenty-three undergraduate students (17 female), aged 18 to 31 years (mean = 19), from the University of Birmingham participated for either course credits or payment. All reported normal or corrected-to-normal vision, including normal colour vision.

Stimulus and Apparatus

The experiment was programmed in Turbo Pascal v7, and run on a Pentium PC attached to a 15-inch super VGA monitor. Items appeared randomly in an invisible 10 × 10 matrix, within a presentation window with a visual angle of 10.4° × 12.2°. The background of both the window, and the unused area around the edge of the screen, was black. In the dynamic conditions, upon onset, the stimuli scrolled vertically downwards, at a speed of 48mm/s (4.9°/second). When the stimuli reached the bottom of the presentation window, they reappeared at the top and then continued to move downwards, akin to a wrap-around scrolling display (see Watson & Humphreys, 1998). In the static conditions the stimuli remained stationary and did not move. The viewing distance was approximately 55cm. The stimuli were heterogeneous letter distractors (H, I, X, Y, Z) and a target letter (the letter 'N'); all were presented in uppercase with a visual angle of 0.46° × 0.93°. Distractors were randomly selected, with replacement, for each trial. At each display size, an equal number of distractors fell within the left and right side of the computer screen, with the target letter (N) falling on the left and right side equally often. Colours were equated for luminance using a colour-flicker calibration test carried out on each participant before the main experiment (described more fully below).

Design and Procedure

The experiment used a 2 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) within-subjects design. There were two dynamic search conditions, and two static search conditions. For each of these, there was a full-set baseline where all the items appeared simultaneously (**Full-Move** & **Full-Static**) and a preview condition, where one set of distractors was presented (**Prev-Move** & **Prev-Static**).

The displays in the full-set baselines were made up of either 8 or 16 items. The preview conditions comprised of a preview display of either 4 or 8 items, followed by a search display of, respectively, 4 or 8 items (with a final display size of either 8 or 16 items, matched to the full-set baselines). The four conditions were presented in separate blocks of 80 trials (40 per display size). The order in which the conditions were presented was randomized across participants. Display size and Target Colour was randomized within experimental blocks. As the target could equally be red or green on each trial, participants had no incentive to prioritize search for one target colour over another.

Before the experiment, each participant undertook a colour-fusion flicker test to establish individual isoluminance values for the red and green items. This test consisted of two square shape outlines presented at different eccentricities (approximating the eccentricity parameters used for the search displays) around a central fixation cross. The squares oscillated between the colours of interest to produce a constant flicker. The flicker rate was 30Hz.

Participants were asked to minimize flicker using button presses that altered the luminance values, with the value for minimal flicker taken as the point of isoluminance. Each participant was given practice at the flicker test before completing 5 experimental calibration trials. The final values were based on an average RGB setting from these 5 trials.

Participants completed a practice block of 20 trials for each experimental condition. Each trial began with the presentation of a white fixation cross in the centre of the screen which was presented alone for 1000ms but then remained present throughout the trial. In the baseline conditions, all items appeared simultaneously. Participants were instructed to search through the display and locate the target as quickly and accurately as possible. For the preview conditions, the preview display first appeared, 1000ms after fixation. Participants were told to keep their eyes fixated on the central cross, and to refrain from search until the second onset of items appeared. After 1000ms, the second set of search items was added to the display. Participants were informed that the target would always appear in the new display, thus rendering the previewed items irrelevant. Responses were made according to whether the target appeared in the left (LVF: respond ‘X’), or the right visual field (RVF: respond ‘M’). There was a ‘time-out’ period of 8000ms. The inter-trial period was 1000ms. On a minority of trials (10%), no target was presented and participants were told not to respond. This was done to ensure that participants were not simply searching one half of the screen (see Watson, Braithwaite & Humphreys, 2008). Participants were provided with error feedback, in the form of a 1000Hz auditory beep for 500ms, which occurred for both response errors and time-outs. The experiment lasted approximately 45 minutes.

Results

Reaction times (RTs) were trimmed for outliers (set at ± 2.5 *SD's* and responses faster than 200ms). The data for one participant data were removed due to a high level of errors (>15% in one cell). We first determined whether a basic preview benefit had occurred by comparing the preview and associated baseline separately for the static and moving conditions.

An overall 4-way 2 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) ANOVA revealed no main effect of Motion, F(1,22)=1.97, p=.18, but there was a main effect of Condition, F(1,22)=29.76, p<.01; Display Size, F(1,22)=207.65, p<.01, and Target Colour, F(1,22)=7.74, p<.05. The following interactions were found: Condition × Target Colour, F(1,22)=53.84, p<.01; Motion × Condition × Target Colour, F(1,22)=5.15, p<.05; Display Size × Target Colour, F(1,22)=6.36, p<.05; Condition × Display Size × Target Colour, F(1,22)=57.05, p<.01. The 4-way Motion × Condition × Display Size × Target Colour interaction was borderline significant, F(1,22)=3.91, p=.06. Overall, preview search was impaired for red targets relative to green targets, and this cost was magnified under dynamic conditions relative to static conditions. These interactions were explored through further analysis.

Static Items: Preview vs Baseline Search

The static baseline (Full-Static) and static preview (Prev-Static) conditions were examined in a 2 × 2 × 2 (Condition × Display Size × Target Colour) within-subjects ANOVA. This revealed a main effect of Condition, F(1,22)=23.87, p<.01, and a main effect of Display Size, F(1,22)=151.25, p<.01. There was also a borderline significant effect of Target Colour, F(1,22)=3.77, p=.06. The Condition × Display Size interaction was not significant, F(1,22)=0.46, p=.50. Although overall RT's were faster in the preview condition compared to the baseline, search efficiency was *overall* unaffected by Condition (see Figure 2.2). The Condition × Target Colour, F(1,22)=43.62, p<.01, and Display Size × Target Colour, F(1,22)=4.59, p<.05, interactions were significant. Of most importance, however, the Condition × Display Size × Target Colour interaction was highly significant, F(1,22)=22.95, p<.01. Overall, search for red targets was impaired relative to green targets, and the effects of Target Colour were increased in preview search, relative to baseline, (see Figure 2.2).

Analysis was then broken down across Target Colour. Red and green target responses were entered into separate 2 × 2 (Condition × Display Size) ANOVA's. For red targets, there was no main effect of Condition, F(1,22)=1.78, p=.20, a main effect of Display Size, F(1,22)=89.23, p<.01, and a significant interaction between Condition and Display Size, F(1,22)=11.44, p<.05. Search for red targets was less efficient in the preview condition, compared to the full-set baseline. The same analysis for green targets revealed a main effect of Condition, F(1,22)=67.92, p<.01, a main effect of Display Size, F(1,22)=122.76, p<.01, and a Condition × Display Size interaction, F(1,22)=6.77, p<.05. Search for green targets was more efficient in the static preview condition compared with the static baseline condition (see Figure 2.2).

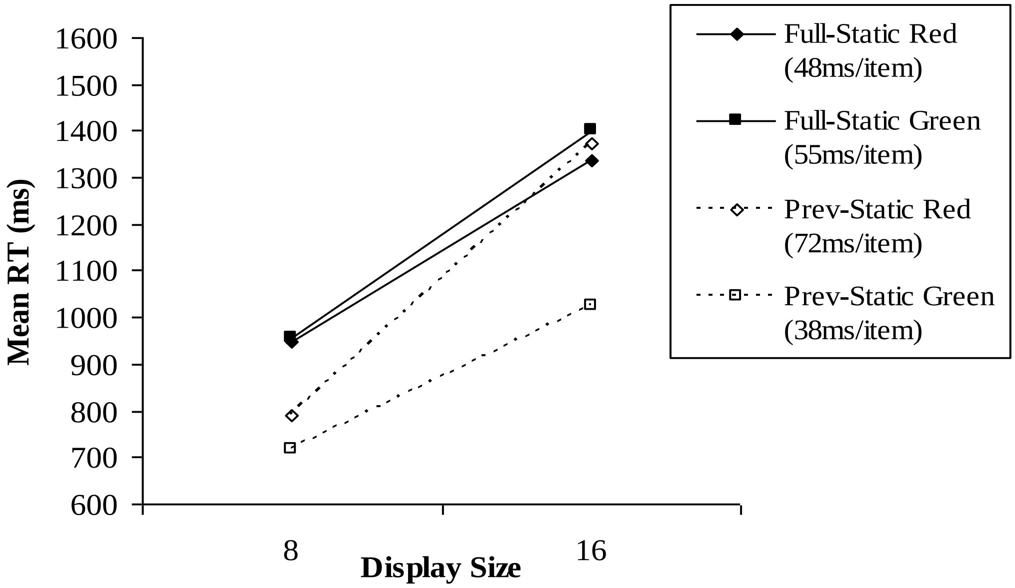

Figure 2.2. Mean RT in the Full-Static & Prev-Static conditions, across Display Size & Target Colour.

Dynamic Items: Preview vs Baseline Search

The two dynamic conditions were then compared (Full-Move versus Prev-Move) in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA. This revealed main effects of Condition, F(1,22)=19.49, p<0.01, Display Size, F(1,22)=182.44, p<.01, and Target Colour, F(1,22)=13.26, p≤0.01. The Condition × Display Size interaction showed a trend towards significance, F(1,22)=3.32, p=.08. Overall RT's were improved in the preview condition, but in contrast to the static conditions, preview search tended to be *less* efficient than the full set baseline. The Condition × Target Colour, F(1,22)=34.19, p<.01, and the Display Size × Target Colour, F(1,22)=6.58, p<.02, and the 3-way Condition × Display Size × Target Colour, F(1,22)=38.52, p<.01, interactions were all highly significant. Overall, search for red targets was impaired relative to green targets, and the effects of Target Colour were increased in the preview condition compared to the full-set baseline, (see Figure 2.3).

Analysis of red target responses in a 2 × 2 (Condition × Display Size) ANOVA revealed no main effect of Condition, F(1,22)=.96, p=.34. However, there were significant effects of Display Size, F(1,22)=108.83, p<.01, and Condition × Display Size, F(1,22)=28.36, p<.01. Red targets search was less efficient in the dynamic preview condition relative to its baseline. The same analysis for green targets revealed a main effects of Condition, F(1,22)=129.07, p<.01, and Display Size, F(1,22)=127.65, p<.01, and a Condition × Display Size interaction, F(1,22)=14.30, p<.01. Search for green targets was more efficient in the preview than the baseline condition, (see Figure 2.3).

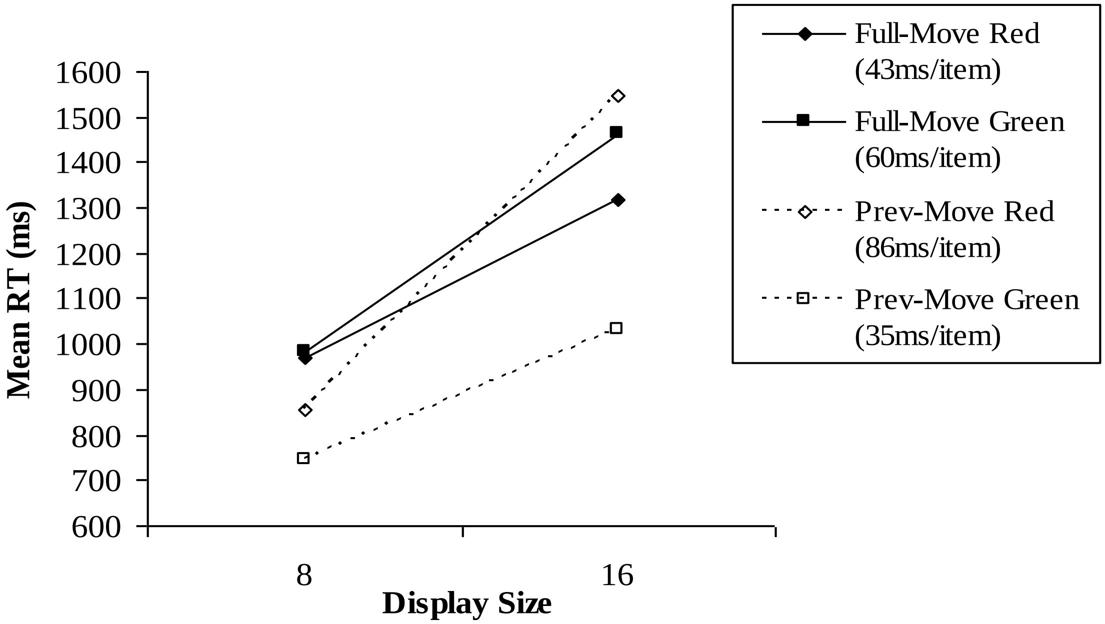

Figure 2.3. Mean RTs (ms) in the Full-Move & Prev-Move conditions, across Display Size & Target Colour.

Static vs Dynamic Search

To investigate the effect of motion on standard conjunctive search, the 2 baseline conditions (Full-Static & Full-Move) were compared in a 2 × 2 × 2 ANOVA (Motion × Display Size × Target Colour). This revealed only a main effect of Display Size, F(1,22)=187.04, p<.01 (all other F's<2.9, all P's>0.1).

To examine the effect of motion on preview search, the two preview conditions (Prev-Static & Prev-Move) were compared in a 3-way (Motion × Display Size × Target Colour) ANOVA. There were main effects of Display Size, F(1,22)=142.87, p<.01, and Target Colour, F(1,22)=33.68, p<.01. The Motion × Target Colour, F(1,22)=6.00, p<0.05, and Display Size × Target Colour, F(1,22)=33.70, p<.01, and the 3-way interaction between Motion x Display Size x Target Colour, F(1,22)=67.51, p<.01, were all significant. The contrast in search efficiency for red and green targets was greater with dynamic than static search displays. The difference between the search slopes for red and green targets was 53.7ms/item for dynamic displays vs. 37.2ms/item for static displays (see Figure 2.4).

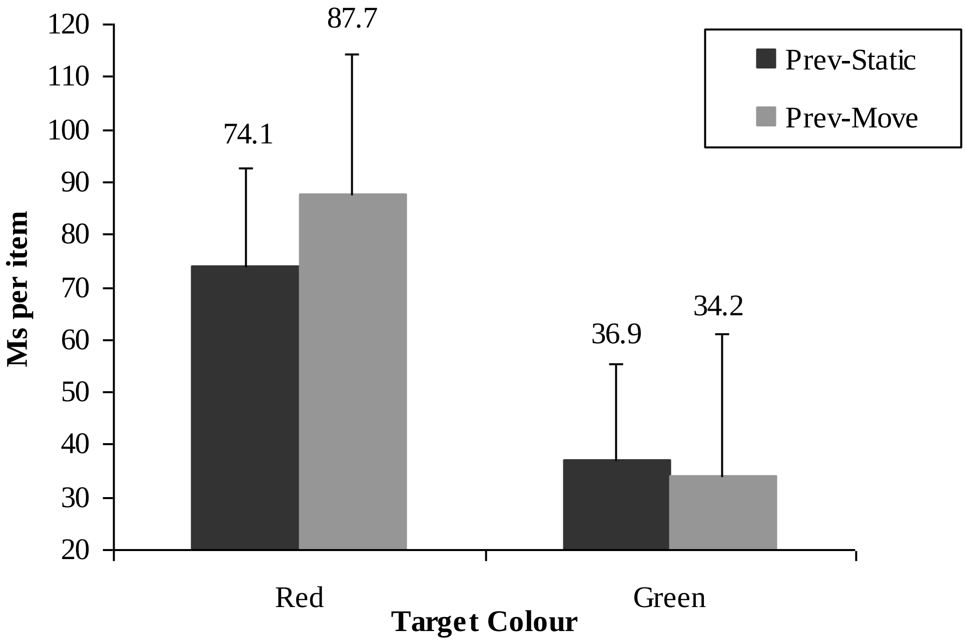

Figure 2.4. Search efficiency slopes (ms/ item) for red and green targets in static and dynamic preview conditions. Error bars represent standard error.

Errors

Overall error rates were 5.2%, (see Table 2.1). Incorrect responses were entered into a 2 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) within-subjects ANOVA. This revealed a main effect of Condition, F(1,22)=4.87, p<.05, and a main effect of Display Size, F(1,22)=7.30, p<.05. There were no significant interactions found, (all F's<.64, all P's>.47). Overall, more errors made in the full-set baselines compared with the preview conditions. Error's followed a similar pattern to the RT data. Therefore, they were not analyzed further.

Table 2.1. Mean % Errors across Motion, Condition, Display Size & Target Colour.

Condition	**Display Size 8**		**Display Size 16**	
	Red Targets	**Green Targets**	**Red Targets**	**Green Targets**
Full-Static	2.39	2.61	4.13	3.48
Prev-Static	1.74	1.09	3.26	2.83
Full-Move	3.04	3.69	4.57	4.47
Prev-Move	3.26	2.39	4.69	3.48

Discussion

In the standard full-set baseline, search efficiency was matched across static and dynamic displays. In contrast, quite different patterns of search efficiency emerged for static and dynamic displays in the preview condition, as a function of the target's colour. For green targets there was a preview benefit for both types of display. For red targets, however, there was a preview cost in terms of search efficiency, and this was significantly larger with dynamic displays than static search displays. This cost occurred despite the fact that, under preview conditions, the red target was a colour singleton in the new search display. This contradicts both the onset capture and the temporal segmentation accounts of preview search (Donk & Theeuwes, 2001, 2003; Jiang et al., 2002), both of which predict that the new red target should pop-out from amongst green distractors. This negative colour-based carry-over effect replicates earlier findings with static displays (e.g., Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003; 2005; 2007; 2010; Olivers & Humphreys, 2003). In fact, in the current study the negative carry-over effect for new red targets was so strong that this cancelled out the benefits of search to the new green targets when the analysis was collapsed across target colour.

The differential effects of colour carry-over with dynamic and moving displays suggest that colour plays a stronger role in the inhibition of dynamic old distractors compared with static old distractors. Colour-based inhibition of moving previews would provide a computationally efficient method of suppressing multiple old distracters (cf. Watson & Humphreys, 1998), and colour inhibition may be strongly weighted when these distractors cannot be suppressed through their locations (cf. Watson & Humphreys, 1997). The corollary of this, however, is that new targets carrying the suppressed colour are difficult to detect, leading to impaired attentional selection and a greater degree of attentional blindness for new targets carrying the colour of previewed items.

An alternative account, though, is that the colour effects were produced by pre-attentive grouping processes, whose effects are more prominent with dynamic displays. For example, a new target carrying the colour of the preview may be grouped by similarity to the old stimuli (cf. Duncan & Humphreys, 1989; 1992), and this makes such targets difficult to detect. If colour-based grouping increases for moving stimuli, then red targets may be selectively more difficult to detect with dynamic relative to static displays. However, this proposal does not receive any support from the baseline conditions, where there was no impact of the target's colour (or stronger colour grouping of the red target to moving red distractors). Nevertheless, the grouping account was tested further in Experiment 2. Based on work showing temporal segmentation of displays separated by 100ms (Donk & Verburg, 2004; Leonards et al., 1996; Yantis & Gibson, 1994), it is assume that pre-attentive grouping must act rapidly to assimilate the new target into the old group – if colour is not coded and grouped within 100ms, then there should be segmentation of the displays and efficient detection of the singleton target. Such rapid grouping should influence search, then, even if the preview is presented briefly (Experiment 2a), or even if the critical colour only appears briefly prior to the new search display (Experiment 2b). On the other hand, there is evidence that the inhibition of previews takes some time to develop. For example, the preview display must be presented for around 400ms or so, before being joined by the search display, for preview search efficiency benefits to emerge, (Humphreys et al., 2004, 2006; Watson & Humphreys, 1997). Hence, negative carry-over effects of colour-based inhibition should be reduced when the critical colour occurs only 200ms or so prior to the new display.

Experiment 2a: Investigating Grouping Effects with Brief Previews

Experiment 2a replicated the dynamic search from Experiment 1, whilst introducing a new condition with a reduced preview duration (200ms).

Method

Unless otherwise mentioned the Method for Experiment 2 was the same as in Experiment 1.

Participants:

Nineteen students (4 male) aged 21-34 years (mean = 21.5) from the University of Birmingham took part for payment or course credits. All reported normal, or corrected to normal vision, including colour vision.

Design:

Only dynamic new stimuli were presented. A 2 × 2 × 2 × 2 (Duration × Condition × Display Size × Target Colour) within-subjects design was used. The **Full-Move** and **Prev-Move** conditions from Experiment 1 were complemented by two new dynamic conditions, (**Full-Move$_{200}$** & **Prev-Move$_{200}$**). The **Prev-Move$_{200}$** condition was identical to the original preview condition **(Prev-Move**), except that the preview display was presented for just 200ms prior to the onset of the second search display. The new baseline condition (**Full-Move$_{200}$**) was matched to this so that the fixation was presented for just 200ms before all the items appeared (to match for differences in temporal anticipation across the conditions; Watson & Humphreys, 1997).

Results

RTs were filtered and analyzed in the same manner as that outlined for Experiment 1. An overall 2 × 2 × 2 × 2 (Duration × Condition × Display Size × Target Colour) ANOVA revealed main effects of Duration, F(1,18)=20.94, p<.01, Condition, F(1,18)=8.73, p<.01, Display Size, F(1,18)=127.95, p<.01, and Target Colour, F(1,18)=15.52, p<.01. All sub-level interactions were subsumed in a Duration × Condition × Display Size × Target Colour interaction, F(1,18)=16.01, p<.01. The colour effects on search efficiency, found selectively with preview search, were reduced with 200ms relative to 1000ms previews.

Preview Search: 200ms vs 1000ms Preview Durations

The two preview conditions (Prev-Move$_{200}$ and Prev-Move) were compared in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA. There was a main effect of Display Size, $F(1,18)=114.88$, $p<.01$, Target Colour, $F(1,18)=65.89$, $p\leq.01$, and Condition, $F(1,18)=6.09$, $p<.03$. All the two-way interactions were highly significant: Condition × Display Size, $F(1,18)=21.13$, $p\leq.01$; Condition × Target Colour, $F(1,18)=35.03$, $p\leq.01$; Display Size × Target Colour, $F(1,18)=30.55$, $p<.01$. The 3-way interaction between Condition × Display Size × Target Colour was also significant, $F(1,18)=29.86$, $p<.01$. The effects of Target Colour were increased following the 1000ms preview compared to the 200ms preview (see Figure 2.5).

Red and green targets were then examined in separate 2 × 2 (Condition × Display Size) ANOVA's. Red targets revealed a main effect of Condition, $F(1,18)=26.06$, $p<.01$, a main effect of Display Size, $F(1,18)=120.54$, $p<.01$, and a Condition × Display Size interaction, $F(1,18)=47.92$, $p<.01$. Red targets were detected less efficiently in the 1000ms preview condition relative to the 200ms preview condition. Green targets revealed a main effect of Condition, $F(1,18)=18.92$, $p<.01$ and Display Size, $F(1,18)=47.17$, $p<.01$, but no Condition × Display Size interaction, $F(1,18)=1.53$, $p=.23$. Green targets were detected significantly faster following a 1000ms relative to a 200ms preview. Reducing the preview from 1000ms to 200ms impaired search for green targets and improved search for red targets (see Figure 2.5).

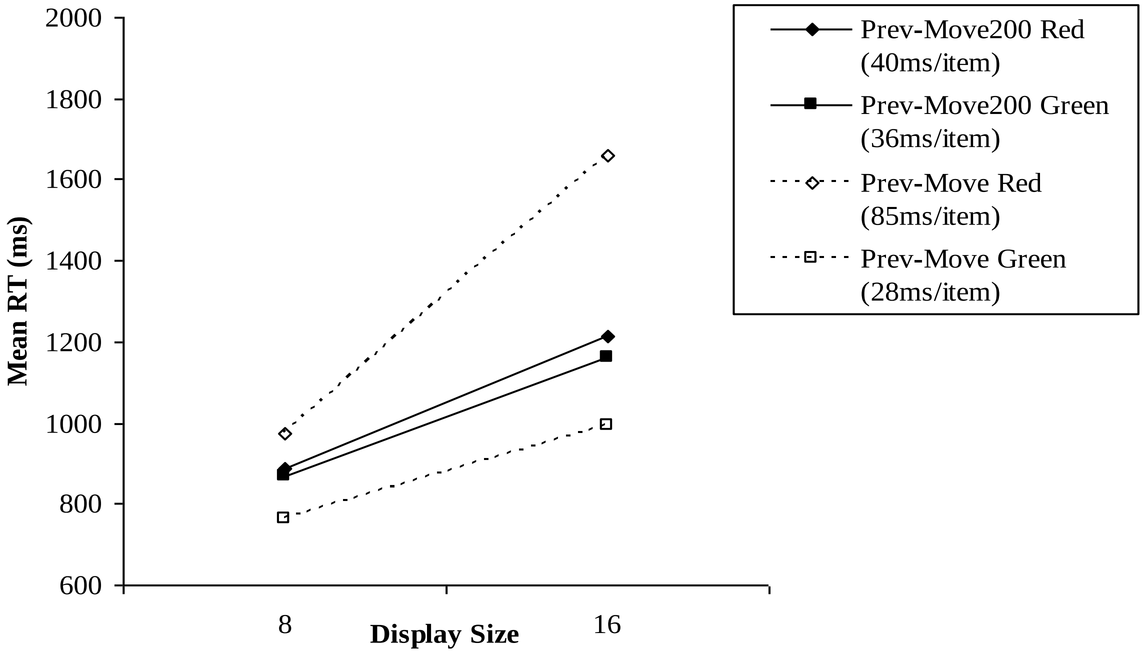

Figure 2.5. Mean RTs (ms) for Prev-Move & Prev-Move$_{200}$ conditions, across Display Size and Target Colour.

Standard Preview vs Baseline Search

The 1000ms preview condition and 1000ms baseline conditions were compared in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA. There was a main effect of Condition, F(1,18)=10.27, p<.01, Display Size, F(1,18)=120.49, p<.01, and Target Colour, F(1,18)=28.33, p<.01. All interactions were significant: Condition × Display Size, F(1,18)=7.62, p≤.01; Condition × Target Colour, F(1,18)=74.49, p<.01; Display Size × Target Colour, F(1,18)=21.27, p<.01; Condition × Display Size × Target Colour, F(1,18)=44.89, p<.01. Consistent with Experiment 1, the effects of Target Colour were increased in the preview condition compared to the full-set baseline, (see Figure 2.6).

Analysis was then broken down across Target Colour. Red targets were first entered into a 2 × 2 (Condition × Display Size) ANOVA. There was a main effect of Condition, F(1,18)=5.73, p<.05, a main effect of Display Size, F(1,18)=99.45, p<.01, and a Condition × Display Size interaction, F(1,18)=33.60, p<.01.Red target search was slower and less efficient in the preview condition compared to the full-set baseline. Green targets were then examined in the same way. There was a main effect of Condition, F(1,18)=139.18, p<.01, a main effect of Display Size, F(1,18)=67.36, p<.01, and a Condition × Display Size interaction, F(1,18)=6.74, p<.02. Search for a green target was faster and more efficient in the preview condition, compared to the full-set baseline.

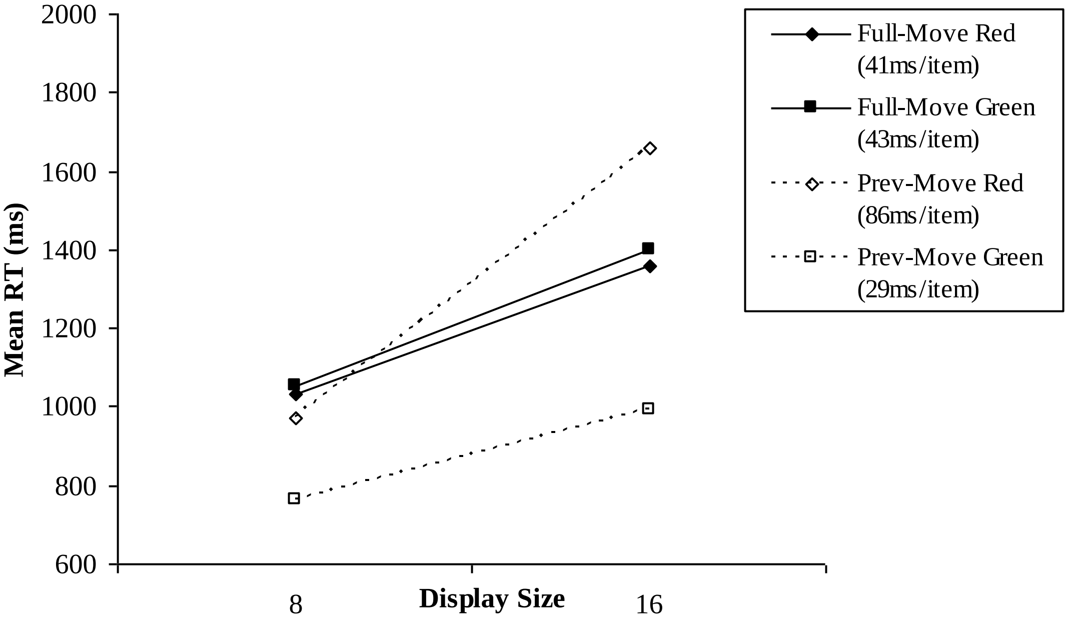

Figure 2.6. Mean RTs (ms) for Full-Move & Prev-Move conditions, across Display Size & Target Colour.

200ms Preview vs Baseline Search

Comparison of the two new conditions (Full-Move$_{200}$ & Prev-Move$_{200}$) in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA revealed a only main effect of Display Size, F(1,18)=95.64, p<.01. There was no main effect of Condition, F(1,18)=2.60, p=.12, or Target Colour, F(1,18)= 0.02, p=.97, and no interactions (all F's<3.2, all P's>.09). As Figure 2.7 shows, there was no difference between search performance in the 200ms preview and baseline conditions.

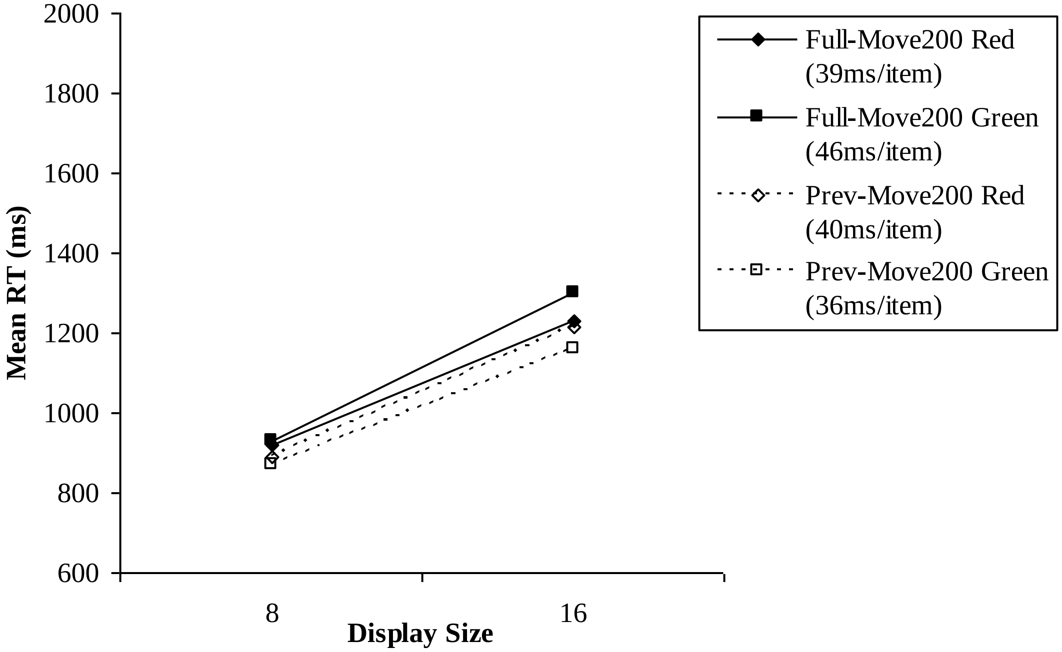

Figure 2.7. Mean RTs (ms) for Full-Move$_{200}$ & Prev-Move$_{200}$ conditions, across Display Size & Target Colour.

Errors

Error rates were low overall and there were no effects or interactions (all P’s>.08, all F’s<3.5).

Experiment 2b: Effects with Brief Colour Sharing

Experiment 2b examined performance when the preview changed its colour 100ms prior to the search display. With the 200ms preview condition in Experiment 2a, the motion signals from the old displays may have been curtailed, possibly limiting colour-based grouping of the target to the preview. Here the previewed items moved for 1000ms before the search display, now matching the total preview time to that in Experiment 1. This allowed time to compute motion, while rapid grouping of the target to the changed-colour in preview should still take place.

Method

Participants:

Twenty-one students (5 male) from the University of Birmingham took part for course credits. Ages ranged from 18 to 36 yrs, with a mean age of 21.2 years.

Stimuli

The stimuli were the same as before except that, in one condition, the preview display was blue for 900ms, before turning red 100ms prior to the onset of the second search display.

Design and Procedure:

The experiment used a 3 × 2 × 2 (Condition × Display Size × Target Colour) within-subjects design. There were two preview conditions (Prev-Move & Prev-Move$_{\text{BcR}}$ and a full-set baseline condition (Full-Move). The Prev-Move & Full-Move conditions were identical to those in Experiments 1 and 2a, (the 1000ms conditions). In the new preview condition (Prev-Move$_{\text{BcR}}$) the preview display was first presented in blue, and only changed to red 100ms before the search display. The colours were matched for luminance through the colour-flicker calibration test to ensure this colour change was isoluminant. Therefore, the final displays in both preview conditions and the full-set baseline were exactly the same, comprising of mixed red and green items.

Results

RT's were cleaned for errors and outliers (+/-2.5*SD's*) before being entered into an overall 3 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA. There was a main effect of Condition, F(2,40)=6.61, p<.01, Display Size, F(1,20)=177.95, p<.01 and Target Colour, F(1,20)=22.60, p<.01. The Condition × Display Size interaction was borderline significant, F(2,40)=3.01, p=.06. All interactions were highly significant: Condition × Target Colour, F(2,40)=14.80, p<.01; Display Size × Target Colour, F(1,20)=12.59, p<.01; Condition × Display Size × Target Colour, F(2,40)=9.91, p<.01. These interactions were explored through further analysis.

Standard Preview vs Baseline Search

Firstly, the standard preview condition was compared to the full-set baseline condition in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA, confirming the same pattern of results as Experiment 1. There was a main effect of Condition, F(1,20)=5.86, p<.03, Display Size, F(1,20)=134.84, p<.01, and Target Colour, F(1,20)=23.54, p<.01. There was no Condition × Display Size interaction, F(1,20)=1.71, p=.21, but all other interactions were significant: Condition × Target Colour, F(1,20)=23.90, p<01; Display Size × Target Colour, F(1,20)=25.44, p<.01; Condition × Display Size × Target Colour. F(1,20)=15.38, p<.01. Consistent with Experiments 1 & 2a, the effects of Target Colour had an increased effect on preview search efficiency, relative to baseline.

Analysis was then broken down across Target Colour. Red and green target responses were analysed in separate 2 × 2 (Condition × Display Size) ANOVAs. This confirmed that red targets showed a preview cost, relative to baseline (Condition × Display Size interaction, F(1,20)=11.19, p<.01), whereas green targets showed a preview benefit relative to baseline, (main effect of Condition, F(1,20)=67.93, p<.01 and a Condition × Display Size interaction, F(1,20)=8.93, p<.01). Baseline search performance is shown in Figure 2.8 and preview search performance is shown in Figure 2.9.

Colour Change Preview vs Baseline

Responses in the new preview condition (Prev-Move$_{BcR}$) were then compared to the full-set baseline. The 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA revealed a main effect of Condition, F(1,20)=16.16, p<.01, and Display Size, F(1,20)=129.19, p<.01, but no main effect of Target Colour, F(1,20)=.92, p=.35. The 3-way Condition Display Size Target Colour interaction approached significance, F(1,20)=3.61, p=.07. There were no other interactions found: Condition Display Size, F(1,20)=1.87, p=.19; Condition Target Colour, F(1,20)=2.29, p=.15; Display Size Target Colour, F(1,20)=.48, p=.50. There was a trend for Target Colour to have increased effects on search efficiency in the Prev-Move$_{\mathrm{BcR}}$ condition, compared to the full-set baseline.

Red target responses were then entered into a 2 × 2 (Condition × Display Size) ANOVA. There was a main effect of Condition, F(1,20)=4.50, p<.05, a main effect of Display Size, F(1,20)=63.82, p<.01, but no Condition × Display Size interaction, F(1,20)=.01, p=.99. Red targets were detected faster in the preview colour-change condition compared to the baseline (see Figure 2.8). The same analysis for green targets revealed main effects of Condition, F(1,20)=19.23, p<.01, and Display Size, F(1,20)=100.79, p<.01, and a Condition × Display Size interaction, F(1,20)=5.05, p<.05. Search for green targets was faster and more efficient in the preview colour change condition, relative to the full-set baseline, (see Figure 2.8).

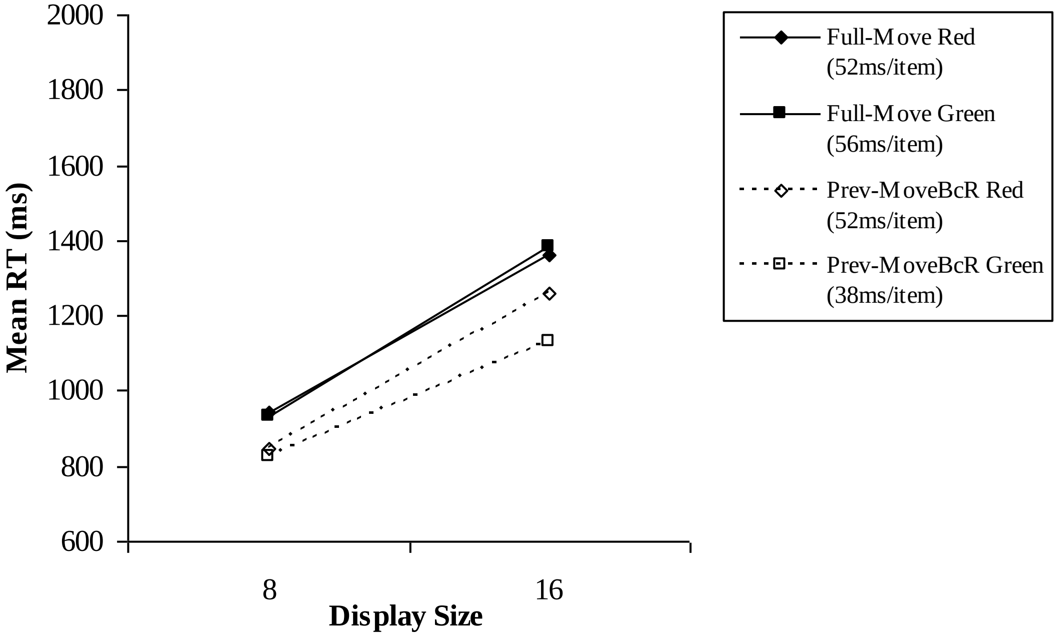

Figure 2.8. Mean RTs (ms) in the Prev-Move$_{BcR}$ and Full-Move conditions, across Display Size and Target Colour.

Standard Preview vs Colour Change Preview Search

The two preview conditions (Prev-Move & Prev-Move$_{BcR}$) were then compared in a 2 × 2 × 2 (Condition × Display Size × Target Colour) ANOVA. There was a main effect of Display Size, F(1,20)=191.21, p<.01, and Target Colour, F(1,20)=33.18, p<.01, but no overall main effect of Condition, F(1,20)=1.59, p=.22. All interactions were significant: Condition × Display Size, F(1,20)=4.54, p<.05; Condition × Target Colour, F(1,20)=12.37, p<.01; Display Size × Target Colour, F(1,20)=19.34, p<.01; Condition × Display Size × Target Colour, F(1,20)=7.52, p<.02. The effects of Target Colour were increased in the standard preview condition compared to the colour-change condition, (see Figure 2.9).

Analysis was then broken down across Target Colour. Red targets were entered into a 2 × 2 (Condition × Display Size) ANOVA revealing a main effect of Condition, F(1,20)=6.20, p<.03, and Display Size, F(1,20)=128.48, p<.01, and a Condition × Display Size interaction, F(1,20)=7.46, p<.02. Search for red targets was significantly impaired in the standard preview condition, compared to the colour-change preview condition, see Figure 2.9). The same analysis for green targets a main effect of Condition, F(1,20)=7.92, p<.02, and Display Size, F(1,20)=82.60, p<.01, but no Condition × Display Size interaction, F(1,20)=.01, p=.92. Green targets were faster, but no more efficient in the standard preview compared to the colour-change preview condition, (see Figure 2.9).

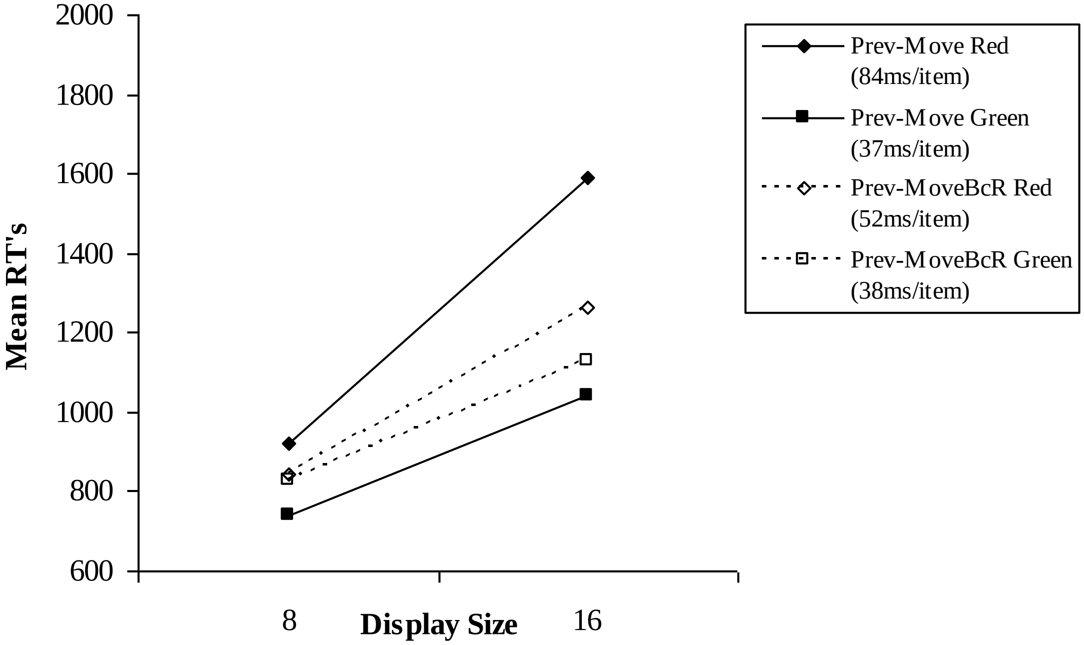

Figure 2.9. Mean RTs (ms) in the Prev-Move and Prev-Move$_{BcR}$ conditions, across Display Size and Target Colour.

Errors

Analysis of errors revealed only a borderline main effect of Display Size, F(1,20)=4.01, p=.06, (all other F's<1.4, all other P's>.26). The error data was not analyzed further.

Discussion of Experiments 2a and 2b

In Experiment 2a, reducing the preview duration from 1000ms to 200ms abolished both the preview benefit for new green items and the cost from the colour carry-over effect for new red items. This is consistent with prior findings using static displays, where the preview has been eradicated with brief exposures of previews (Braithwaite & Humphreys, 2007; Braithwaite et al., 2007; Humphreys et al., 2004, 2006; Watson & Humphreys, 1997). In contrast, search for a red singleton target was significantly improved (relative to performance for the same condition at 1000ms) by shortening the preview duration to 200ms and there was now no cost to performance.

These results suggest that the preview benefits and costs in Experiment 1 are unlikely to be due to an amplified role of pre-attentive colour-grouping in dynamic displays, since any amplified effects of perceptual grouping that occur with dynamic stimuli should have been present with a reduced preview duration. Clearly, this was not the case. Experiment 2b generated similar results. The negative colour carry-over effect (for red targets) was greatly reduced under these conditions. This again goes against the idea that the colour carry-over effect is due purely to low-level pre-attentive colour grouping between the new target and the old items when their colour is shared. Prior work indicates that distractor suppression has a relatively slow time course (Humphreys et al., 2004, 2006; Watson & Humphreys, 1997). In this respect the data from Experiment 2b are also interesting in that they show there was still a preview benefit for new green targets in the colour change condition (Prev-Move$_{BcR}$) – though the colour change was not long enough to induce colour-based inhibition. However, there may be suppression of the moving configuration of old items, in addition to colour-based inhibition, which is sufficient to generate the preview advantage relative to baseline (see also Kunar, Humphreys, Smith & Hulleman, 2003; Osugi, Kumada, Kawahara, 2009; Watson, 2001). This would have been sustained even when the old items changed colour.

General Discussion

I present the first empirical investigation of negative carry-over effects in dynamic preview search. Moreover, I show that negative colour carry-over effects are stronger when displays move compared to when displays are static – with the effects with dynamic stimuli being sufficient even to generate a cost to finding a single target in a new search display, relative to the full-set baseline (all the items presented together).

These data are consistent not only with the proposal that there is inhibition of the old distractors under preview conditions, but also with this inhibition being flexible, so that the inhibitory weight applied to distractor features can vary with how critical they are for segmenting relevant from irrelevant stimuli. I suggest that, with dynamic displays, colour is assigned a high weight in mediating distractor suppression, perhaps because it is difficult to inhibit the locations of moving items (cf. Watson & Humphreys, 1998). My study goes beyond prior experiments which have shown that colour is important for generating a preview benefit with moving items (Olivers et al., 1999), since earlier data could have been due to expectancies for targets having a pre-designated colour. This was not the case here. Moreover, my argument is based on a negative carry-over from distractors, which cannot easily be explained in terms of excitatory processing.

A further point to note is that the inhibitory carry-over effects reported here (and indeed elsewhere) appears to be most prevalent at the larger display sizes. This might reflect a process of 'spreading suppression' (Duncan & Humphreys, 1989). When more distractors are present there may be a monotonic increase in the strength of inhibition, and this in turn makes targets carrying the same features particularly difficult to detect at the larger display sizes.

In Experiment 2, I provided evidence against the idea that the rapid and automatic grouping of the new target with the old items led to the negative carry-over effects. I showed that the carry-over effects were greatly weakened when I reduced (i) the preview duration to 200ms (Experiment 2a), and (ii) the length of time that colour was shared between old and new items to 100ms. Given that temporal segmentation can be achieved within 100ms (Donk & Verburg, 2004; Leonards et al., 1996; Yantis & Gibson, 1994), then colour grouping would need to operate within that period in order to group the new target with the old distractors. However, limiting colour processing to these intervals reversed the results. I conclude that rapid, pre-attentive grouping was not sufficient to generate the results. Similarly, the carry-over effects on singleton targets goes against onset capture and temporal segmentation accounts of preview search (Donk & Theeuwes, 2001, 2003; Jiang et al., 2002).

The apparently long time course of the current effects (with the preview colour needing to be presented for over 200ms before colour carry-over effects emerge), also counters another proposal – which is that the carry-over effect is due to a process of active colour grouping between the old and new displays. The conditions in Experiment 2b allowed as long as the standard preview condition for participants to adopt an active set to group and use colour to guide search. Despite this, the colour carry-over effect was reduced. My account differs from this in that I propose that any active set that participants adopt against old items operates through suppression of the features of those items (e.g., their locations and colour). This inhibition is slow-acting and contingent on the features displayed; hence the colour properties of the old items need to be present for over 200ms in order for active feature-suppression to emerge.

One other alternative is that a signal of relative change is critical for selectively attending to a target in a new display, irrespective of distractor suppression. Under the current conditions of preview search, a new red target may generate a weak change signal, which makes it difficult to detect. However, this relative change signal should again have been difficult to compute with briefly presented previews and / or colours, but I failed to find this (Experiment 2). If rapid pre-attentive grouping is not responsible for the colour carry-over effect, could some higher-order grouping process be critical (cf. Schulz & Sanocki, 2003)? Again this seems unlikely. For example, higher-order grouping may be too slow to explain the costs on selection under negative carry-over conditions, and there is no motivation to impose higher-order grouping in a top-down manner, given that it impaired target detection on half the trials. In addition, this account does not predict why such guidance should be greatly amplified for dynamic stimuli relative to static stimuli (an important finding from the present study). Under both circumstances the colour relations between the displays was matched. I conclude that negative carry-over effects reflect distractor suppression, and there is stronger inhibitory weighting of the colour of moving than of static old items. Suppressive processes are sensitive to search context.

Feature-based Carry-over Effects and Active Search Guidance

There is a substantial literature demonstrating that, in visual displays containing unequal number of features, participants can actively guide search to the stimuli in the minority set of distractors (see Bacon & Egeth, 1997; Egeth, Virsi & Gabart, 1984; Kaptein et al., 1995; Moore & Egeth, 1998). This raises the question of whether this form of active search guidance uses similar mechanisms to preview search. There are reasons to think that the two sets of processes may differ. Braithwaite and colleagues (see Braithwaite & Humphreys, 2003; 2007; Braithwaite et al. 2005; 2007) have examined preview search where the old and new displays contain unequal numbers of distractors in one of two colours, with the overall numbers of items in each colour balanced in the final display. Thus there may be a majority of green and a minority of red distractors in the preview, and a minority of green and a majority of red distractors in the search display. Based on active search guidance, it should be relatively easy to find a target carrying the minority colour in the new search display (e.g., a green target). However, the opposite result has been consistently reported – targets in the new minority colour are difficult to detect. The difficulty in detecting such targets fits with the idea of active inhibition weighted towards the colour carried by the majority of preview items (green). In contrast to this, guidance to the minority set in a search display may be based on active positive expectancies of the minority colour in the search display.

To conclude, the severe cost effects found under dynamic search conditions places feature-based inhibitory processes in a central role of guidance and selection, not only contributing towards the attentional prioritisation of new and important visual information, but also inadvertently contributing towards the impaired detection of new and important visual information.

CHAPTER 3

DIFFERENTIAL IMPACTS ON SELECTION BETWEEN COMMON AND RANDOM MOTION REVEAL IMPORTANT CHARACTERISTICS OF HOW INORMATION IS FILTERED IN PREVIEW SEARCH

Synopsis

Chapter 3 examined the role of configuration in dynamic preview search. This was done by examining the colour-based carry-over effect in two types of dynamic preview search conditions: one in which items moved together (in the same common motion pattern used in Chapter 2), and one in which the items moved in different, random directions. The selective attentional cost for new targets sharing the preview colour was greatly increased when items moved at random, compared with when items moved in a uniform manner. The findings are consistent with a flexible weighting system, in which the spatial and featural information available is used for inhibitory filtering of the old irrelevant items, which allows new information to enjoy an increased degree of attentional priority. However, the increased reliance on the feature-based component of inhibition when space-based guidance cues are less reliable results in a severe attentional cost for new information sharing the old inhibited feature. This chapter is based on a paper that has been submitted to the journal ‘Cognition’.

Introduction

Theories of visual search assume that selection is determined both by excitatory processes that respond to target features and by inhibitory processes that suppress representations of distractors (e.g., Braithwaite & Humphreys, 2003; Duncan & Humphreys, 1992; Treisman & Sato, 1990). Preview search has been shown to be a useful procedure to isolate these processes. In preview search observers are presented with half of the distractor items early, before the rest of the distractors and the target are added to the display (see Watson & Humphreys, 1997, for the original demonstrations). Relative to when the target and all the distractors appear together (the 'full-set baseline'), there is a benefit in search efficiency for the preview condition, with search often being as efficient as when the new items from the preview displays appear alone.

Inhibitory processes in preview search have been demonstrated through negative carry-over effects: targets are difficult to detect if they share features with the old distractors that are currently being ignored (Braithwaite & Humphreys, 2003; 2007; Braithwaite et al., 2003; 2005; Olivers & Humphreys, 2003). The negative carry-over effect occurs only when participants attempt to prioritize search to new targets (Braithwaite & Humphreys, 2007), and it leads to luminance increments being more difficult to detect on stimuli carrying old features than on new stimuli not carrying old features (Braithwaite et al., 2005, 2007). Evidence for excitatory guidance is provided by data showing that the negative carry-over effect can be reduced to some degree when participants have foreknowledge of the target's colour (Braithwaite & Humphreys, 2003).

Although inhibitory and excitatory processes mediating selection have been identified, the nature of these effects remains to be determined. In particular, are the processes applied in an all-or-none manner to a stimulus, or are feature values differentially excited or inhibited according to the nature of the information differentiating targets and distractors? Theories of top-down guidance in search (e.g., Wolfe, 1994) assume that there can be excitatory pre-setting of feature values defining targets. The evidence from preview search indicating that top-down excitatory guidance can over-rule negative carry-over effects is consistent with this (Braithwaite & Humphreys, 2003). However, evidence on inhibitory effects in selection is less clear.

An Important Role for Features in Dynamic Preview Search

Relevant data here come from studies of search using moving items. To date, there are only four published studies investigating preview search under more ecologically valid dynamic circumstances (Kunar, Humphreys & Smith, 2003; Olivers et al., 1999; Watson, 2001; Watson & Humphreys, 1998). These investigations have shown that, while it is possible under static conditions to selectively attend to new search items that differ from old stimuli in terms of their form properties (e.g., Olivers, Watson & Humphreys, 1999), when the display items are moving, such search advantages are abolished. These benefits can be reinstated by adding colour differences between the preview and the new stimuli (Olivers et al., 1999; Watson & Humphreys, 1998). This suggests that, with moving displays, colour-based inhibition may be critical to differentiate old from new items.

However, previous studies of dynamic preview search effects have typically employed comparisons where colour is either absent from the displays (fully achromatic) or applied separately to old and new stimuli (e.g. the preview display being all green and the search display being all blue: Kunar et al., 2003; Olivers et al., 1999; Watson, 2001; Watson & Humphreys, 1998). One problem here is that, under these conditions, the effects of colour could reflect a positive expectancy for the target colour. This may be even more the case when search is staggered over time. In addition, it is not clear whether selective colour-based inhibition, if it occurs, has a differential effect on moving relative to static displays, since effects of colour across these different display contexts have not been compared directly.

Furthermore, the majority of these previous investigations have only used common-motion patterns, where items move together in one direction (Olivers et al., 1999; Watson & Humphreys, 1998; Watson, 2001), or predictable motion patterns, where items move continuously in one direction, (Kunar et al., 2003; Watson, 2001) to examine 'dynamic' search. In addition, none of these previous studies have examined search performance when the colour of the target is unknown and where features can be shared across displays. As a consequence there has been no systematic investigation of the existence of the carry-over effect in dynamic search conditions. My previous study was the first to explore carry-over effects under dynamic motion conditions when the colour of the target was unknown (Andrews, Watson, Humphreys & Braithwaite, submitted / Chapter 2).

Configural Processing in Preview Search

However, although the work of Andrews et al., (Chapter 2) demonstrated an increased role for feature-based inhibition in dynamic preview search, compared with static preview search, these dynamic displays used only a uniform common-motion pattern. Under conditions of common motion, although the specific locations of the display items were constantly changing, the spatial relation between items (i.e., their configuration) remains relatively stable, at least until items reach the bottom of the presentation window and disappear. In addition, the results do indicate that configuration-based encoding may contribute towards the preview benefit under these common motion conditions. When the old items changed colour just 100ms prior to the onset of the second search display, although this removed the carry-over cost for new items holding the original preview colour, the preview benefit was maintained. If old items were inhibited purely via their shared colour-map representation, then a colour change should disrupt inhibition, suggesting that suppression via some other means enables old items to remain de-prioritised despite the colour change.

Previous findings investigating the role of configural-processing in preview search present a mixed picture. For example, Olivers et al (1999) found that no preview benefit occurred when old and new items were presented achromatically under conditions of common-motion (when the configural properties of the preview items were maintained). Olivers et al., (1999) argued that configuration-based representations play no role in the inhibitory filtering of the preview items. However, Kunar et al (2003) have shown that, with achromatic displays, configural stability is crucial for preview benefits to survive an off set to the previewed items. They used conditions in which the preview items were removed during the preview period, and reappeared either in new random locations, or one visual degree to the left or right of their original positions. In the latter condition, all items moved in the same direction, therefore the configuration of the display was identical to the original, but moved to a new position on the screen. When the items reappeared in new random locations the preview benefit was abolished, and was re-established only when colour differences existed between preview and search displays. However, when the configuration remained the same, the preview benefit was maintained across the location change, even when preview and search items all held the same colour. This suggests that a fixed configuration-based representation can contribute to the inhibitory filtering of the old items.

A similar finding has been shown for dynamic displays. Watson (2001) employed rotating displays in which there were no feature differences between old and new items. Watson (2001) found that when items all rotated in the same direction and the interspatial relationship between items remained constant, a preview benefit occurred. However, when half of the items within each display moved clockwise and the other half moved anticlockwise, and spatial relation between items was no longer held constant, the preview benefit was abolished. The configuration of these rotating displays remains constant throughout the entire trial, whereas the configuration of the vertical scrolling displays used in our previous study (Andrews et al, submitted) is disrupted as items reach the bottom of the screen and reappear at the top. The demonstration that a preview benefit occurs in achromatic rotating common motion search, but not scrolling common motion search (Olivers et al., 1999) suggests that a stable configural representation is crucial for this to be sufficient alone for old items to be successfully filtered from search.

As a consequence of these diverging findings, the contribution and role of configural processing in our previous investigation of common-motion is unclear. One possible way to reconcile the mixed findings in the literature is that perhaps configural-processing is dependent on the co-presence of featural-differences to help establish a stable object-based (i.e., surface) representation of the preview items. Once this representation is established, and inhibition is applied to it, features may not be crucial for the maintenance of the representation. This would explain why there are no effects of configural processing for achromatic stimuli under dynamic circumstances (Olivers et al., 1999) but there can be for static stimuli if featural differences exist between the displays (Kunar et al., 2003). If configural-processing does contribute to preview search under common-motion conditions (when featural differences are present) then this may still serve to reduce and off-set the feature-based effects to some degree. As a consequence, even the increased degree of carry-over reported by our previous studies may still be a severe under-representation of the negative impacts possible in more ecologically valid circumstances.

The Present Study

While many of these previous investigations have shown that colour is important in dynamic preview search, none of them evidences a role for direct feature-based inhibition and none have investigated carry-over effects in dynamic preview search. The findings from both the studies of Watson & Humphreys (1998) and Olivers et al., (1999) could both be explained merely by (i) the increased role of featural differences under dynamic conditions (acting as additional low-level segmentation cues); (ii) by contributions from configural processing of the preview which may be aided by the co-presence of featural differences; or by (iii) foreknowledge of the upcoming target's colour. If feature-based carry-over effects are important for situated real-world perception then it is important to demonstrate that such effects can and do occur under more ecologically valid dynamic motion conditions.

I provide here the first empirical investigation of the negative colour carry-over under dynamic random motion conditions. In addition, I investigated the contributions from location-based, configural, and feature-based processing to both benefits and costs in selection when search is extended over time. If significant benefits to search efficiency emerge for non carry-over targets (i.e., green targets) under random-motion dynamic conditions (relative to appropriate full-set simultaneous baselines), then this would suggest that neither location nor configural information is contributing to performance in that condition. In random-motion the locations of the items are constantly changing and no stable configuration exists. Something else must be considered and I would suggest that this 'something else' is feature-based inhibition mediating preview benefits for non carry-over targets.

It should also be pointed out that the present study provides the most conservative test of random-motion in studies of preview search. As already noted, most of the previous dynamic preview search studies have used common motion displays, (Olivers et al, 1999; Watson, 2001; Watson & Humphreys, 1998), and the two studies which have used multiple trajectories have only shown that colour differences between old and new items are crucial for preview benefits to occur, (Kunar, et al., 2003; Watson, 2001), which could simply be explained by colour grouping. In addition, these have not used completely random motion. Watson (2001) used just two directions of motion (clockwise and anticlockwise) and Kunar et al (2003) used conditions in which items moved in one of four possible directions (vertical and horizontal) throughout the trial. In the present study, for random motion conditions, all the preview and search items moved along truly random, unpredictable and constantly changing trajectories.

Furthermore, building on and extending the previous findings I predicted that if the preview items are being filtered by a flexible-weighting inhibitory system which encompasses feature-based processing, then the magnitude of the cost to efficiency for carry-over targets would increase further still for random-motion relative to common-motion and static items. If both preview benefits to non carry-over targets and costs to carry-over targets do emerge and are increased in magnitude under random-motion conditions then this would also help to bridge the paradigmatic-gap between studies of preview-based visual search and other procedures for measuring attentional-blindness (i.e., the Selective-Looking paradigm: Most et al., 2001, 2005). As a consequence the present findings here may have implications for more general models of failures of selection and awareness and provide a more detailed assessment of the underlying contributions to it (i.e., location, configuration, feature-based mechanisms).

Overview of the Experiments

Four preview-based visual search experiments investigated the inhibitory processes underlying attentional guidance and the impact of negative carry-over effects under both common motion and random motion search conditions. A static preview condition was also employed to establish that colour carry-over effects do occur in circumstances where they have been previously demonstrated (Braithwaite & Humphreys, 2003; Olivers & Humphreys, 2003). If the carry-over effect is mediated by the flexible inhibition of a feature-map, then as the reliance on the feature-map increases, so should the magnitude of the carry-over. If I selectively impair the ability of observers to use (i) location, (by having all the items move), (ii) positive feature-based expectancies (by employing conditions where the target can be any colour) and (ii) configural processing of the preview items (by having them move along random trajectories) then this should gradually increase the role of the features of the old items as being the main critical component mediating inhibition. In addition, if such patterns of performance do emerge then this would also imply that other forms of coding (i.e., location, and configuration) may also be lessening the impact of feature-based processing under conditions where all processes can contribute to selection (i.e., static search).

Experiment 1 examined preview benefits and carry-over effects for three different types of visual search display. In one condition all the display items remained static and did not move. This provides a control condition where I expect the participants to show a cost for targets carrying the colour of the old preview items under static conditions (an effect which has been well documented: Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2004, 2007, 2010a, 2010b; Olivers & Humphreys, 2003). In addition to this, a new dynamic condition was devised where all the items continuously scrolled vertically down the screen via common motion (cf., Olivers et al., 1999; Watson & Humphreys, 1998). This condition should impair the availability of stable location-based processing contributing to preview effects. Furthermore, a new random motion dynamic condition was also employed where the items moved in random, different, and unpredictable directions. This latter condition should impair both stable location-based processing and configural processing of the old preview items. As a consequence the reliance on feature-based processing to inhibit the old items should be increased in the random motion condition relative to both the common motion and static conditions.

For each of these conditions of motion, preview search was compared with a full-set baseline in which all items were presented at the same time but also contained the same static or motion properties as its preview counterpart. Importantly, the displays contained items of different colours (red and green) and the new target could be either red or green equally often. Based on previous research, a number of predictions were made. Firstly, for the static conditions I expected to replicate the pattern of effects found in previous research - a preview benefit for new items not carrying the colour of the preview items (i.e., green targets), and a selective cost for new items which do carry the colour of the preview items (i.e., the feature-based carry-over effect: Braithwaite & Humphreys, 2003; Braithwaite et al., 2003, 2005, 2007, 2010a). Secondly, for the common motion conditions, as stable location information would no longer be available, I predicted an increased effect of the carry-over, in comparison to the static conditions (cf. Braithwaite et al., 2010b for isoluminant stimuli). In addition to these effects, for the random motion conditions I also predicted a further increased effect of feature-based carry-over inhibition (relative to common motion and static conditions) due to the fact that under these conditions neither spatial location nor configural information remained constant.

Experiment 2 tested and rejected the potential counter explanation that the role of low-level grouping may be increased under dynamic search conditions relative to static conditions due simply to the fact that motion itself may impact on low-level segmentation processes. This was done by reducing the time that colour was shared between the preview (background) items and the new carry-over target. Here, although the preview duration was the same as in all other cases (1000ms), the preview display was initially presented in blue for 900ms, and only changed to red 100ms before the search display was added. A time period of 100ms is not sufficient for a top-down inhibitory bias to develop (Braithwaite et al., 2003, 2007; Watson & Humphreys, 1997). As a consequence of this manipulation, a direct assessment of how much any increased effects of colour might be due to non-inhibitory low-level factors can be ascertained.

In a previous study (Chapter 2) I found that, in common motion search, the preview benefit for non carry-over targets was maintained across this colour change manipulation. That is to say, the colour change itself did not appear to impact on the preview benefit. This may be explained by a configuration-based component directed towards coding the old items under conditions of common-motion – which may enable old items to remain suppressed even when they change colour. Importantly, if this suggestion is true, the same preview benefit would not be expected to be preserved across the colour change in random motion search, when this configural information is no longer available.

In Experiment 3 colour differences were removed from the display and all items were presented achromatically. Here colour differences do not exist between the displays in preview search and as such cannot be employed to segment or inhibit the old items. Accordingly, contributions to performance are likely to come from feature-blind guidance processes, such as automatic attentional capture of the new luminance onsets (Donk & Theeuwes, 2001, 2003) and temporal segmentation between the displays (Jiang et al., 2002). All-grey preview search was examined under both types of dynamic displays. If the role of colour, as a feature, is more central to performance under random and unpredictable motion conditions, then removing such important colour differences should impact on performance more in these conditions.

Experiment 4, examined whether the cost for carry-over targets actually reflects a positive prioritisation of the non-carry-over colour as opposed to any active de-prioritisation of the old colour. By this account, performance might be explained by observers merely directing their attention first to the non-carry-over items first before moving on the carry-over target. To test this, performance was compared between conditions where the target colour was typically unknown to a new preview condition in which the target was known to appear in the new non-carry over colour. If the default strategy of observers is to prioritise the non carry over colour then providing such instruction explicitly and having conditions where the target is always a given colour, should have a minimal impact on search performance (as such strategies should already be in place). However, if significant improvements to search are observed when target colour foreknowledge is provided then this would imply that such strategies are not in place under the more typical conditions.

Experiment 3.1 – Increasing the Reliance on Featural Differences in Preview Search

Experiment 1 investigated the involvement of flexible feature-based weighting in search guidance. This was done by reducing the role of other factors impacting on performance and mediating selection. Experiment 1 investigated preview-based colour effects under (i) *static* search conditions, (ii) *common motion search*, in which display items scrolled down the screen in a uniform pattern of common motion which maintained their relative configuration; and (iii) *random motion search*, in which display items moved along different, randomly generated trajectories. It is expected that a greater reliance on feature-based inhibitory processes will result in a magnified cost for new items sharing the old inhibited colour. Therefore, the carry-over is expected to be increased in dynamic preview search compared with static search. In addition, the colour-based carry-over effect is expected to be even larger when items move in a random fashion, than when items move together in a uniform manner.

Method

Participants

Twenty-two undergraduate / postgraduate students, aged between 18 and 20yrs old, (two males) from the University of Birmingham took part for course credits. All self-reported normal or corrected-to-normal vision, including normal colour vision.

Stimuli & Apparatus

The experiments were run on a Pentium PC fitted with a 17-inch super VGA monitor. Stimuli consisted of a set of uppercase letters, (distractors H, I, X, V, and target N), with a visual angle of 0.46° × 0.93°. Items presented appeared randomly within a 10 × 10 matrix, in a 90 mm × 105 mm (10.4° × 12.2°) presentation window. In all conditions, each display consisted of an equal number of items appearing on the left and right side of the screen. In the static conditions, items remained in the position in which they first appeared and never moved. In the common motion condition, upon onset, the items moved vertically downwards. When the stimuli reached the bottom of the presentation window, they reappeared at the top and then continued to move downwards, akin to a wrap-around scrolling display (cf. Watson & Humphreys, 1998). In the random motion conditions, the presentation window was split into 2 rectangles on the left and right side of the computer screen, with a 4mm gap down the centre of the screen. In the random dynamic conditions, upon onset, each display item moved in a different, linear direction. Each trajectory was randomly generated, and when items met the edges of the presentation window, or came within 1.45° of another item, they rebounded off into a new direction. There was also an invisible divide between the left and right hand side of the screen, which display items never crossed. Therefore, no occlusion occurred, and items remained on the same side of the screen throughout the trial. Items moved at an approximate speed of 48mm/s, (4.9°/second) in both motion conditions.

The background of the computer screen, including the presentation window, was black, (the edges of the presentation windows were not visible). The letter stimuli consisted of a heterogeneous group of distractor letters (H, I, X, V) and the target letter (the letter 'N'), all presented in uppercase. Distractors were selected randomly with replacement for each trial. For each given display size, an equal number of distractors fell in each visual field, with the target letter (N) falling in the left (LVF) and right (RVF) visual fields equally often. Stimuli were either red or green in colour. Colour values were equated for luminance using a colour-flicker calibration test carried out on each participant before the experiment. A more detailed description of this flicker test is outlined in the procedure section.

Design & Procedure

The experiment employed a four-factor within-subjects design, which comprised of 3 (Motion: static / common / random) × 2 (Condition: baseline vs preview) × 2 (Display size: 8 / 16) × 2 (Target Colour: red / green). Each motion condition had a preview and matched full-set baseline condition. The full set baselines were (i) Full-Static, (ii) Full-CM (common motion) and (iii) Full-RM, (random motion), respectively. Preview conditions were (i) Prev-Static, (ii) Prev-CM, and (iii) Prev-RM. In the full-set baseline conditions, all items were presented at the same time. Half of the distractor letters were red and the other half were green. The target could be red or green equally often. In the preview conditions, the initial distractors were presented (the *preview display)*, for 1000ms, before being joined by the green distractors and the target letter (the *search display)*. The target letter could be red or green equally often. However, when the target was red it was a colour singleton in terms of the second search display. When it was green, all new items were green. The final combined displays consisted of 8 or 16 items (in the preview condition, this was 4 or 8 preview items + 4 or 8 search items). See Figure 3.1 - 3.3 for an example display for each type of motion display. The conditions were run in separate blocks of 80 trials (40 per Display Size). Display Size and Target Colour were randomised within blocks.

Before the experiment, each participant undertook the colour-fusion flicker test to establish individual isoluminance values for the red and green items. Two square shape outlines were presented on the screen, at different eccentricities around a central fixation cross (approximating the eccentricity parameters used for the search displays). The squares oscillated between the colours of interest to produce a constant flicker. The flicker rate was 30Hz. Participants were asked to minimize the flicker using button presses to alter the luminance values. The value for the minimal flicker was taken as the point of isoluminance for that individual. Each participant was given practice at the flicker test before completing 5 experimental calibration trials. The final values were based on an average RGB setting from these 5 trials.

Participants completed a block of 24 practice trials for each condition, before each experimental block was run. These practice trials were not analyzed. Each trial began with presentation of a white fixation cross in the centre of the screen. This remained present throughout the trial. Following a fixation period of 1000ms the display items were presented. In the full-set baseline conditions, all items were presented simultaneously, and participants were instructed to search for the target as soon as the items appeared. In the preview conditions, following the fixation period, the preview display was presented for 1000ms. During this period the participants were told to keep fixated and wait for the second set of items before initiating search. They were aware that the target would always appear within the second search display, rendering the previewed items as irrelevant. Participants responded as fast and accurately as possible, by pressing ‘M’ if the target appeared in their right visual field (RVF), or ‘X’ if the target appeared in their left visual field (LVF). There was a time-out period of 10,000ms imposed for each trial. To combat the strategy of simply monitoring one visual field and basing all decisions on this, ten percent of trials were ‘catch’ trials where there was no target present. In these cases participants were instructed to withhold their response. The order in which the conditions were run was randomised across participants.

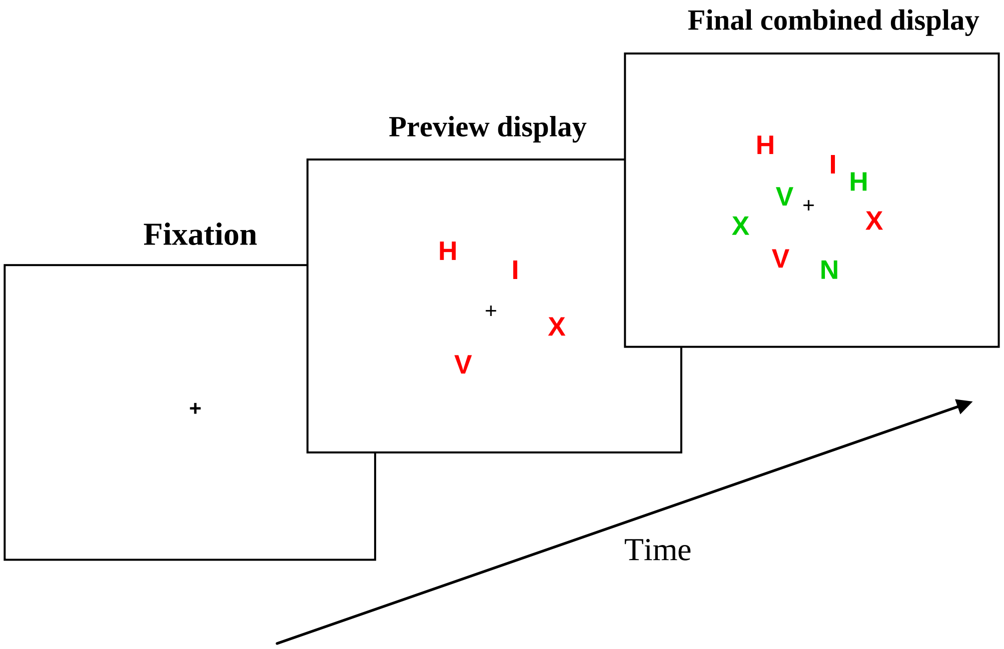

Figure 3.1. An illustration of the displays used in the static conditions of Experiment 1. In the full-set baseline condition (Full-Static), all display items were presented together. The display comprised mixed red and green distractor letters, and the target letter (N) could fall into either of these colour sets equally often. In the preview condition (Prev-Static – shown above) the preview display was first presented, which comprised one colour (i.e. red distractor). Following a period of 1000ms, this was joined by the search display, comprising the green distractors and the target, which again could be either red or green equally often. When the target was red it (i) carried the colour of the preview (hence it was the carry-over target) and (ii) was a singleton in terms of the search display.

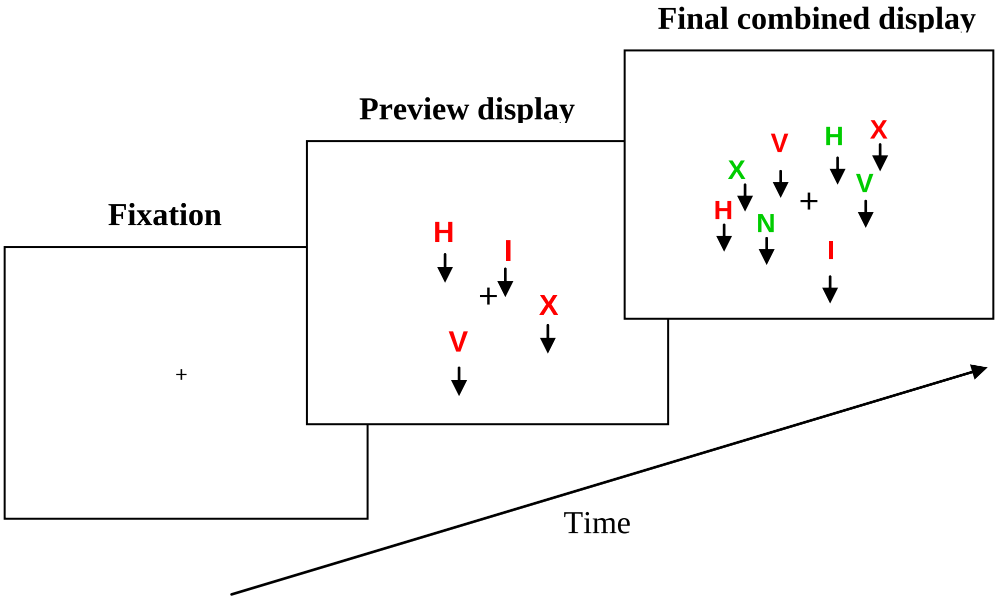

Figure 3.2. An illustration of the displays used in the common motion condition of Experiment 1. Upon onset, the display items moved vertically downwards, maintaining their configural properties. They remained in motion throughout the entire trial. When the stimuli reached the bottom of the presentation window, the items filtered off the screen and reappeared at the top of the window.

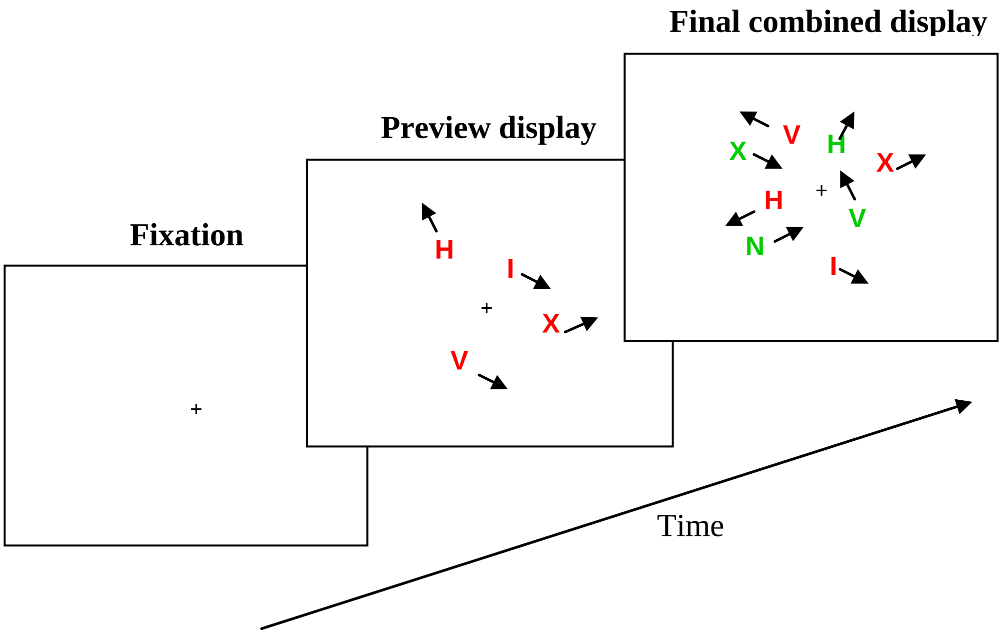

Figure 3.3. An illustration of the displays used in the random motion conditions of Experiment 1. Upon onset, the display items moved in different, randomly generated directions. When the stimuli met the edges of the presentation window, the invisible divide running vertically down the centre of the computer screen, or each other, they rebounded off into another random direction.

Results

RT's were first screened for errors and outliers (+/- 2.5 *SD's* from the cell mean). Four participants made errors on more than 10% of trials. Due to the very low error rate from the other participants, these four were removed from analysis. Slope data were computed from the mean correct RT data, which denote search efficiency (milliseconds per item), and these were used for the analysis. Mean efficiency data were first entered into an overall 3 × 2 × 2 (Motion × Condition × Target Colour) within-subjects ANOVA. There was a main effect of Motion, F(2,42)=6.99, p<.01, Condition, F(1,21)=6.74, p<.02 and Target Colour, F(1,21)=42.56, p<.01. All interactions were significant: Motion × Target Colour, F(2,42)=8.35, p<.01; Motion × Condition, F(2,42)=8.47, p<.01; Condition × Target Colour, F(1, 21)=39.37, p<.01; Motion × Condition × Target Colour, F(2,42)=6.48, p<.01. The effect of Target Colour was significantly magnified in preview search conditions relative to baseline conditions and the magnitudes of these effects also varied under the different types of Motion. These complex interactions were explored through further analysis.

Firstly, I analysed effects under standard baseline visual search conditions to assess how the manipulations of motion impacted on general search performance. Following this, red and green targets were examined separately, to compare the effects of Condition (Full-set baseline & Preview) across the 3 conditions of Motion (static, common motion & random motion).

Baseline Search

The 3 baseline conditions (Full-Static, Full-CM, Full-RM) were compared in a 3 × 2 (Motion × Target Colour) ANOVA. There was no main effect of Motion, F(2,42)=1.78, p=.18, no effect of Target Colour, F(1,21)=.08, p=.78, and no Motion × Target Colour interaction, F(2,42)=.53, p=.59. Search performance was matched for all three baseline conditions.

Search Efficiency (msec / item): Carry-over Targets

Search efficiency for red target responses was entered into a 3 × 2 (Motion × Condition) ANOVA. There was an overall main effect of Motion, F(2,42)=9.49, p<.01. Search efficiency was significantly influenced by the motion factor. There was also a significant main effect of Condition, F(1,21)=20.37, p<.01. Search for carry-over targets was significantly less efficient in the preview condition relative to the full-set baseline condition. There was also a significant Motion × Condition interaction, F(2,42)=5.54, p<.01. The effect of motion on carry-over targets impacted more on performance in the preview condition than in the baseline condition (see Figure 3.4).

The overall effect of Motion was explored further by comparing the 3 baseline conditions in a one-way ANOVA, which revealed no overall effect of Motion, F(2,42)=2.54, p=.12, followed by a comparison of the 3 preview conditions, which did reveal a significant effect of Motion, F(2,42)=11.38, p<.01. Separate paired t-tests confirmed that red targets were impaired in the Prev-CM condition relative to the Prev-Static condition, t(21)=2.73, p<.01, and were impaired in the Prev-RM condition compared with the Prev-CM condition, t(21)=1.91, p<.05. Search for carry-over targets was significantly less efficient in the random motion condition (94msec/item) relative to both the common motion (77msec/item) and static conditions (50msec/item: see Figures 3.4).

To explore the Motion × Condition interaction, analysis was then broken down into a set of paired t-tests comparing each preview condition to its baseline. Comparison of red targets in the Full-Static & Prev-Static condition showed that red target search was equivalent in the static preview and baseline conditions, t(21)=1.66, p=.11. Comparison of the Full-CM & Prev-CM conditions showed that red targets were significantly impaired in the common motion preview condition compared with the common motion baseline, t(21)=2.40, p<.03. Similarly, comparison of the Full-RM & Prev-RM conditions showed that red targets were impaired in the random motion preview compared to the random motion baseline, t(21)=6.39, p<.01.

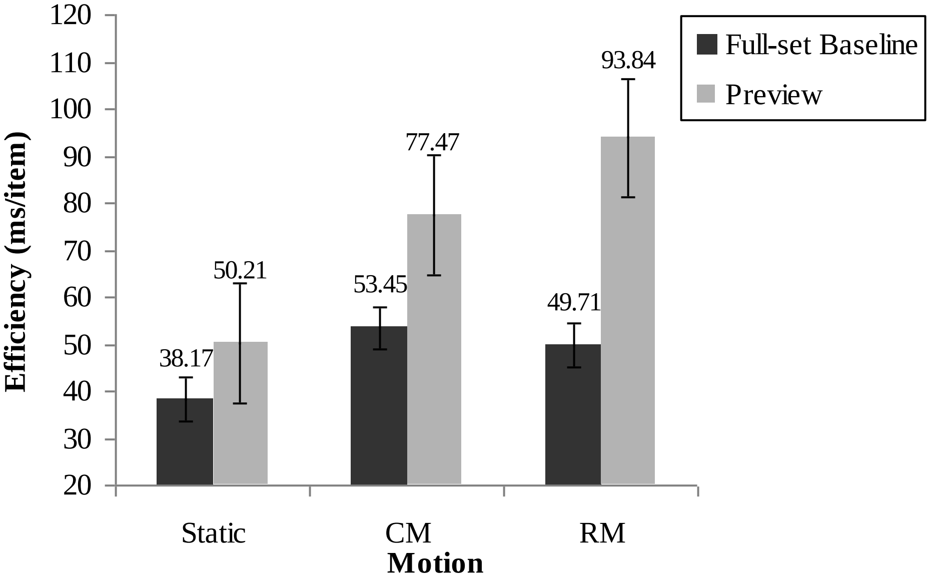

Figure 3.4. Mean search efficiency (ms/item) for carry-over targets (i.e., red targets), across Motion & Condition. Error bars represent standard error.

Search Efficiency (msec/item): Non Carry-over Targets

Search efficiency for non carry-over targets (i.e., green targets) was analysed in the same way as that described above. The 3 x 2 (Motion x Condition) ANOVA revealed a main effect of Condition, F(1,21)=14.75, p<.01. Search was significantly more efficient in the preview relative to baseline conditions. However, there was no main effect of Motion, F(2,42)=.15, p=.86, and no Motion × Condition interaction, F(2,42)=.42, p=.66. Although search was more efficient in the preview condition for non carry-over targets, this did not alter further as a function of motion type. Search, was equivalent for all 3 types of display (see Figure 3.5).

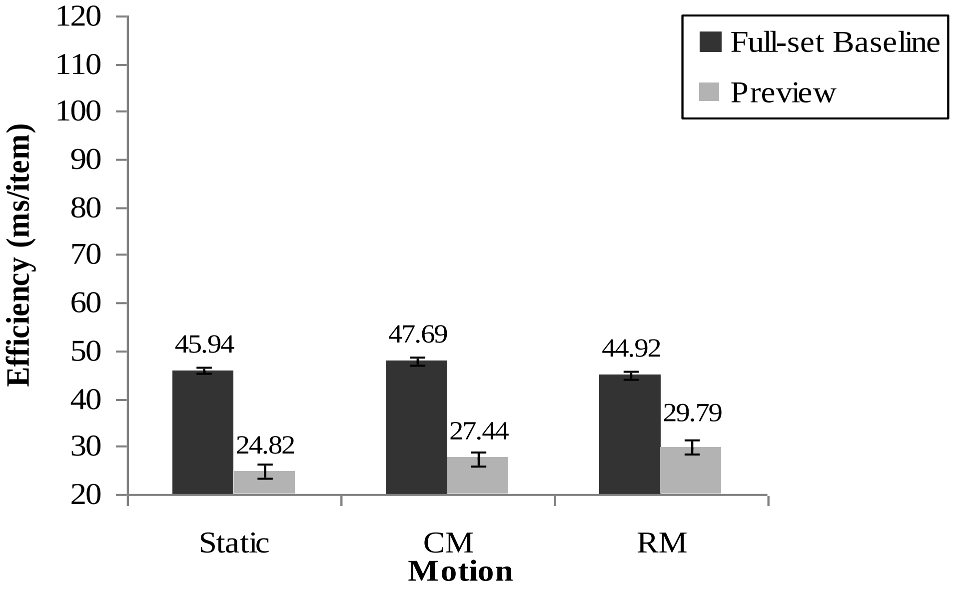

Figure 3.5. Mean search efficiency (ms/item) for non carry-over (i.e., green targets), as a function of motion and condition. Error bars represent standard error.

The above analyses reveal separate effects on new targets as a function of (i) the colour the target is carrying and (ii) the type of motion present within the search display. Figure 3.6 illustrates the separate effects within the preview conditions alone. As can be seen, the effects of motion are crucially impacting on red carry-over targets relative to green non carry-over targets.

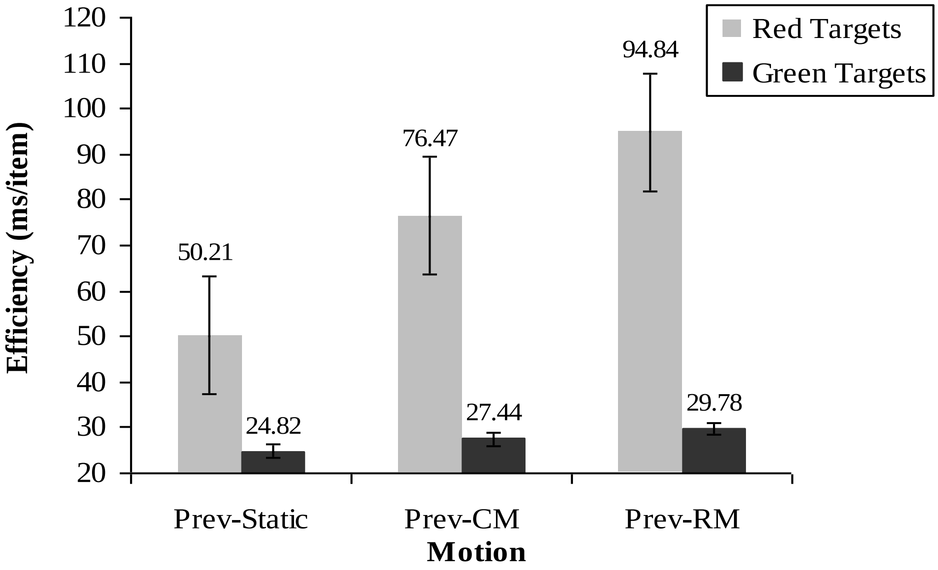

Figure 3.6. Mean preview search efficiency (ms/item) for the preview conditions, across Motion & Target Colour. Error bars represent standard error.

Error Data

The mean error rate was low at 2.57%, (see Table 3.1 for the error data across Motion, Condition, Display Size & Target Colour). As with RTs, errors were entered in a 3 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) ANOVA, revealing only a main effect of Display Size, F(1,21)=6.44, p<.02, and Target Colour, F(1,21)=11.58, p<.01. Consistent with the RT data, there were more errors made responses to red targets and more errors made at the larger display size.

Table 3.1. Mean % errors across Motion, Condition, Target Colour & Display Size.

Motion	**Condition**	**Target Colour**	**Display Size 8 (% Errors)**	**Display Size 16 (% Errors)**
Static	Full-set Baseline	Red Targets	2.05	2.05
		Green Targets	2.05	1.82
	Preview	Red Targets	2.27	3.18
		Green Targets	1.82	2.05
Common Motion	Full-set Baseline	Red Targets	1.59	1.82
		Green Targets	1.36	1.82
	Preview	Red Targets	2.05	3.64
		Green Targets	0.91	2.27
Random Motion	Full-set Baseline	Red Targets	3.18	4.77
		Green Targets	2.95	3.86
	Preview	Red Targets	3.18	4.77
		Green Targets	2.73	3.41

Discussion

The present study provides the first investigation of colour carry-over effects in dynamic random-motion displays. The findings are clear. Firstly, there were no reliable effects of motion on performance with the simultaneous baseline visual search conditions. Search was as efficient in the random motion condition as it was in the static condition and as such, complex motion per-se did not seem to hamper selection. This is in line with other recent findings showing that search efficiency in random motion displays is also not influenced by the speed or velocity of those moving items (Hulleman, 2009). These findings suggest that any additional effects seen in the preview conditions cannot be attributed merely to complex random motion conditions being more difficult – as clearly this is not the case.

Secondly, providing observers with a preview of the initial distractors produced significant benefits to search efficiency under all preview conditions (relative to their appropriate full-set baseline) for non carry-over green targets (see Figure 3.5). This finding is consistent with performance being improved by the inhibition of the old preview items (cf. Watson & Humphreys, 1998; Watson, 2001; Olivers et al., 1999). Interestingly, the preview benefit for non carry-over green targets remained roughly the same for all three types of displays. This result suggests that, location-based coding is not necessary for the old items to be successfully excluded from search and that other mechanisms must be contributing to de-prioritisation under dynamic circumstances. .

For static search, in addition to any effects from onset capture and temporal grouping, we suggest that performance here is mediated by (i) location-based inhibition and (ii) feature-based inhibition of the old preview items. For common motion search, stable location based processing is not possible and as such a greater role of feature-based inhibition and perhaps some form of configural inhibition processing or object-based inhibition may well be mediating performance. For random motion conditions, top-down inhibition is most likely principally mediated through featural properties between the displays as neither location-based or configural processing is possible.

However, having said this, is it not a problem that the benefit for non carry-over targets does not appear to be reliably influenced by the different motion conditions? Would we not expect search to suffer somewhat from simply not having location-based or configural processing contributing to the preview benefit in random motion situations? To explain this finding, I suggest that performance for the new green non carry-over targets is probably at floor level under all these preview search circumstances. In addition, while there were no significant differences found, the data does provide an indication that the random motion preview benefit is moderated. Static and common motion displays show a green target preview benefit of 21ms/item and 20ms/item respectively, whereas random motion displays show a benefit of just 15ms/item, suggesting that participants are less efficient at limiting search to the new items when inhibition must rely on features alone, than when location or configuration is also available for filtering.

In contrast to the pattern seen for green targets, search was significantly less efficient in the preview condition for targets which carried the colour of the old and irrelevant preview items. With static displays, the cost for these carry-over targets completely removed any preview benefit, and search here was no more efficient than the full-set baseline. This is consistent with previous studies of the carry-over effect, (cf. Braithwaite & Humphreys, 2003; Braithwaite et al., 2003, 2005; 2007; 2010a, 2010b). When display items were moving, however, the cost for carry-over targets was greatly increased, and the preview benefit was not only off-set but completely overturned into a preview cost. For both the common and random motion displays, search for these targets was actually *less* efficient in preview search than the full-set baseline.

Furthermore, the cost was increased further when display items moved at random trajectories, compared with when they had a common motion. In common motion (CM) search, red target search efficiency was, on average, 24ms/item worse in the preview condition than the baseline condition, whereas in random motion (RM) search, efficiency was impaired on average by 44ms/item – the cost was almost doubled relative to the full-set baseline.

The present findings are consistent with the notion that observers show a degree of impairment in selecting the relevant target when it carries the critical featural attribute of the irrelevant preview items (Braithwaite et al., 2003, 2007, 2010a). However, here I show, for the first time, that this selective attentional-blindness becomes increasingly magnified as other processes underlying the preview benefit are selectively removed (i.e., stable location-based inhibition and configural processing). When observers rely more on the featural attributes of the irrelevant items to filter them from selection, this manifests itself as significant increases in the efficient selection of new items carrying that attribute.

In static search, filtering is proposed to occur primarily via the old locations represented within a spatial-map (Watson & Humphreys, 1997), and the carry-over effect is argued to reflect the spreading of suppression within this colour group, over time, (Braithwaite et al., 2003, 2007). In dynamic preview search, however, when item locations are constantly changing, it has been suggested that filtering via a whole feature-map representation enables the old items to be de-prioritised from attention, (Watson & Humphreys, 1998). Andrews et al (submitted / Chapter 2) have recently provided support for this notion, by extending the colour-based carry-over to dynamic search conditions, in which they found the cost of feature sharing was increased in common motion search compared with static search. Here we extend current research by demonstrating an even greater carry-over cost when items move at random and stable spatial continuity between moving items is removed.

Together, these results implicate a flexible weighting system, in which inhibitory guidance recruits both spatial cues and featural information in order to filter old information from selection. When no location-based cues are available, the increased reliance on feature-map inhibition results in a severe cost for new items sharing this feature. However, when location-based inhibition is also possible, (either via specific locations within a fixed spatial-map or the locations within a moving configuration-map), the negative carry-over effect of feature-based inhibition is off-set somewhat by these non feature-based components. The degree of this off-set is far greater in static search, than in common motion search. I return to explore these issues and provide a more explicit functional account in the General Discussion.

While the results of Experiment 1 are consistent with an inhibitory account, there are some potential low-level factors that may be contributing to the current findings and hence may offer a counter explanation. For example, one possibility is that the impact of the featural differences available in the displays may become magnified when items move due purely to low-level reasons such as an increased role of perceptual grouping. In the motion conditions there are more grouping cues than in the static conditions. For static search, items can be grouped and segmented on the basis of their (i) colour differences (ii) the temporal asynchrony between the displays; and (iii) the onset capture of the new items. In the motion displays there is the additional role of motion itself. Having items move may magnify the contributions from all these other sources of information. This might also lead to an increased cost for new targets carrying the same features as the preview items – but by this account, this has nothing to do with the top-down feature-based inhibition of irrelevant items.

Therefore, Experiment 2 was carried out to address the contribution of low-level grouping processes in the dynamic colour-based carry-over effect. This was examined by reducing the time that colour was shared between the preview display and the new carry-over target down to just 100ms. This time period is far too brief for the top-down inhibition of a feature-map to develop (Braithwaite et al., 2003; 2005; 2007), but is more than sufficient for fast-acting perceptual grouping processes such as temporal segmentation (Leonards et al., 1996) and onset capture processes (Yantis & Gibson, 1994) to operate. Therefore, this manipulation facilitates an assessment of the role of these low-level contributions to the magnified effects reported in Experiment 1.

Experiment 3.2 – Low-Level Grouping

In Experiment 2 preview items were presented in a new colour (blue) for the initial 900ms of the preview period, before changing to red just 100ms prior to the onset of the second search display. As a consequence of this new manipulation, insufficient time is provided for feature-based inhibition to accrue and manifest itself as a negative carry-over to new information (Braithwaite et al., 2003, 2007). Therefore, if the negative carry-over and the increased magnitude of it seen for dynamic displays is based in a feature-based inhibitory process, we predict that this manipulation will disrupt both the preview benefit and the cost for new items sharing the preview colour (now for only 100ms), and any effects that remain will implicate alternative guidance processes.

Method

Participants

Twenty-four students from the University of Birmingham took part for course credits (2 male), aged between 18 and 23, with a mean of 20.4 years of age.

Design & Procedure

The experiment employed a 2 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) within-subjects design. There were 2 preview conditions and 2 full-set baselines, and for each of these there was a common motion condition (FullCM & PrevCMcc, respectively – note the ‘cc’ refers to a colour change condition) and a random motion condition, (FullRM & PrevRMcc, respectively). The baseline conditions were identical to those of Experiment 1, and so were the preview conditions except that now the preview display was initially presented in blue, only turning red after 900ms, (100ms before the search display was presented).

Results

RT’s were prepared for analysis by removing incorrect responses and outliers (+/- 2.5 SD’s from the mean). As with Experiment 1, efficiency slope data was used for the main analysis. Mean search efficiency (ms/item) was entered overall 2 × 2 × 2 (Motion × Condition × Target Colour) ANOVA carried out on the mean correct RTs revealed a main effect of Condition, F(1,23)=5.80, p<.03, but no main effect of Motion, F(1,23)=.32, p=.58, or Target Colour, F(1,23)=.08, p=.78. There was no Motion x Target Colour, F(1,23)=1.93, p=.18, and no

Condition x Target Colour, F(1,23)=1.29, p=.27, interaction, but there was a significant Motion x Condition, F(1,23)=5.51, p≤.01, and a Motion × Condition × Target Colour, F(1,23)=5.72, p<.03, interaction. The interaction between Target Colour and Condition was increased in common motion search compared with random motion search. These interactions were examined through further analysis.

Common Motion Search

Mean search efficiency in the two common motion conditions (FullCM & PrevCM$_{cc}$) was entered into a 2 × 2 (Condition × Target Colour) ANOVA. There was no main effect of Target Colour, F(1,23)=1.42, p=.25, but there was a main effect of Condition, F(1,23)=10.67, p<.01, and a Condition × Target Colour, F(1,14)=5.00, p<.05, interaction. There was an increased effect of condition on green target search compared with red target search (see Figure 3.7). A set of paired t-tests carried out on red and green targets separately revealed that red target search was equivalent under both conditions, t(23)=.36, p=.73, whereas green target search was more efficient in the preview condition than in the full-set baseline, t(23)=4.32, p<.01.

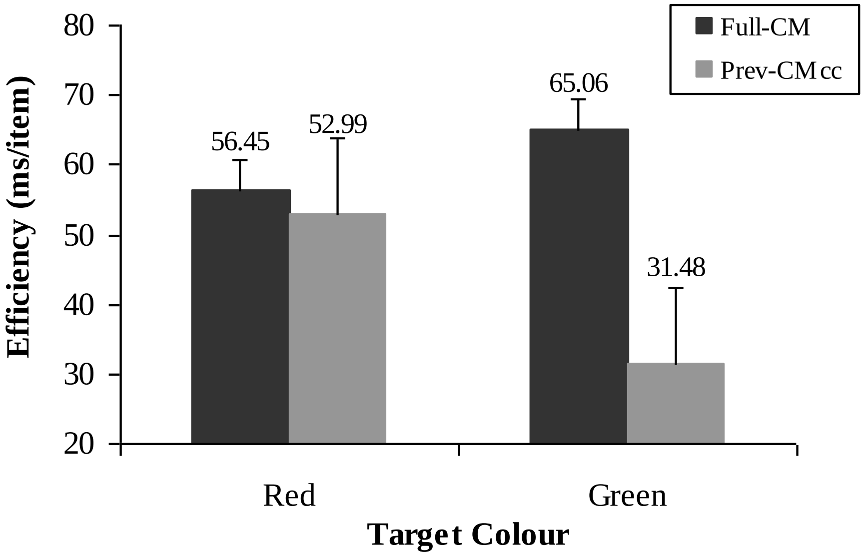

Figure 3.7. Mean search efficiency (ms/item) in the FullCM & PrevCM$_{cc}$ conditions, across Target Colour. Error bars represent standard error.

Random Motion Search

The two random dynamic conditions (FullRM & PrevRM$_{cc}$) conditions were then compared in a 2 × 2 (Condition × Target Colour) ANOVA. There was no main effect of Condition, F(1,14)=.02, p=.89, no main effect of Target Colour, F(1,23)=.64, p=.43, and no Condition × Target Colour interaction, F(1,23)=.39, p=.54. Both red and green target search efficiency was equivalent in both conditions (see Figure 3.8).

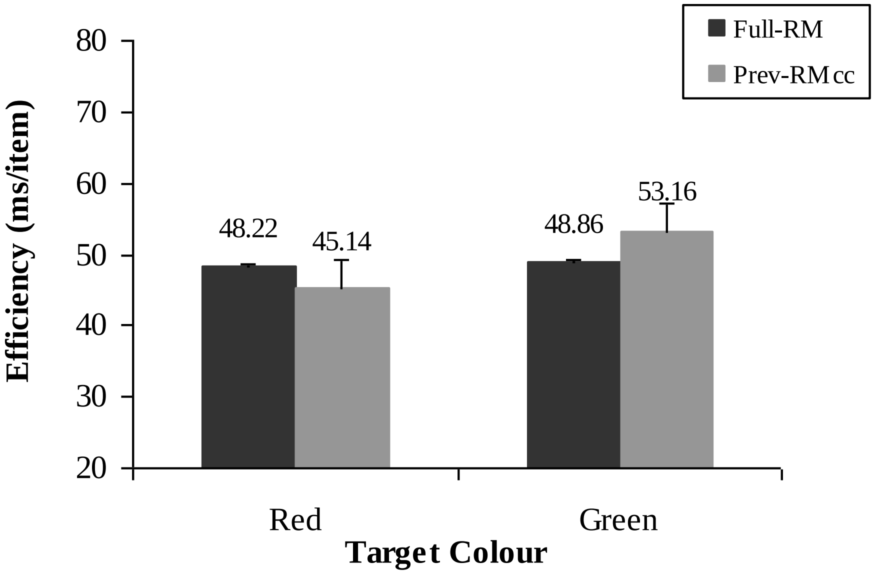

Figure 3.8. Mean search efficiency (ms/item) in the FullRM & PrevRM$_{cc}$ conditions, across Target Colour. Error bars represent standard error.

Errors

The overall error rates were low at 3.4%. Errors were entered into a 2 × 2 × 2 (Motion × Condition × Target Colour) ANOVA, revealing a main effect of Display Size, F(1,24)=5.85, p<.05, and a Motion x Target Colour interaction, F(1,24)=7.19, p<.05. Like the RT data, errors increased with display size, and there were increased effects of Target Colour in common motion search compared to random motion search. There were no other main effects or interactions, (all F's<2.65, all P's>1.12) and errors were not analysed further.

Discussion

Experiment 2 produced a number of notable findings. Firstly, under both conditions of motion, the selective cost for new carry-over targets was diminished when colour was shared for just 100ms. In contrast to Experiment 1, search for new red targets was equivalent in the preview condition and the full-set baseline, and this was true for both common-motion and random-motion conditions. Thus, the cost for new targets shared the preview colour was abolished in the present experiment. This result is consistent with the view that 100ms is insufficient time period to allow for top-down inhibition to build up to an optimal level and have maximal impact on new carry-over targets.

Secondly, although the colour change removed the preview cost for carry-over targets in both common and random motion search, this colour change did not have the same effect on search for non carry-over targets under both motion conditions. For the common motion displays, the preview benefit for non carry-over targets (green targets) was maintained across the colour change manipulation. How can I explain this selective preview advantage seen for green targets in common-motion search but not random motion search? One possibility is that under common motion conditions, the old items can still be coded in terms of their configural processes, where their relative spatial layout is maintained even when the items move. In these conditions, the preview display may appear to the visual system to denote an object surface through which suppression can be applied. This configural processing may be feature-blind and is not concerned with the featural properties available within the display. As a consequence, colour changes present in the display would have a minimal impact on performance. This is consistent with the view that aspects of the marking mechanism may also be able to operate at an object-level (Watson, 2001; Watson et al., 2003).

In contrast to the findings from common motion, performance for non carry-over targets in random motion preview search was disrupted by the colour change. Here there was no preview benefit to search efficiency, suggesting the old items were not effectively filtered and continued to compete for selection. When stable location, feature, and configuration information is not available to the inhibitory system, both the negative costs and positive benefits are abolished and red and green targets continue to compete for selection in a manner similar to that in the full-set baseline. These findings for random motion also provide further support for the view that, in common motion, the configuration of the preview items may well be contributing in a small way to mediate preview benefits. However, such information is simply not available and unable to contribute to search in the random motion condition. As a consequence, the improvements to search efficiency seen for non carry-over targets when configuration is maintained suggest that such factors are able to assist in the de-prioritisation of irrelevant items.

The converging findings from Experiment 1 and 2 are consistent with the view that feature-based inhibition plays an important role in mediating both positive and negative effects on preview search performance. In addition, the present findings show that negative carry-over effects can and do occur under dynamic search conditions and become increasing magnified as the contribution of other visual information is reduced. This implies a flexible inhibitory system mediating attentional selection over space and time. Low-level grouping processes, though obviously present, appear to have a minimal impact on performance and cannot explain the magnitude of the effects reported in Experiment 1. Instead, I suggest that the present findings are consistent with the view that top-down inhibitory biases are directed towards filtering the activations associated with irrelevant information – and this can impact on the selection of future information.

The remaining benefit to non carry-over targets in the common motion condition is also intriguing. As noted above, this might be explained by the configural properties of the irrelevant items acting to form an object-based or surface type representation to which inhibition can be applied (Jiang et al., 2002; Kunar, Humphreys, Smith & Hulleman, 2003; Watson 2001). However, what is not currently very clear in the present context is whether configural properties alone are capable of supporting inhibitory filtering and benefitting search efficiency or whether feature-based differences are also assisting in this process. It could be that as all the old items had one homogeneous colour (blue) this may itself aid configural processing and both mechanisms may contribute to setting up an object-based representation of the preview items. Even though the preview items change colour, the 900ms presence of the blue items may be sufficient to help establish and strengthen configural processing.

The previous literature provides mixed evidence on this issue. Olivers et al., (1999) questioned the extent to which filtering via configuration alone allowed old items to be de-prioritised from attention under common motion conditions. They employed a similar scrolling motion pattern to that I used in the present study, to show that no preview benefit occurred when all items were presented achromatically with no colour differences between preview and search displays. Taken together with the present findings, this suggests that, while configural information may *contribute* to an inhibitory filtering system, it is not sufficient for filtering the old items (perhaps due to the disruption caused when items reach the bottom of the screen and scroll off). However, Watson (2001) did provide evidence that visual marking can be applied to achromatic items, improving search efficiency, providing the preview and search displays maintain separate and stable configurations. However, none of these studies investigated situations where colour was shared across displays or employed conditions of random-motion.

To address these issues in the present content I carried out Experiment 3, in which performance for achromatic stimuli (all grey) under common motion and random motion conditions was examined. If feature-based inhibition helps to guide the inhibition to process configural properties and help establish an object-based representation for de-prioritization, then removing such feature differences from the displays should remove the preview benefit to search. In contrast, if the configural properties available in common-motion displays are sufficient on their own, then we would expect to see a benefit to search efficiency here for the common but not the random motion preview conditions with achromatic stimuli. In addition, if there is an increased reliance on colour-based inhibition when items move at random, then the disruption from removing such cues would be expected to be greater under random motion search compared with common motion search.

Experiment 3.3 – Configural Processing with Achromatic Stimuli.

The common dynamic and random dynamic search conditions of Experiment 1 were replicated except that now all stimuli were presented achromatically (all grey).

Method

Participants

18 students from the University of Birmingham took part for course credits. They were aged between 18 and 24, with an average age of 19.8 years.

Design & Procedure

A 2 × 2 × 2 (Motion × Condition × Display Size) within-subjects design was employed. There were 2 common motion conditions, and two random motion conditions. For each of these there was a preview condition (PrevCM-Grey & PrevRM-Grey) and a full-set baseline condition (FullCM-Grey & FullRM-Grey). The conditions were identical to the conditions of Experiment 1 except that all items from both the preview display and the search display, including the target, were the same shade of grey. The remaining method matched that of Experiment 1.

Results

RT data was cleaned for errors and outliers (+/- 2.5 *SD's* from the mean), before search efficiency data was calculated (ms/item). Mean efficiencies were then entered into an overall 2

× 2 (Motion × Condition) ANOVA, revealing only a main effect of Motion, F(1,17)=5.70, p<.05. There was no main effect of Condition, F(1,17)=1.99, p=.18, and no Motion × Condition interaction, F(1,17)=3.07, p=.10. Overall, random motion search was less efficient than common motion search, see Figure 3.9. Analysis was first broken down across condition then motion. A set of paired t-tests revealed no difference between the FullCM-Grey & PrevCM-Grey conditions, t(17)=.89, p=.39. However, there a tendency for search to be impaired in the PrevRM-Grey condition compared with the FullRM-Grey, t(17)=1.89, p=.07. There was no difference between the two baseline conditions (FullCM-Grey & FullRM-Grey), T(17)=.47, P=.64. However, preview search was significantly impaired in random motion search compared with common motion search, t(17)=2.59, p≤.01.

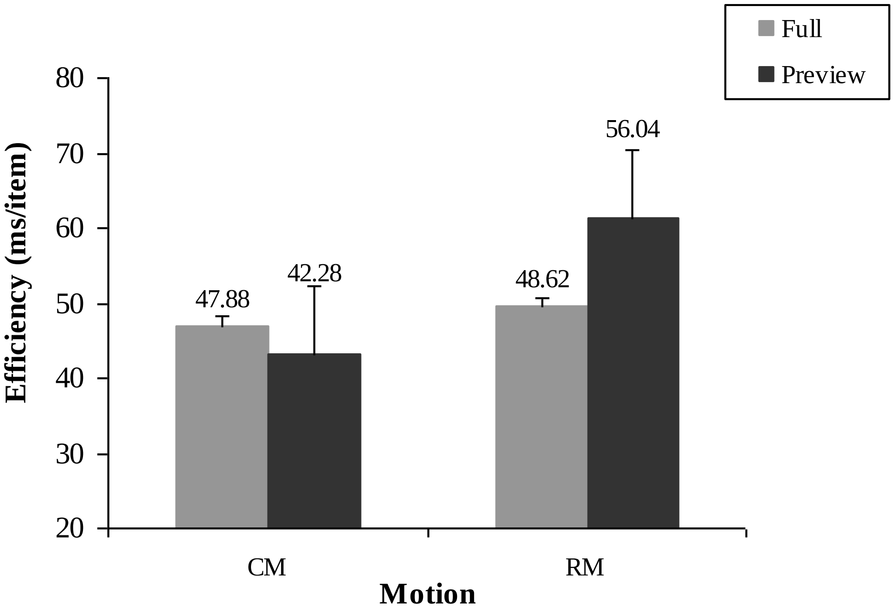

Figure 3.9. Mean search efficiency (ms/item) across Motion and Condition. Error bars represent standard error.

Error data

The mean error rate was low, at 2.04% across participants. The errors were entered into a 2 × 2 (Motion × Condition) ANOVA. There were no main effects or interactions found, (all P’s>.94 F’s<.3.1). There was no evidence of a speed-accuracy trade off’s and errors were not analysed further

Discussion

Removing the featural differences between preview and search displays had an impact on performance in both the common and random motion conditions. For both types of moving displays, the preview benefit to search efficiency was eliminated. The lack of any benefit to search efficiency seen for the common-motion preview condition supports the findings of Olivers et al (1999) in suggesting that configuration-based filtering is not sufficient, on its own, to mediate inhibition within these displays. This contrasts to the findings obtained by Watson (2001) who *did* find a preview benefit under achromatic common motion conditions, suggesting that configural processing was sufficient for the old items to be inhibited. I suggest this difference is likely to be due to the type of motion used. Watson (2001) used a rotating motion pattern, where items remained on the screen, and the configuration remained stable for the entire trial. However, in the vertical scrolling displays, although configuration remains stable for a period of time, it is altered as items filter off the bottom of the screen and then reappear at the top. The current findings suggest that, under common motion conditions where the configuration experiences changes, additional colour-based inhibition is crucial for suppression to survive these alterations to the configuration.

The results also suggest that removing colour differences causes more disruption to random motion preview search, than in common motion preview search. For the common motion displays, preview and baseline search was equivalent. However, for random motion displays there was a tendency for preview search to be *less* efficient than baseline search. Furthermore, random motion preview search was significantly less efficient that common motion preview search suggesting that preview search with achromatic stimuli was particular difficult when items moved at random compared with when items moved together.

Collectively the results from Experiment 3 are consistent with the view that under common-motion conditions, featural differences between the displays are important in helping to establish an object-based or surface-type representation of the old items to which inhibition can be applied. Configural processing on its own was not sufficient – at least with the current displays. In addition to this, the fact that the old preview items remain effectively filtered from search, even when the old items change colour (Experiment 2), implies that colour may be important for establishing a stable representation of the old items, but may not be crucial for the maintenance of it (Watson & Humphreys, 2002). The present findings also confirm the observation that feature-based guidance is particularly important in dynamic preview search when display items move in random unpredictable directions. This condition suffered the most from not having any featural difference between the displays and not having any configural processing to aid segmentation either.

Finally, the presence of the overall RT benefit for preview search performance under situations of common-motion may reflect contributions from (i) onset capture mechanisms (ii) temporal segmentation processes and some (iii) configural processing – all of which may combine to make a more salient contribution to guidance in common motion than random motion conditions. However, none of these factors was sufficient to produce reliable benefits to search efficiency in the common-motion condition.

The present findings are consistent with the view that irrelevant items can be filtered from search by the goal-directed inhibition of the featural properties of the old items and that such processes can operate in both static and dynamic search conditions. However, one remaining alternative suggestion is worth considering. One counter-argument might be that rather than the carry-over target being impaired due to the negative effects of active inhibition spreading from the preview to the new target item, perhaps observers are setting themselves to prioritise new non carry-over items instead. By this account, observers may be searching green items before moving on to search the red item. This might also produce a pattern of performance where RTs for red items are elevated and less efficient relative to the green items which may enjoy a degree of positive feature-based prioritisation.

There are some findings which speak against this type of account. For example, it is not clear why an irrelevant colour change to the old items (Experiment 2) would disrupt the active prioritisation of the new colour. In addition, there is no top-down reason or benefit to be had by adopting (as a default strategy) an attentional-set to prioritise green items. The target can be red or green equally often and as such, prioritising green items would only produce an advantage for half of the trials. Furthermore, the carry-over target is a singleton in terms of the second search display – which should receive considerable bottom-up prioritisation relative to a whole group of green items (Theeuwes, 1992, 1994). Previous research has shown that (i) for static items search can be further improved for non carry-over targets by providing observers with explicit valid foreknowledge of the targets colour, and (ii) implicit prioritisation strategies are not reliably influenced by the presence of biases in the frequency of different target colours (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003). However, these factors have never previously been explored with dynamic preview search stimuli. Irrespective of these reservations Experiment 4 provided a direct assessment of a colour-based prioritisation account of the carry-over effect with dynamic stimuli.

Experiment 4 – Target Colour Foreknowledge

Experiment 4 compared common and random dynamic preview search under two conditions – the standard ambiguous preview condition in which the target could be red or green equally often, with a new condition in which the target was known to always be green. If, under the more typical conditions explored previously, participants are engaged in an inhibitory strategy directed towards filtering the featural properties of the old / irrelevant items rather than directing a facilitatory strategy towards the new colour, then I would expect a reliable benefit to emerge when observers are explicit told to attentionally prioritize green items. In contrast, no benefit to search would be expected if such a strategy were already the default position of the observer.

Method

Participants:

Sixteen participants took part for course credits. All were undergraduate students from the University of Birmingham, aged between 18 and 21, with an average age of 18.9 years.

Design & Procedure:

The experiment employed a 2 × 2 × 2 × 2 (Motion × Condition × Display Size × Target Colour) within-subjects design. There were 2 random dynamic preview conditions (PrevRM & $\text{PrevRM}_{\text{Gtrgt}}$), and common dynamic preview conditions (PrevCM & $\text{PrevCM}_{\text{Gtrgt}}$). The PrevRM & PrevCM conditions were the same as the previous experiments - the preview display consisted of red distractors, and the search display consisted of green distractors and the target (which could be either red or green equally often). The $\text{PrevRM}_{\text{Gtrgt}}$ & $\text{PrevCM}_{\text{Gtrgt}}$ conditions were identical to these except that now the target was always a green item and observers were explicitly instructed to prioritise these green items. Note – as with previous experiments, a red singleton distractor was present in the search display when the target was green. The remaining method matched the previous experiments.

Results

Red target responses were removed from analysis, as the experiment was interested in the effects of target foreknowledge on green target search. RT's for green targets in the PrevCM & PrevRM were entered into a 2 × 2 (Motion × Condition) ANOVA. There was a main effect of Condition, F(1,15)=5.84, $p<.05$, but no main effect of Motion, F(1,15)=.01, p=.97, and no Motion × Condition interaction, F(1,15)=.51, p=.49. Green targets were located more efficiently when the target was known to be green in colour, than when it could be red or green equally, and this was equivalent for common motion and random motion displays, (see Figures 3.10).

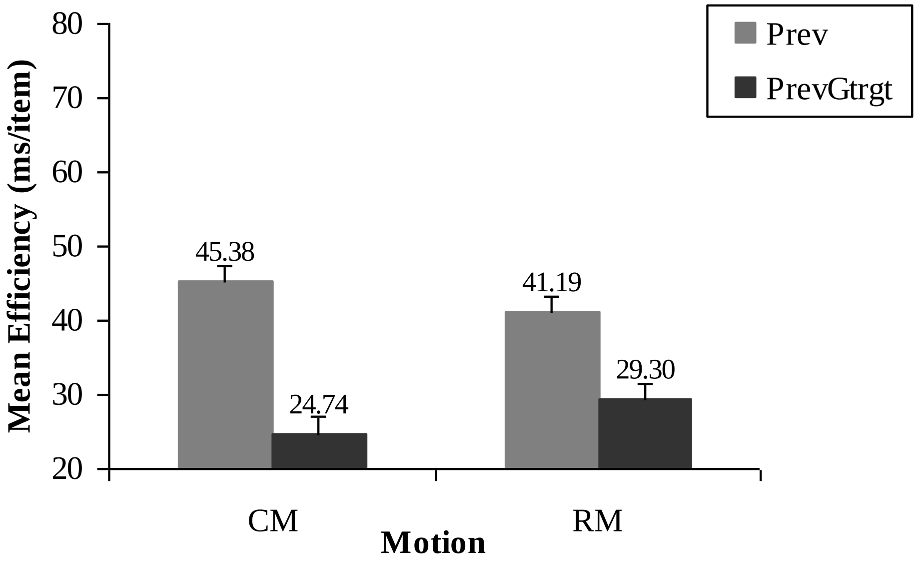

Figure 3.10. Mean search efficiency (ms/item) for green targets across motion and condition. Error bars represent standard error.

Errors

Mean error rates were 2.85% of responses being incorrect. Errors were entered into a 2 × 2 × 2 (Motion × Condition × Display Size) ANOVA. There was only a main effect of Display Size found, F(1,15)=13.60, p<.01, (all other F's<1.3, all other P's>1.27). There was no evidence of a speed accuracy trade-off. Therefore, errors were not analysed further.

Discussion

Search performance was reliably improved when observers were given explicit target colour foreknowledge suggesting that participants did not automatically default to search the green set of items under more typical conditions employed across previous experiments in the present study. If this strategy were employed, then the prioritisation of green should not be improved by target colour foreknowledge. These finding are consistent with the view that the selective cost for carry-over red targets cannot be accounted for by the colour-based prioritisation of the opposite colour (green). Instead, the results suggest that the negative effect for carry-over targets reflects an active top-down deprioritisation of the featural-properties of the irrelevant items.

General Discussion

The present study examined preview search for three types of visual displays. Items either remained stationary throughout the entire trial (static search), moved continuously downwards in a uniform manner, or items moved in different, randomly generated and continuously changing directions. I found that for all types of displays search was significantly benefited by presenting half of the distractors 1000ms earlier than the remaining items. However, the results also reveal that the selective attentional cost experienced by new items sharing the colour of the earlier set of items becomes considerable increased as location-based guidance becomes less reliable. These diverging colour-based cost effects lead us to suggest that different inhibitory components contribute to new item prioritisation under these different types of visual conditions. I will first discuss the beneficial effects of preview inhibition found for the different displays before discussing the diverging negative carry-over effects found for static, uniformly moving and randomly moving displays.

Preview Benefits for Non Carry-over Targets

Consistent with previous research I found significant benefits to search efficiency when observers were given a preview of the irrelevant distractors first (Watson & Humphreys, 1997; 1998; 2000; Watson et al., 2003). However, this benefit was only observed for new targets that did not carry the featural attributes of the irrelevant preview items. In Experiment 1, the advantage to search efficiency was matched across static, common-motion and random-motion displays. All situations benefitted to a roughly equal degree (though there was a small trend for efficiency to become reduced as the displays moved towards the more complex random-motion displays). I suggest that this reflects a possible floor effect for non carry-over targets, where, in all circumstances, featural differences can mediate optimal benefits to search efficiency.

Interestingly, when the preview items changed colour 100ms before the arrival of the new items (Experiment 2) – there was still a benefit to search efficiency for non carry-over targets (i.e., new green targets) in the common-motion but not the random motion condition. This is a new and noteworthy finding. To account for this I suggest that that the processing of the configural properties of the preview items, which is possible under common but not random-motion conditions, is also contributing to the preview benefit, at least to some degree.

The configural properties present in the common-motion condition may act as a salient object-based cue – where the preview items may be represented as an object surface scrolling down the screen. Once a stable representation of the preview items is established, inhibitory filtering can then be applied to this object-level representation. One possibility is that the features of the irrelevant preview items may be inconsequential for this process. By this account, configural information per se is sufficient to generate and sustain a negative bias against irrelevant information. Indeed, previous research suggests that in certain situations, configuration-based coding is indeed sufficient for old items to be inhibited, without any additional feature-based guidance. For example Watson (2001) found that, with rotating displays in which items remained present on the screen for the entire trial, a preview benefit was found for achromatic stimuli. Similarly, Kunar et al (2003) found that, when preview items were removed and replaced in new locations, but maintaining an identical configuration, a preview benefit was found for achromatic stimuli.

However, in contrast with the current conditions, these studies used configurations that remained stable throughout the entire trial. In the current common motion conditions however, the display may be grouped and encoded as one single object via its configuration. But this configuration experiences changes as elements of this object (i.e. individual items) become temporarily occluded. There are a number of findings to suggest that, under these conditions, more representative of motion in real world vision, configuration cannot operate alone. Firstly, if this were the case then a carry-over may not be expected to occur at all, as configural processing is feature-blind and if such processes were singularly capable of mediating optimal search benefits, then this would off-set the contribution of featural (i.e., colour) processes. At the very least the magnitude of the carry-over would not be expected to increase in common-motion relative to static conditions. In addition, if configural properties were sufficient to mediate search improvements than with achromatic stimuli, a preview benefit would be found under achromatic search conditions. However, both the current study and previous research shows this is not the case (Olivers et al., 1999).

Therefore, my findings here suggest that the configural properties of the preview items can contribute to preview benefits, but that featural properties may be important for helping to establish the ‘object-hood’ of the preview items (in conjunction with configuration). Once such a stable representation is in place, the colour of the old items can then change, but as long as the configural properties of the preview items remain – then irrelevant items continue to be effectively filtered from selection. Similarly, the colour-based component enables inhibition to survive alterations to the configuration of the display, as items become briefly occluded and reappear in new positions.

A combined role for configuration and colour in common motion search can explain (i) why non carry-over targets are advantaged in terms of search efficiency relative to the same targets in random-motion conditions; and (ii) why configuration alone does not produce search benefits under achromatic conditions. As a consequence, these findings considerably extend those of previous studies that have failed to reveal or be sensitive to how configural processing could contribute under more ecologically valid dynamic search conditions.

Preview Costs for Carry-over Targets

Search efficiency was significantly impaired for targets which carried the colour of the irrelevant preview items – a finding consistent with previous research on static items (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2004, 2007; Olivers & Humphreys, 2003). However, the present study not only extends these findings into the dynamic domain but also shows, for the first time, that the magnitude of the carry-over is significantly impaired in random-motion relative to both static and common-motion displays.

As the contribution of other forms of visual information are reduced or abolished (i.e., stable location-based information / configural information) the weighting placed on featural processing increased. As a consequence, the impact of the carry-over to new important information vastly increased resulting in a large attentional-blindness to new target information.

These findings are consistent not only with the proposal that there is feature-based inhibition of the irrelevant items under preview conditions, but also with this inhibition being mediated in a flexible manner, so that the inhibitory weight applied to distractor features can vary with how critical they are for segmenting relevant from irrelevant stimuli. The more the attentional system relies on using features to track and filter the old items, the larger the impact on selection of the new items. I suggest that, with random-motion dynamic displays, colour is perhaps the main (if not only) attribute available to filter the irrelevant items and as such is assigned a high weight in mediating distractor suppression (because it is difficult to inhibit the locations of moving items, or group them into an object-based representation, cf. Watson & Humphreys, 1998).

The increased magnitude of the carry-over seen for random motion relative to common-motion and static displays cannot be explained merely by the increased role of low-level perceptual grouping mechanisms. One counter argument explored in Experiment 2 was that perhaps, as more grouping cues were available in dynamic displays (i.e., motion itself) then these were contributing to the increased effect seen for carry-over targets. By this account, perhaps the new items merely ‘sink’ into their background more effectively under dynamic conditions relative to static conditions. In Experiment 2 I had the preview items adopt the critical carry-over colour (i.e., red) only for the last 100ms of the preview duration. If the increased effects seen for the carry-over were due to the top-down, goal-directed inhibition of the featural attributes of the irrelevant items – then 100ms would be insufficient for this process to become optimal (see Braithwaite et al., 2003, 2007, 2010a, for evidence of the temporal constraints of inhibitory filtering by features). However, 100ms is more than sufficient for fast acting low-level perceptual processes to impact on performance and when the target item arrives – it is presented against a background of same-coloured preview items. As such, grouping should be more than capable of impacting on performance here just as with the more typical case. The findings from Experiment 2 clearly show that the carry-over is severely modulated when the preview items adopt the critical colour only for the last 100ms of the preview duration. As such, low-level passive perceptual grouping mechanisms, though present, cannot explain the increased magnitude of the carry-over effects seen in the random motion condition. Instead, it is suggested that the present findings are more consistent with an active inhibitory account of the featural properties of the irrelevant items.

In line with my previous investigations (Andrews et al., submitted, Chapter 2), the present study goes beyond prior experiments which have shown only that colour is important for generating a preview benefit with moving items (Watson & Humphreys, 1998; Watson, 2001) and that configural processing is not sufficient for de-prioritization of the old items (Olivers et al., 1999). The differential effect of colour carry-over with random-motion relative to common-motion and static displays implies that both colour and configuration may play a more important role in more ecologically valid situations.

Flexible Inhibition in Preview Search

The present findings are consistent with, and considerably extend the notion of a flexible inhibitory mechanism mediating selection over space and time for static information (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003; 2005; 2007). Collectively the present findings suggest that in addition to location-based inhibition for static items and contributions from configural processing in some dynamic circumstances, all types of search revealed that the inhibition of the preview items can be based on their featural properties (i.e., their colour). Such feature-based inhibition may occur in a number of ways. In line with previous research it is suggested that this may operate via the direct inhibition of a colour-map activated by items in the preview (Treisman & Sato, 1990; Treisman, 1993, 1999). In a revised Feature-Integration Theory, Treisman and Sato (1990) argued that visual search could operate efficiently if participants could directly inhibit a whole ‘feature-map’ that was activated selectively by distractors. Here all activations coded within a particular feature dimension (like a specific colour) could be attenuated. Such a process would be computationally useful, since it would facilitate the filtering of the preview items en-masse and produce a global attenuation of activations associated with multiple distractors. Under most circumstances such filtering processes would increase the efficiency of selection in a limited capacity attentional system. However, one negative consequence of such a mechanism would be a cost for new information if it carries the critical feature attribute of the irrelevant items currently being ignored. This is because activation associated with the new items would be coded in a feature-map already in a state of active de-prioritization. Direct feature-map inhibition has been prescribed as a potential mechanism for impairments in selection seen under static preview search conditions

(Braithwaite & Humphreys, 2003; Braithwaite et al., 2003) and for mediating search benefits in some common motion dynamic search conditions (Olivers et al., 1999; Watson & Humphreys, 1998). However, the present study provides the first evidence not only that such a mechanism can be extended to random dynamic circumstances but that the weighting ascribed to inhibiting the feature-map can vary in a flexible manner dependent to some degree on the statistical and dynamic properties available in the visual field. As the dynamic properties in the present investigation approached those available in more ecologically valid circumstances, the impact on selection increased. As a consequence, new and important information (i.e., the relevant target information) carrying the suppressed colour were difficult to detect, leading to impaired attentional selection and significantly increased degrees of attentional-blindness for those items. As a consequence these findings dovetail nicely with previous inhibitory accounts of preview search and are difficult to accommodate with the notion that preview benefits are solely mediated by (i) the onset capture of the new items or (ii) grouping by temporal asynchrony. Neither account predicts either the benefits seen for new non carry-over targets or the costs seen for carry-over targets as neither account prescribes a role for colour or the attentional—bias against featural attributes.

A Role for Object-based Inhibition?

Recent findings from Multiple Object Tracking (MOT) strongly implicate an inhibitory component in the tracking of moving items, (Doran & Hoffman, 2010; Pylyshyn, 2004, 2006; Pylyshyn et al., 2008). Pylyshyn (2006) carried out an MOT study, incorporating a probe detection task. Displays of 8 identical white disks moved randomly around the display, and a subset of 4 items (the ‘target set’) had to be kept track of throughout the trial. On half of the trials a luminance probe-dot was briefly presented for 128ms somewhere on the display. Results showed that this probe was much less likely to be noticed when it fell on one of the 4 distractor items than when it fell on empty background space. In this task all items were identical and moved in a random and unpredictable manner. Therefore, no location-based or feature-based inhibition of the distractor items was possible suggesting that the cost for probes resulted from individual object-based inhibition of the distractor items. The notion of distractor suppression in MOT has also gained neurological support, where ERP responses to the luminance probes are attenuated when falling on a distractor item compared with a target item or background space, (Doran & Hoffman, 2010; but see also Drew, McCollough, Horowitz & Vogel, 2009).

These findings suggest that individual object-based tracking and suppression may be involved in the current random dynamic search conditions. However, these previous studies have used displays with a maximum of 8 items in total, (4 items to be tracked and 4 items to be ignored). This is comparable to the current displays at the smallest display size, where there are 4 preview items and 4 search items. Therefore it is feasible to suggest that each individual preview item may be tracked and inhibited via an individual object-based representation, as a form of inhibitory tagging, while the 4 new items are searched. However, at the larger displays there are 16 items in total, stretching well beyond the capacities of MOT, (Pylyshyn & Storm, 1988; Yantis, 1992). Although more recent evidence suggests the MOT capacity can be increased above 4 when items move slowly (Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009), item speed must be reduced to around 0.5-1°/second for capacity to increase above 4-5, whereas a speed of 4.9°/second was used in the current study. In addition, although MOT is improved when items are constrained by hemifield compared with when items appear within the same visual field, successfully tracking has still only been demonstrated for a maximum of 4 items (2 appearing within each visual field: Alvarez & Cavanagh, 2005), making it difficult to extend these findings to the current displays, where up to 8 items must be ignored, while another 8 are searched.

Furthermore, Experiment 3 clearly shows that object-based inhibition is not sufficient for new items to be prioritised over old under the current dynamic search conditions – a colour difference between old and new items is essential. In addition, object-based inhibition cannot explain the colour-based carry-over effect. Both of these findings strongly implicate a role for colour-based inhibition. Therefore, it is suggested that additional object-based inhibition may contribute in filtering at the smaller display size, which may reduce the reliance on colour inhibition and moderate the carry-over effect. However, as display size is increased to 16 items, object-based inhibition would not be possible, and as a result the carry-over of feature inhibition becomes greatly magnified. Supporting this notion are the results from achromatic random dynamic search (Experiment 3). At the small display size, there is a tendency for search to be faster in the preview condition compared to the baseline condition. However, at the larger display size this effect is abolished, consistent with the notion that object-based inhibition may allow up to 4 randomly moving items to be filtered from search.

Wider Implications: A Functional Account for Instances of Sustained Inattentional-Blindness?

The present study extends the existence of negative carry-over effects into random-motion situations – thus increasing the ecological validity of these effects into real world vision. In addition, the fact that the impairments seen for search efficiency are magnified considerably the more that the displays become more representative of perception in the real world; also have implications for models of selection and failures of awareness.

For example, studies employing a selective looking paradigm have produced striking failures of awareness – when observers are set against attending to one set of stimuli and directed towards prioritizing another (Most & Astur, 2007; Most et al, 2001, 2005; Simons & Chabris, 1999). This has also been shown under both naturalistic visual conditions employing real-world visual stimuli (Most & Astur, 2007; Simons & Chabris, 1999) and more controlled conditions (Most et al, 2001, 2005). Importantly, these failures of awareness, termed instances of *'sustained inattentional-blindness',* tend to occur when the unexpected event shares featural attributes with irrelevant information currently being ignored in the primary task. This bears a likeness with our previous (Andrews et al., submitted) and the present findings, in that targets which shared featural attributes with the old irrelevant items were significantly impaired at being selected. As a consequence of this similarity, perhaps the present findings and the proposed functional accounts here have implications for wider findings in the field of attentional-blindness research.

The phenomenon of attentional-blindness is well known in academic and public circles. The demonstrations are striking and persuasive. However, the demonstrations of the effects do not seem to be accompanied by equally explicit or detailed functional accounts for how or why such instances occur. There is no currently accepted dominant theory for these effects from the studies that have employed the selective-looking paradigm. This is in stark contrast to the functional accounts proposed for mediating the varieties of preview-benefits which include mechanisms for location-based inhibition of static items (Watson & Humphreys, 1997; 2000; Watson et al., 2003); for the feature-based inhibition of static items (Braithwaite & Humphreys, 2003; 2007; Braithwaite et al., 2003; 2010a, 2010b); for the existence of dual positive expectancy attentional-sets directed toward new information and negative inhibitory-sets directed towards filtering irrelevant information and the co-existence of both location and feature-based inhibitory effects within the same manipulations (see Braithwaite & Humphreys, 2003; 2005; 2007; Braithwaite et al., 2003; 2010b) and for the flexible involvement of different inhibitory codes (Braithwaite et al., 2010b; and the present findings here).

Demonstrating the existence of carry-over effects in dynamic motion situations significantly increases the similarities between the present findings and those reported from selective-looking paradigms which typically employ randomly moving naturalistic stimuli even more so than our previous investigations: Andrews et al., (submitted). These additional similarities further imply that a common mechanism may underlie both the *impairments* to selection reported in the present study and complete *failures* in selection report from other paradigms. Both paradigms require (i) observers to prioritise a relevant group of stimuli whilst ignoring and de-prioritising another group of stimuli; (ii) time for the effects to accrue; (iii) are influenced by the goal-directed attentional-set of the observer, and (iv) are highly influenced by the featural similarities between the groups of (Braithwaite & Humphreys, 2007; Braithwaite et al, 2005; 2007; Most & Astur, 2007; Most et al, 2001; Simons & Chabris, 1999).

The present study demonstrates that, in preview search, feature-based inhibition can and does occur with dynamic arrays containing random-motion displays and that the magnitude of the negative carry-over is significantly increased relative to other common-motion conditions and static items. I speculate that, in both instances, performance may be influenced by feature-based inhibition of stimuli that are being ignored (at least to some degree). Therefore the present study not only provides evidence of feature-based inhibition under dynamic conditions more representative of real world cognition, but also highlights the link between these feature-based inhibitory effects of attention, and failures of awareness in inattentional-blindness research (Most et al., 2001, 2007; Simons & Chabris, 1999). In addition, I have shown here significant and incremental increases in the magnitude of the negative carry-over effects as a function of the information available to the inhibitory mechanism with which to successfully inhibit the irrelevant items.

The similarities between preview effects and inattentional blindness lead me to suggest that they may share overlapping mechanisms. As such, the properties and characteristics that have thus far been revealed in preview search studies ought to apply and predict performance in selective-looking conditions (and vice versa) – a useful guide for future research. More generally, my findings place colour-based inhibitory guidance in a more central role of awareness and attention in the real world than previous investigations have suggested. This colour-based mechanism not only serves to enhance the attentional status of new, over old, visual information, but is also implicated as a critical contributor to cognitive impairments, in the form of sustained blindness for unexpected events, and severely impaired detection of anticipated information.

CHAPTER 4

RE-EXAMINING THE CAPACTIY CONSTRAINTS OF NEGATIVE PRIMING: NEW IMPLICATIONS FROM STUDIES OF PREVIEW-BASED VISUAL SEARCH

Synopsis

Previous research has shown that negative priming is limited to conditions of visual selection where the target must be selected from just two stimuli, and is abolished at display sizes in excess of this (Neumann & DeShepper, 1992). However, these previous studies have confounded the number of distractors with the number of distractor types (i.e., exemplars). I address this confound and reveal that negative priming effects can extend far beyond these previous estimates of capacity, under conditions where multiple distractor items can be grouped via a common feature (i.e., colour). Furthermore, the effects can even occur when the task requires active visual search through a heterogeneous letter display. These new observations suggest there may be some overlap between the enduring inhibitory processes underlying negative priming and the feature-based cost effects observed in preview search, (Braithwaite et al., 2003).

Introduction

The Negative Priming Paradigm (Tipper, 1985; also see Fox, 1995; May et al., 1995; Tipper, 2001, for reviews) investigates selection across time, and demonstrates that what we have recently ignored can have a considerable negative effect on later selection. Negative priming (NP) experiments involve presentation of two displays, a *prime* display followed by a *probe* display, and for each display participants must respond to the target item and ignore the distractor item. These studies have found that, when the probe target is the same as, or shares characteristics with the preceding prime distractor, such as spatial location (Tipper et al., 1990), shape (DeShepper & Treisman, 1996), colour (Tipper et al., 1994), size, (Tipper et al., 1995), semantic meaning (Lowe, 1979; Neill, 1977; Tipper & Driver, 1988), or semantic category (Allport et al., 1985; Tipper, 1985), probe responses are slowed, compared with when the probe target is a completely new and unrelated item. This effect, termed the 'Negative Priming Effect' is proposed to reflect an inhibitory process of selection, where the target is selected, in part, by inhibiting the distractor stimulus, (Allport et al., 1985; Houghton & Tipper, 1994; Houghton et al., 1996; Neill, 1977).

More recently, Houghton & Tipper (1994) have put forward a computational 2-stage model of selective attention. Under this account, all visual input is first activated in parallel. These initial activations are then compared to an internal target-template, and the activations that do not match the target features receive inhibitory feedback and are suppression. For example, if observers are set to respond to the red item within each display, then any non-red activation will be inhibited. Following this inhibition, the stimulus left with the highest degree of activation (i.e. the stimulus with the closest match to the target-template) gains access to the response mechanism.

This inhibitory mechanism is proposed to be reactive (Houghton & Tipper, 1994), in that the degree of inhibition applied to an irrelevant distracting stimulus depends on the level of initial activation – a higher activation requiring a greater degree of inhibition in order to eliminate this from selection. Inhibition is also proposed to be selective in nature (Milliken, Tipper & Weaver, 1994; Tipper et al., 1994), in that only the response related information is inhibited. For example, Tipper et al (1994) found that, in a spatial discrimination task, responses were slowed when the probe target fell in the same *location* as the prime distractor, but not when the target held the same letter identity as the prime distractor, (appearing in a new location). In contrast, when the task switched to target letter identification, they found a negative priming effect for repeated letter identities but not repeated spatial locations, (see Milliken et al., 1994, for similar findings).

To explain these differences, Tipper et al (1994) suggest that, while a distractor stimulus is represented on multiple levels, only those representations specifically competing for a response are suppressed, leaving the others in a state of activation. This would explain why repetition of a task relevant component can produce negative priming, whereas repetition of other components of the same stimulus can produce positive priming (Tipper et al., 1994).

Capacity Limits of Negative Priming

Negative priming experiments typically involve selection from just two stimuli, and only a small handful of studies have examined negative priming for displays containing multiple distractors, (Houghton et al., 1996; Neumann et al., 1993; Neumann & DeShepper, 1992). These studies have investigated negative priming effects when new probe targets are presented in the same location as *one* of the preceding prime distractors (Houghton et al., 1996) or hold the same letter identity as *one* of the preceding prime distractors (Neumann & DeShepper, 1992). These studies have shown that negative priming becomes reduced as the number of distractors presented within the display is increased, (Houghton et al., 1996; Neumann et al., 1993; Neumann & DeShepper, 1992), and is completely abolished when as few as just 3 distractors are present, (Neumann & DeShepper, 1992). This has lead to the conclusion that negative priming is limited to selection tasks where just one distractor must be filtered.

The magnitude of the negative priming effect is proposed to be a direct reflection of the level of earlier inhibition applied to that representation. Therefore, the findings above suggest that as the number of distractors within a display is increased, the level of inhibition applied to each distractor representation is reduced. In line with this notion, Neumann & DeShepper (1992) have proposed an Inhibitory Fan Effect, suggesting that inhibition is of limited capacity. Therefore, when there are multiple distractors involved in selection, inhibition must spread over multiple internal representations.

Alternatively, Houghton et al (1996) have taken a different approach. Rather than inhibition being of limited capacity, they propose that less inhibition is *needed* when there are more distractors present. They suggest that when several distractors are presented together, each of these produces a smaller initial activation, compared to the level of activation produced by the appearance of one distractor alone. Inhibition is proposed as reactive (Houghton & Tipper, 1994). Therefore, a smaller activation signal produces a smaller inhibitory rebound, which would account for the smaller cost on later response to this representation. While there is some discrepancy in the literature over whether multiple distractor representations receive less inhibition due to less inhibition being available, or less inhibition being needed, these accounts are both in agreement that, with more distractors present during selection, the level of inhibition applied to each distractor representation is reduced. This results in a smaller cost for later responses to one of these previously inhibited representations.

The demonstration that negative priming is strictly limited to conditions of selection involving just two stimuli has isolated these effects from the processes involved in other, more complex conditions of selection such as visual search. In particular, preview search studies show similar inhibitory carry-over effects, where responses are impaired when the target shares features with an old irrelevant set of items, (Braithwaite et al., 2003, 2004, 2007). Like negative priming, these preview cost effects are also proposed to reflect the carry-over of distractor inhibition. However, preview-search displays far exceed the capacities of negative priming, leading to the assumption that carry-over effects in the negative priming paradigm and preview search reflect separate processes.

In addition, the limited conditions in which negative priming can be obtained makes it impossible to extend these effects to real world selection and questions its functional value. In the current study I re-address this capacity limitation, investigating whether the phenomenon could, in fact, be extended to wider selection conditions.

The Present Study

The present study re-examined the arguments for a strong limitation in negative priming and that such capacity limitations mean that such processes are not implicated in mediating preview search benefits, (Olivers et al., 1999 Watson & Humphreys, 1997). The fact that negative priming effects had never been shown for displays containing more than one additional distractor, whereas preview benefits to visual search efficiency had been demonstrated for up to 12 – 15 items strongly undermines the idea that shared representations and / or shared processes are implicated in both effects. However, previous investigations of the capacity limits of negative priming appear to have contained a confound which, if addressed and re-investigated, may reveal significantly elevated estimates of the capacity of negative priming.

The present study questioned the assumption that preview-search and negative priming effects represent completely distinct inhibitory processes based on the argument of different limits in capacity (Braithwaite & Humphreys, Olivers et al., 1999; Watson & Humphreys, 1997). I did this by investigating whether the reported capacity differences may have resulted from paradigmatic differences, rather than different underlying processes. Previous research into the capacity limits of negative priming have been confounded in that they employed displays in which each distractor item held a different letter identity and different colour value to other items (Houghton et al., 1996; Neumann & DeShepper, 1992). As a consequence, the addition of every new distractor was also an addition of a new distractor type. Therefore, it is conceivable that these previous investigations have employed displays in which each separate distractor had to be encoded and inhibited via a separate object-based internal representation (i.e., different exemplars). As such, the limitation may be better and more accurately conceptualised as being mediated by object-based and hence ‘bound’ representations rather than the number of items per-se. This distinction has been ignored in previous investigations of negative priming and in studies of preview search where it has been argued that both mechanisms are largely functionally distinct (due to the apparent differences in capacity).

In the current study I address this confound and re-examine negative priming capacity limits for displays in which distractors share a common feature. This is more representative of conditions of selection and filtering in preview search, providing a more conservative comparison of their capacity differences than that achieved by the research to date.

Overview of the Experiments

I carried out a set of negative priming experiments where the number of items within each display was varied. Trials involved presentation of two displays in succession - a ‘prime’ display followed by a ‘probe’ display, each containing a target letter and a number of distractor letters. The task required a manual key press response corresponding to the identity of the target letter in each display. I examined colour-based negative priming effects by comparing probe responses to control targets (a new letter holding a new colour) with repeated targets, (a new letter sharing the colour of one of the prime distractors in the preceding display), (see Tipper et al., 1994, for a similar colour-based negative priming experiment).

Experiment 1 replicated previous findings by demonstrating that a negative priming effect was limited to displays containing just 1 distractor. When 2 or 3 distractors were present within each display, and the probe target shared the colour of *one* of the prime distractors, no cost of colour sharing was observed. In Experiment 2, all of the distractors within each display were presented in the same colour. Therefore, repeated probe targets now shared the colour of *all* of the preceding prime distractors. Here the negative priming effect was preserved when displays contained up to 3 distractor items, suggesting that multiple distractor items are filtered via their shared feature, which spreads across time to new items also sharing this feature. Experiment 3 tested and rejected a low-level adaption account of these effects. Removing the target (and hence the process of selection) from the prime display removed the negative priming effect for new items sharing the previous distractor colour. This demonstrates that mere perception of the prime colour is not sufficient for new items sharing this colour to suffer a cost. Experiment 4 extended the negative priming effect to displays consisting of up to 7 items, suggesting the effects do not result from individual object-based filtering, but grouping and suppression of distractor items via a shared feature-map representation. Finally, Experiment 5 revealed that negative priming is not limited to the very basic conditions of selection used in the research to date. The phenomenon also occurs when the target is not defined by colour and must be actively searched for within an array of up to 12 items. This suggests that the inhibitory processes underlying the negative priming effect may share some overlap with the inhibitory processes of visual search.

Experiment 4.1 - Establishing the Negative priming Effect

Experiment 1 examined whether the current experimental conditions / stimuli would produce the same capacity restrictions of negative priming as has been reported in previous investigations, (Houghton et al., 1996; Neumann & DeShepper, 1992).

Method

Participants

Eighteen students (4 male) from the University of Birmingham took part for course credits. Students were aged between 19 and 28, with a mean age of 23 years. All self-reported normal, or corrected to normal vision, including normal colour vision.

Stimuli & Apparatus

The experiment was programmed in E-prime, and run on a Pentium PC fitted with a 17inch monitor. The unrestrained viewing distance was 60 cm. Stimuli consisted of a set of uppercase letters written in Arial font, (10mm x 12mm, 0.95 º x 1.15º). The prime distractors were picked randomly without replacement from 6 possible letters (D, E, G, H, S, B), and the probe distractors were picked from another set of possible letters (K, O, R, U, C, J). The prime target letter was a Z or an X, and the probe target letter was an N or an M (fully randomised within blocks and across Condition and Display Size).

The stimuli were presented on a plain black background, and the colours of the letter stimuli were chosen randomly without replacement, from a set of eight possible colours (Blue, Red, Yellow, Purple, Green, Grey, Orange & Pink). The distractor letters, both within and between the displays, never shared the same colour

In each display, a cluster of 2, 3 or 4 stimuli were presented in one of the four quadrants of the display, presented at a visual angle of 2.86º x 2.86º from the centre. The quadrant in which the prime display appeared was chosen randomly for each trial, and the probe display was presented in one of the remaining 3 quadrants at random. The distracter letters overlapped the corner of the target letter by 5mm x 5mm (0.48º x 0.48º). When there was just one distractor present, this always overlapped the top left corner of the target. When there were two distractors, they overlapped the top left corner and the bottom right corner. When there were three distractors, they overlapped the top left, the bottom right and the bottom left corner of the target. A fixed configuration for each display size was used to minimise any differences between the difficulty levels of each display size. See Figure 4.1 for an illustration of the displays used in Experiment 1.

Design & Procedure:

A 2 × 3 (Condition × Display Size) within-subjects design was used. There were two conditions, the Repeated condition and the Control condition. These were identical except that on repeated trials, the probe target was presented in the same colour as one of the prime distractors, whereas on control trials the probe target was presented in a new colour. The displays consisted of the target letter, and 1, 2 or 3 distractor letters. Condition and display size were randomised within experimental blocks.

Participants first completed a practice block of 36 trials containing both repeated and control trial types. However, they were not told that the probe target would sometimes carry the same colour as a prime distractor.

Each trial began with the presentation of a central fixation cross for 1000ms. Following this, the prime display was presented and participants were required to respond to prime target by pressing either ‘X’ or ‘Z’ accordingly, using the left index and middle finger, and this response cleared the display. Following an SOA of 500ms, the probe display was presented and participants responded to the probe target by pressing either ‘N’ or ‘M’ with the right hand. Again, the response cleared the display for an ISI of 1000ms before the next trial was initiated. Participants were instructed to respond as accurately as possible.

At the end of the experiment, participants were asked if they had noticed any relationship between the two displays within each trial. Those that responded ‘yes’ they were asked to specify as to what they had noticed. Participants that accurately reported the colour repetition between prime distractors and probe targets were removed from analysis. Each participant completed 4 experimental blocks, each consisting of 108 trials. There were a total of 72 trials per Condition × Display Size. A 5 minute break was imposed between each block. The entire experiment lasted approximately 50 minutes.

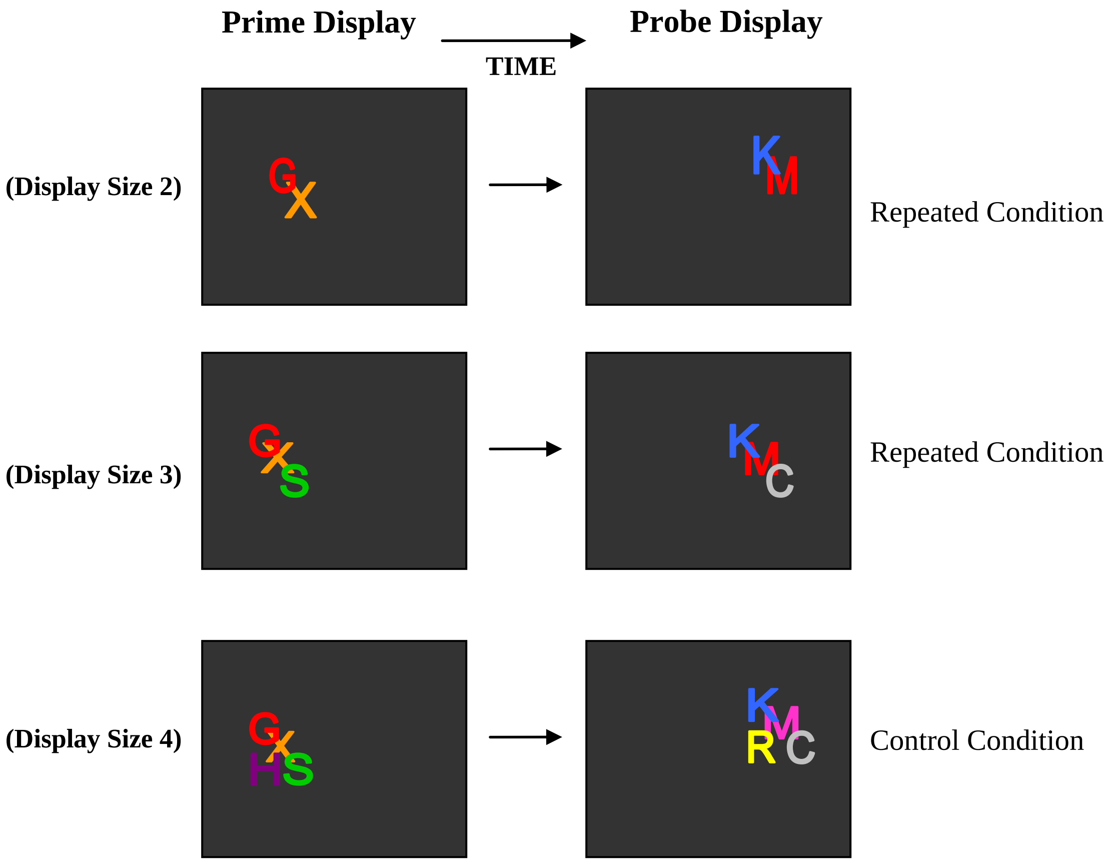

Figure 4.1. An illustration of the displays used in Experiment 1. Displays consisted of a target letter and 1, 2 or 3 distractor letters. The prime target was an X or a Z. The probe target was an N or an M. All distractors were different letters, presented in different colours (both within and across prime & probe displays). In the Repeated condition, the probe target was the same colour as one of the prime distractors. In the Control condition, the probe target was a new colour, not present within the preceding prime display.

Results

Two participants reported the colour repetition and were removed from analysis[2]. For the remaining 16 participants, trials which contained an error in response to either the prime or probe display or an outlier (+/- 2.5*SD's* from the mean) were removed from the analysis. The remaining analysis was carried out on the mean correct reaction times (RTs).

Mean RTs for probe responses were entered into a 2-way (Condition × Display Size), within-subjects ANOVA. There was a significant main effect of Condition, F(1,15)=6.85, p<.02, and Display Size, F(2,30)=65.88, p<.01, and a significant Condition × Display Size interaction, F(2,30)=3.22, p<.05. The cost for repeated targets relative to control targets decreased with Display Size, see Figure 4.2.

A set of paired t-tests carried out at each display size revealed that, when there was just one distractor present, responses were significantly slowed in the Repeated condition compared to the Control condition, t(15)=3.37, p<.01. However, when there were two or three distractors present, there was no difference between the two conditions, (t(15)=.30, p=.77 and t(15)=.24, p=.82,respectively), see Figure 4.2.

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[2] Negative priming studies typically remove participants that notice a repetition between the prime distractor and the probe target, as these participants tend to show a facilitation effect as opposed to an inhibitory effect. A brief analysis of these participants excluded in the current study reveal the same trend.

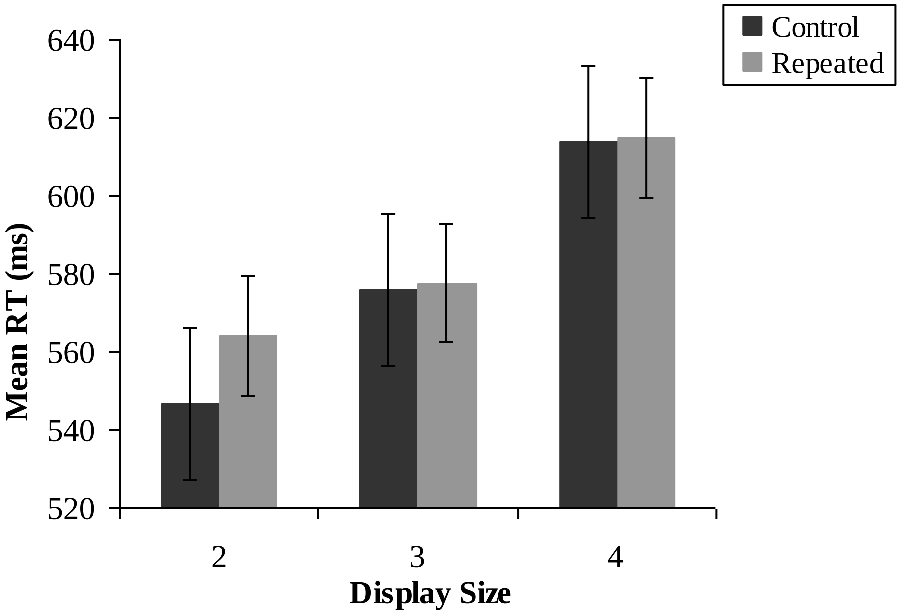

Figure 4.2. Mean Probe RT's in Experiment 1, across Condition & Display Size, (error bars = 1SE).

Errors

The overall error rate averaged across participants was low at 5.42%. The percentage of trials in which an error was made in response to the probe display averaged at 3.26%. Probe errors[3] were entered into a 2 × 3 (Condition × Display Size) ANOVA. There were no main effects or interactions found, (all F's<.72, all P's>.53.) and errors were not analysed further. Errors generally followed the pattern of RTs but the differences were not significant.

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[3] Error analysis was carried out to confirm no speed-accuracy trade-off occurred in the probe RT data of the main analysis. Therefore, only probe errors were fully analysed.

Discussion

The results from Experiment 1 are clear. Firstly, with just one distractor item I found a significant negative priming effect with the present stimuli and methodology. Probe RTs were slowed when the probe target was presented in the same colour as the preceding prime distractor, compared to when the probe target was presented in a new colour.

However, when there was more than one distractor present within the display, this selective cost for probe targets which carried the colour of one of the prime items, was abolished. Here, the negative-priming effect was removed and search was matched across repeated and control conditions. These results are consistent with previous investigations (Houghton et al., 1996; Neumann & DeShepper, 1992), in suggesting that negative priming is limited to conditions of selection where just one distractor must be filtered from attention. When multiple items must be filtered during selection, the cost on later responses to stimuli sharing features with one of these old ignored items is removed.

In the present study, I show a negative priming effect for new targets sharing the previous distractor colour, suggesting that distractor items are filtered, at least in part, via their colour, and this colour-based suppression endures over time to new items holding this perceptual feature. The diminishing cost as more distractors are added suggests that as the number of distractors is increased, the level of inhibition each of these receives is reduced. This is consistent with the previous suggestion that the carry-over of distractor suppression produces a negative effect on later responses only when selection requires just one distractor to be filtered from selection, (Houghton et al., 1996; Neumann & DeShepper, 1992). However, consistent with previous studies, as more distracters were added here, more distractor exemplars were also added (each had its own colour). As a consequence there is an issue as to whether the capacity is truly limited by the number of items, or the number of item types.

The purpose of Experiment 1 was to (i) establish a negative priming effect with my stimuli and methodology, and (ii) to replicate the effect of abolishing negative priming as the display size increases above one distractor. Having demonstrated that negative priming occurs under the current experimental conditions, and these are subject to the same capacity constraints as that found in previous research, I now examined the functional consequences of removing the confound between number of distracters and distractor types (exemplars). This was done by increasing the display size (as with Experiment 1) but now having a shared feature amongst distractor items in the prime display. Thus, I could increase the number of distracters, but not via increasing the number of completely new exemplars. If the negative priming effect can be maintained with increasing display sizes when probe display items share a common feature, then this would argue against the notion that negative priming is strictly limited to only one distractor. As a consequence, such findings would necessitate a major revision not only in terms of the current functional constraints of negative priming, but also the implications that such processes may have for the wider field of research on selective attention.

Experiment 4.2 - Re-examining the Capacity Limits in Negative Priming: Separating Multiple Distractors from Multiple Distractor Types

Experiment 2 examined negative priming effects when displays contained multiple distractors. However, in contrast to Experiment 1, all distractor letters were now presented in one distractor colour.

Method

Participants:

Twenty-three participants from the University of Birmingham took part for course credits. Ages ranged from 18 to 23, with a mean age of 19.1 years. All reported normal, corrected to normal vision, including normal colour vision.

Stimuli:

The stimuli and displays used were identical to Experiment 1, except that distractor letters within each display were presented in the same colour. Therefore, probe targets could share the colour of *all* of the preceding prime distractors (Repeated condition), or a new colour (Control condition), see Figure 4.3 for an illustration of the displays used. The remaining method section is identical to Experiment 1.

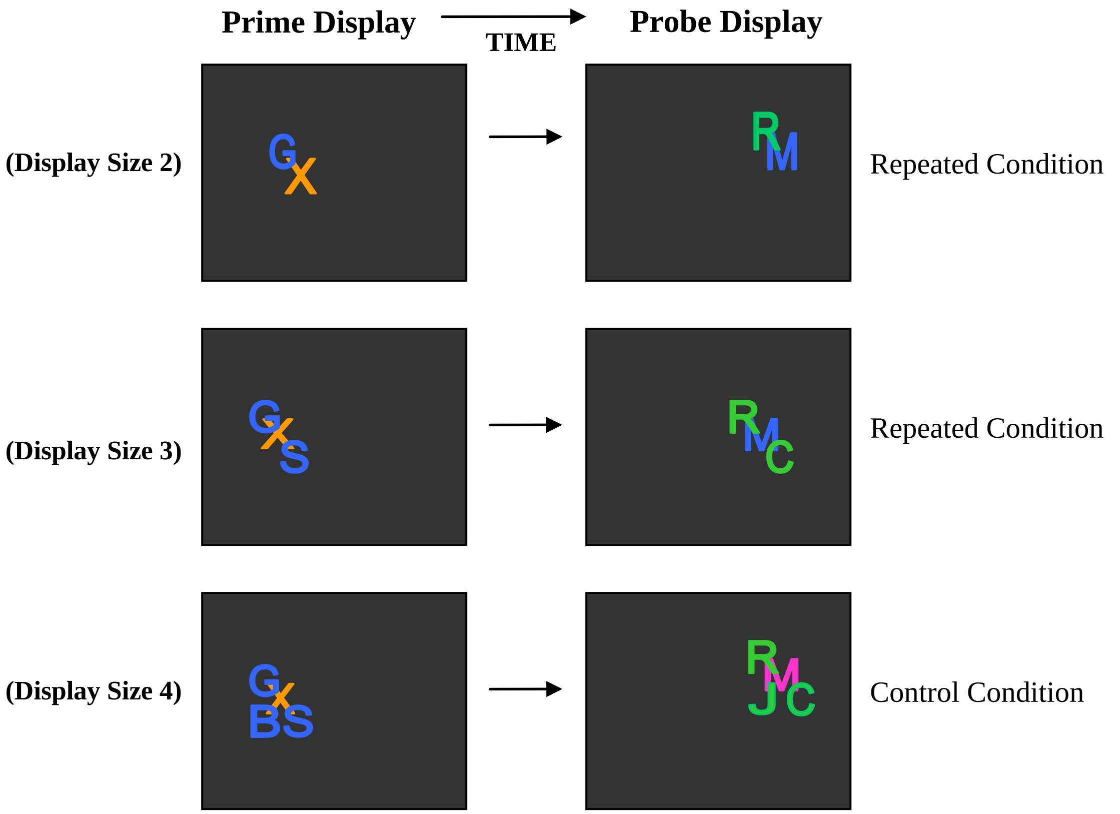

Figure 4.3. An illustration of the displays used in Experiment 2. Each display contained the target letter and 1, 2 or 3 distractors. All distractors within each display were presented in the same colour. In the Repeated condition, the probe target was presented in the same colour as the preceding prime distractors. In the Control condition the probe target was presented in a new colour.

Results

When asked, 6 of the 23 participants reported noticing the colour repetition. These participants were removed from analysis. The data from the remaining 17 participants was cleaned for errors and outliers and entered into a 2 × 3 (Condition × Display Size) ANOVA. There was a main effect of Condition, F(1,16)=23.82, p<.01, and a main effect of Display Size, F(2,32)=22.90, p<.01, but no Condition × Display Size interaction, F(2,32)=.20, p=.82. Overall, responses to repeated targets were slowed compared to control targets, and this effect was not affected by display sizes.

Separate paired t-tests were then carried out at each Display Size. There was a significant cost for repeated targets compared to control targets at all 3 display sizes: Display Size 2: t(16)=2.21, p<.05; Display Size 3: t(16)=5.37, p<.01; Display Size 4: t(16)=4.64, p<.01, see Figure 4.4.

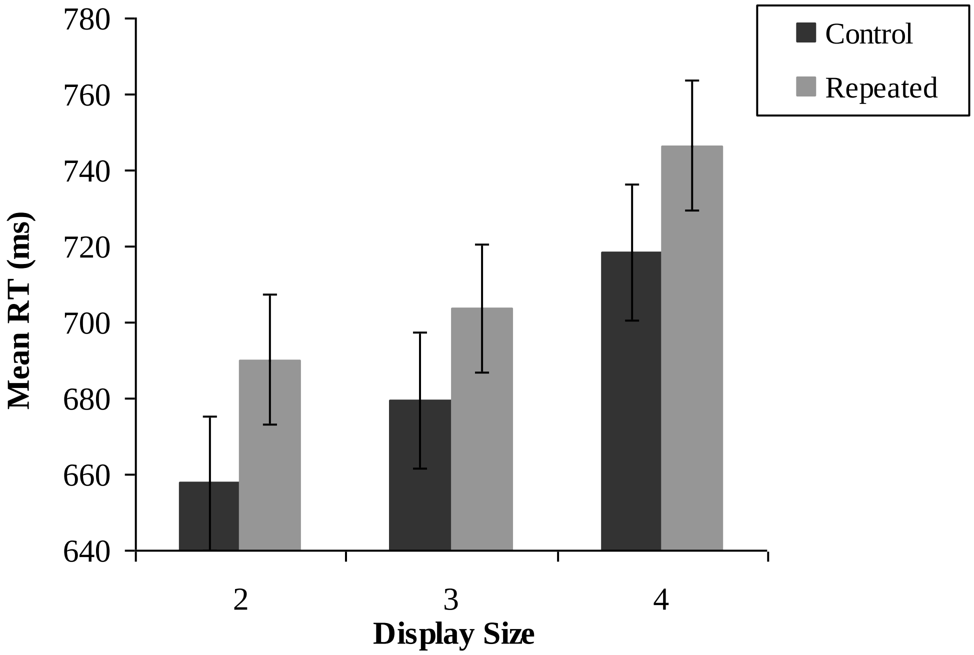

Figure 4.4. Mean RT's for Experiment 2 across Condition & Display Size, (error bars = 1SE).

Errors

Overall error rates were low at 5.55 %, and probe error rate averaged at 3.24%. The probe error count was entered into a 2 × 3 (Condition × Display Size) ANOVA, revealing only a main effect of Condition, F(116)=19.67, p<.01. There was no overall main effect of Display Size, F(2,32)=2.28, p=.12, and no Condition × Display Size interaction, F(2,32)=2.44, p=.10. Overall, errors were increased in the Repeated condition compared with the Control condition, following the same pattern as the RT data. There was no evidence of a speed-accuracy trade-off.

Discussion

For single distractor displays, probe-trial responses were slowed when the target shared the colour of the prime distractors, relative to when the target held a new colour. This replicates the basic negative priming effect (see Experiment 1). However, in contrast to Experiment 1, the negative-priming effect remained across all display size manipulations employed here. The negative priming effect was maintained when both prime and probe selection involved up to 4 distractor items. To the best of my knowledge, this is the first empirical demonstration of negative priming with multiple distractors.

The finding that negative priming can be obtained for more than one distractor item stands in stark contrast to the previous literature on negative priming (Houghton et al., 1996; Neumann & DeShepper, 1992) and other paradigms which have ruled out negative priming as being important on the basis of capacity (cf. Olivers et al., 1999; Watson et al., 2003). Clearly, once the confound between increasing the number of items in the display is separated from increasing the number of exemplar types is addressed, then the effect merged across all display sizes employed. To my mind, the presence of this confound explains why previous investigations have failed to observe effects of negative priming beyond display sizes containing one distractor.

To account for these new findings, I suggest that multiple distractors are filtered by a feature-based (i.e., colour-based) inhibitory mechanism directed towards filtering the activations associated with the items in the prime display. If a degree of this colour-map suppression remained when the following display were presented, it would result in new activations occurring within this colour-map being attenuated, which would explain why later selection for new items holding the old distractor colour is impaired. I will return to discuss the details of this mechanism, and integrate these findings into the wider literature, in the General Discussion

Although the results are consistent with a feature-based inhibitory account there are some alternative possibilities to be explored. For example, one potential counter-explanation is that such effects may instead reflect low-level colour adaption processes that accrue due to the presentation of a homogeneously coloured prime display. Goolsby et al (2005) demonstrated a reduction in the salience of a colour singleton when it shared the colour of a set of distractors presented in a preceding display. This effect was found when the initial distractor display was presented for as little as 27ms implicating a very fast-acting, low-level perceptual mechanism. Goolsby et al (2005) termed this cost effect the *colour-salience after-effect*, suggesting that neural adaption to the perceived colour within the first display lowers the signal produced by new activations occurring within this colour-map. Rather than the current proposal that the distractor colour is actively inhibited during selection of a target, colour adaption is an automatic perceptual process, occurring for any perceived colour, regardless of whether the stimuli are involved in selection or not, (Goolsby et al., 2005).

Although the methodologies are different between the present study and those of Goolsby et al (2005) there is sufficient similarity to support the contention that the effects seen in Experiment 2 are merely low-level effects and do not represent the top-down inhibition of featural values. It is possible that neural adaption to the majority colour perceived in the prime display reduces the activation of new singletons when they hold this colour, compared with when they hold a new colour that has not been recently perceived.

In Experiment 3 the role of low-level neural adaption was tested by removing the process of active selection from the prime display. The colour-salience after-effect occurs when the initial colour is merely presented and perceived, - no selection or response is required or necessary (Goolsby et al., 2005). In contrast, the attentional-demanding processes underlying the filtering of negative priming are only recruited when the task involves the selection of a target and the filtering of irrelevant distractors, (Allport et al., 1985; Guy et al., 2004; Lowe et al., 1979; Neill et al., 1990; Tipper et al., 1990; Tipper & Cranston, 1985). Therefore, the very process of the need for selection induces the effects seen on same-coloured probe targets. However, if the effect for multiple distractors seen in Experiment 2 is due to perceptual adaptation, then when the prime display contains no target, and is passively viewed, the negative priming effect for larger display sizes should remain. In contrast, if the effects are based in an attentional-filtering process then the effects should be attenuated or abolished is the need for selection is removed (cf. Guy et al., 2004). Therefore, if the present colour effects reflect perceptual colour adaption they will remain present in Experiment 3. However, if the effects reflect the carry-over of the inhibitory component of selection they will no longer be found when prime selection is removed from the task.

Experiment 4.3 – Colour-based Inhibition or Low-level Colour Adaption?

The displays used in Experiment 3 were identical to those used in Experiment 2, except that the prime display never contained a target. The prime display was now presented briefly for 300ms, during which participants were required to passively view this display and simply wait for the probe display to be presented before making a response. Note, by current estimates, 300ms is more than sufficient for such perceptual adaptation to occur (see Goolsby et al., 2005; Theeuwes & Lucassen, 1993)

Method

Participants

18 students from the University took part for course credits, (1 male). Ages ranged from 18 to 38, with a mean age of 22 years. All reported normal, or corrected to normal vision, including colour vision.

Stimuli

The prime display now consisted of just one, two or three distractor letters. As with Experiment 2, all distractors within each display were presented in the same colour, and the probe target either shared the preceding prime distractor colour (Repeated condition) or held a new colour (Control condition), see Figure 4.5 for an example of the displays used.

Design & Procedure

The design and procedure were identical to the previous experiments except that participants were now only required to respond to the probe display. The prime display was presented for 300ms, and participants were told to remain fixated and ignore this first display as it was irrelevant to the task. Following the ISI of 500ms, the probe display was presented and participants responded to the target (‘N’ or ‘M’) within this second display.

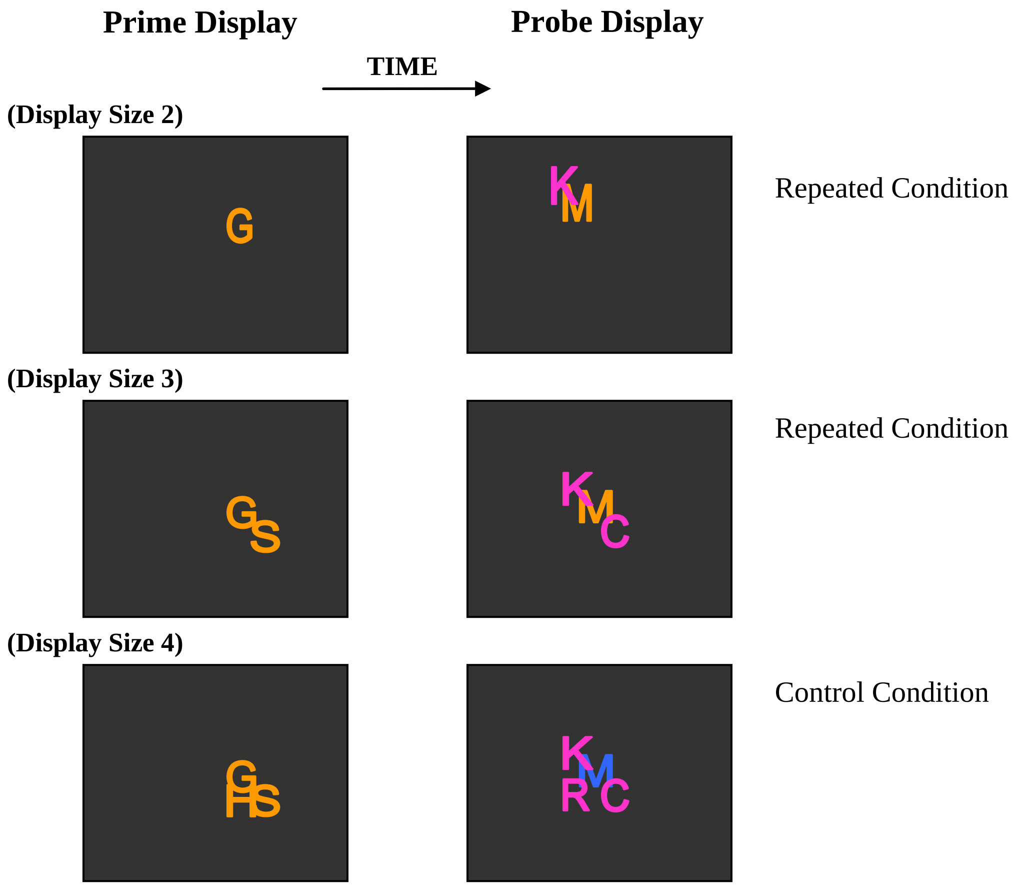

Figure 4.5. An illustration of the displays used in Experiment 3. The prime display was presented for 300ms, containing 1, 2 or 3 distractors. This display never contained a target and never required a response. The probe display contained the target (N or M) and 1, 2 or 3 distractors. Distractors within each display were all presented in the same colour.

Results

Three participants reported the colour repetition and were removed from analysis. The data from the remaining 15 participants were cleaned for errors and outliers (+/- 2.5*SD*'s from the mean), and entered into a 2 × 3 (Condition × Display Size) ANOVA. There was an overall effect of Display Size, F(2,28)=61.91, p<.01, but no effect of Condition, F(1,14)=.03, p=.87, and no Display Size × Condition interaction, F(2,28)=.89, p=.42. There was no difference between repeated and control targets, and this was the case for all 3 display sizes. As Figure 4.6 shows, RTs slowed as display size was increased, but this was equivalent for both the control and repeat conditions. There was no negative priming effect for repeated targets.

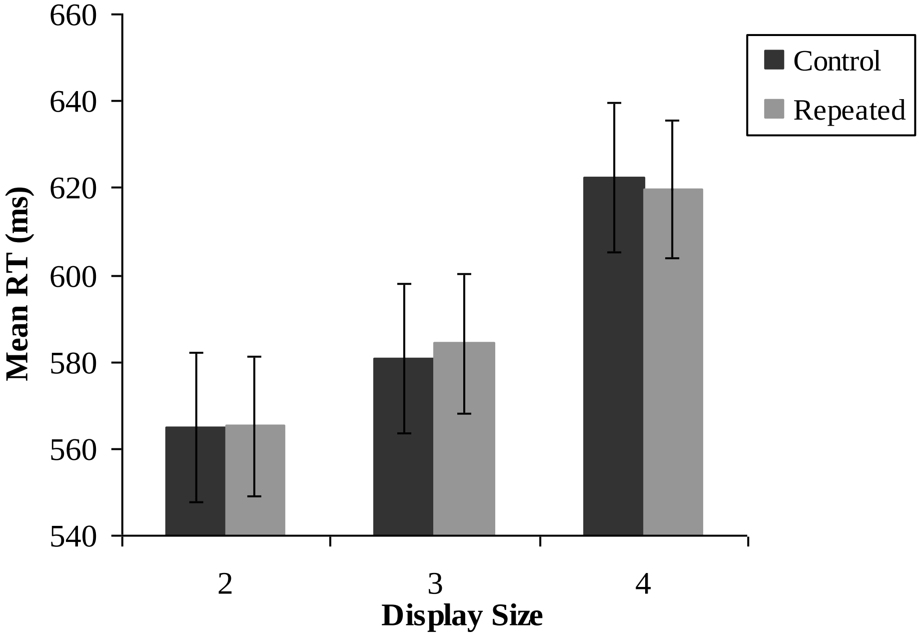

Figure 4.6. Mean RTs for Experiment 3, across Condition & Display Size, (error bars = 1SE).

Error Data

Errors averaged 2.61%. Errors were entered into a 2 × 3 (Condition × Display Size) ANOVA, revealing no main effects or interactions, (all F's<.91, all P'>.34). There was no evidence of a speed accuracy trade-off and errors were not analysed further.

Discussion

Removing the need to select a target from the prime display abolished the negative-priming effect. Probe responses were matched, regardless of whether the probe target shared the prime distractor colour, or held a new colour. Indeed, this was the case across all 3 display sizes. When the task removed the need to select a target and actively filter the distractors from the prime display and they were just passively viewed - negative priming effect was abolished.

This finding is particularly difficult to explain via the notion of low-level, automatic colour-adaptation (Goolsby et al., 2005). By this account, the impact of passively viewing a homogenously coloured prime display should have been more than sufficient for such adaptation to impact on all display sizes. It did not. Under the current experimental conditions any effects of low-level perceptual adaption (which may be present to some degree) cannot explain the effects previously reported. Something additional is required.

Instead the results are consistent with the inhibitory account of the negative-priming effect - where distractors are de-prioritised by effortful inhibitory processes coding featural attributes of competing distractors (Baylis et al., 1997; Houghton & Tipper, 1994; Tipper & Cranston, 1985). This model proposes that negative priming only occurs when in a ‘selection state’ where distractors receive inhibitory filtering when their attributes do not match with the internal target-template. Therefore, when no target-template is set up and no selection is required, there is no need to inhibit the distractor items, and so the carry-over of this inhibition on later responses (the negative priming effect) is no longer observed.

In line with previous investigations (Houghton et al., 1996; Neumann & DeSchepper, 1992) Experiments 1-3 have used displays containing up to 3 distractor items. This is also well within the capacities of visual short-term working memory and is a limit seen across many paradigms aimed at measuring attention and inhibitory filtering (i.e., Multiple Object Tracking, Pylyshyn & Storm, 1988; Inhibition of Return, Snyder & Kingstone, 2000; Onset capture, Yantis & Jones, 1991). However, in the present study, the negative priming effect did not show any reliable deterioration at the largest display size compared with the smallest. This might imply that I have not yet reached the capacity limits of negative-priming. This is an important question not just in terms of assessing the functional constraints of negative priming, but also for integrating the present findings into a wider literature and a more integrative functional framework. Therefore, in Experiment 4 I tested whether negative priming effects would occur in displays containing more than 4 items, and the largest display size was now increased to 7 items (6 distractors and the target). This would indicate whether the capacity of negative priming capacity can stretch beyond the limit of 4-5 items, which many other attentional processes are limited to.

Experiment 4.4 – Does Negative Priming Extend Beyond 3 Items?

In Experiment 4, all distractors within each display shared the same colour, as in Experiment 2. However, now there were double the number of distractors at the largest display size (1, 3 or 6 distractors here instead of 1, 2 or 3 employed previously).

Method

Participants

Twenty-four undergraduates took part for course credits (4 male). Ages raged from 18 to 26, with a mean age of 19.4 years. All reported normal or corrected to normal vision, including normal colour vision.

The remaining method was identical to Experiment 2, except that displays now contained 1, 3 or 6 distractors along with the target. See Figure 4.7 for an example of the displays used.

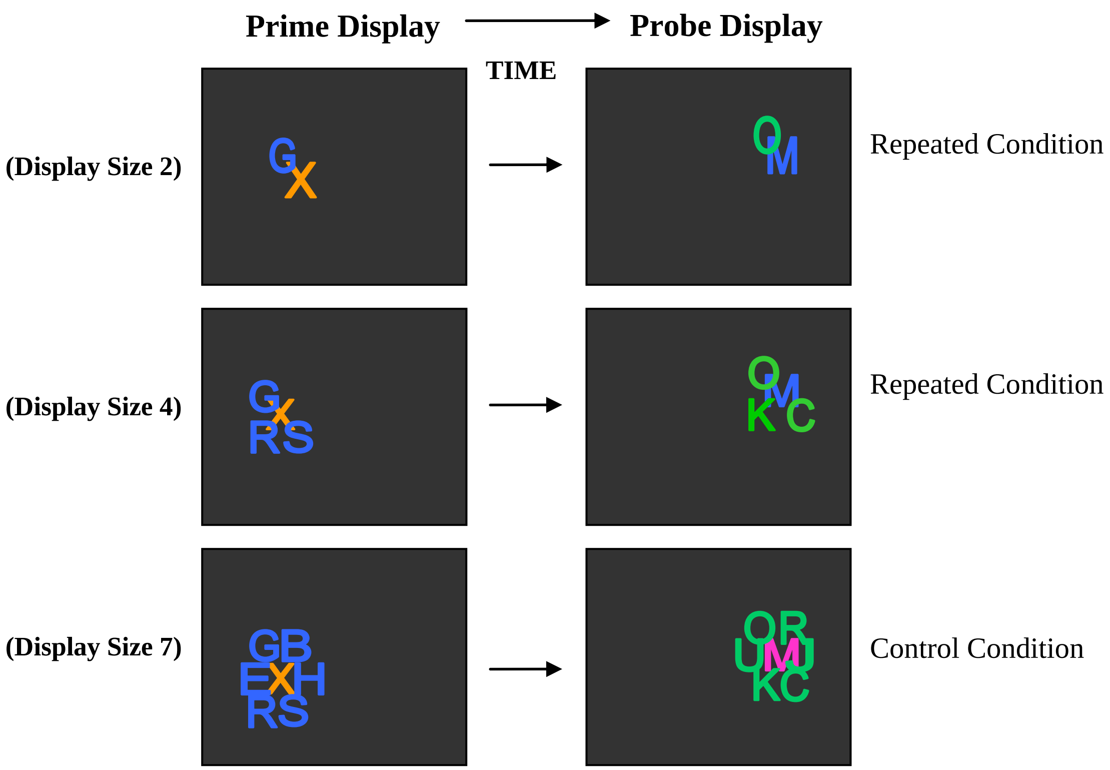

Figure 4.7. An illustration of the displays used in Experiment 4. There were 1, 3 or 6 distractors presented in each display, all sharing the same colour. In the Repeated condition the probe target was presented in the same colour as the preceding prime distractors and in the Control condition the probe target was presented in a new colour, not present within the prime display.

Results

Five participants reported the colour repetition when asked and were subsequently removed from analysis. The data from the remaining 19 participants was first trimmed for errors and outliers (+/- 2.5 *SD's* from the mean) and then entered into a 2 × 3 (Condition × Display Size) ANOVA. There was a main effect of Condition F(1,18)=29.00, p<.01, and a main effect of Display Size, F(2,36)=106.92, p<.01, but no Condition × Display interaction, F(2,36)=.12, p=.88. Overall, probe responses were impaired for repeated targets compared with control targets, and this was unaffected by display size.

Paired t-tests carried out at each display size confirmed that responses were significantly slowed in the Repeated condition compared with the Control condition at all 3 display sizes: Display Size 1, t(18)=2.69, p<.02; Display Size 3, t(18)=2.89, p<.01, Display Size 6, t(18)=2.85, p≤.01, see Figure 4.8.

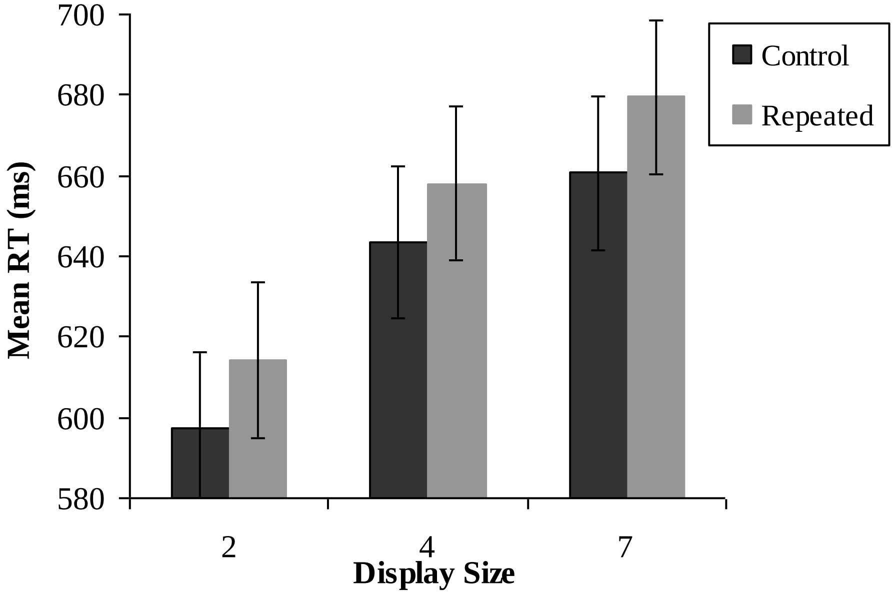

Figure 4.8. Mean probe RT's in Experiment 4, across Condition & Display Size, (error bars = 1SE).

Error data

The percentage of trials in which an error was made in response to either the prime or the probe display averaged across participants 6.65%. In response to probe displays, errors averaged across participants at 4.02%. The probe response error count was entered into a 2 × 3 (Condition × Display Size) ANOVA, revealing only a main effect of Display Size, F(2,36)=7.40, p<.01. Like the RT data, errors increased with Display Size.

Discussion

The present findings show clearly that the negative-priming effect was impacting on performance at all display sizes – including those twice as large as we have seen previously (Experiment 2). Responses to targets in the probe displays which carried the colour of the distractors in the prime display were significantly slowed relative to the control condition where colour was not repeated. Interestingly, in real terms the magnitude of the RT difference between repeat and control conditions was roughly matched across all display sizes (18ms with 1 distractors; 16ms with 3 distractors and 19ms with 6 distractors present). There was no significant Condition x Display size interaction, confirming the view that the cost did not reliably differ across display size. As a consequence, the present findings provide additional evidence that at least part of the inhibitory filtering mechanism underlying negative priming can not only exist above one distractor item, but can occur with display sizes double that employed across previous investigations.- where no effects were reported (Houghton et al., 1996; Neumann & DeShepper, 1992). Collectively, the findings from the present experiments suggest that previous demonstrations of the capacity of negative priming were, at the very least, a severe underestimation.

Extending the negative priming effect to conditions of selection where up to 6 items must be filtered from selection strongly suggests that multiple distractor items are actively filtered via their shared feature – in this case colour (cf. Duncan & Humphreys, 1989; Treisman & Sato, 1990), and it is this feature-map suppression that spreads across time to produce the colour-based negative priming effect. The observation of clear costs at 7 items is also in excess of that seen from other paradigms that show a clear restriction of filtering to around 4 items (the accepted capacity of working memory: Fisher, 1984; Luck & Vogel, 1997). This may well be due to the fact that investigations of, for example, inhibition-of-return and multiple-object tracking typically cast their effects as being mediated at an object-based (often involving some form of binding) level of representation (Muller & Muhlenan, 2000; Pylyhyn & Storm, 1988; Takeda & Yagi, 2000; Tipper et al., 1991). Therefore, while it is possible that whole object-based inhibition can be used to filter up to four separate items, this does not appear to extend beyond these limits (Pylyshyn & Storm, 1988; Snyder & Kingstone, 2000). To account for the increased capacity we have found here, and to reconcile this with the wider literature on inhibitory tracking and filtering, I propose that the colour-based negative priming effect emerges due to the direct inhibition of a feature-map (during the filtering process employed on the prime display) which then carried over and impacts on selection in the probe display. This selective cost then occurs due to an attenuation of new activations which become represented in a system already in a state of de-prioritisation (i.e., an inhibited feature-map).

The current demonstration that NP effects can be obtained under conditions involving multiple distractors highlights a similarity between negative priming and carry-over effects seen in studies of preview-search (Braithwaite & Humphreys, 2003; 2007; Braithwaite et al., 2003; 2005; 2007, 2010a, 2010b). Previously it has been strongly argued that preview benefits, carryover costs and negative priming, are quite distinct mechanisms, a view based largely upon their capacity differences (Braithwaite & Humphreys, 2003; Olivers et al., 1999; Watson & Humphreys, 1999; Watson et al., 2003). However, the present investigation questions the motivation for arguing against negative priming processes providing, at least in part, an explanation for some of the findings from preview search studies.

It is important to point out here that I am not arguing that all effects of preview search and negative priming are based on shared representations or processes. Studies of preview search have demonstrated separate effects of (i) location-based coding (ii) configuration, (iii) group-based representations, and (iv) feature-based coding. The present findings here do not speak to all of these processes. Where perhaps there is scope for overlap is the similarity between the feature-based negative-priming effects shown here for larger display sizes and the negative colour-based carry-over seen in some studies of preview search (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2004, 2007, 2010a; Olivers & Humphreys, 2003).

As noted in the Introduction, preview benefits to search have been seen for displays containing up to 15 old and 15 new items (Theeuwes et al., 1998), and feature-based carry-over effects have been shown typically for up to around 12 items, becoming greatly magnified with increased display size (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003, 2004). In contrast, negative priming has been found to be diminished when displays contain more than one distractor, and is completely abolished with just three distractors present (Houghton et al., 1996; Neumann & DeShepper, 1992). However, these previous investigations of negative priming employed displays in which each separate distractor had to be encoded and inhibited via a separate internal representation (i.e., different exemplars). Here I use displays more akin to those employed in preview search tasks, where irrelevant distractor items can be grouped and inhibited via a shared feature (Braithwaite et al., 2003). This common feature may mean that the inhibitory system can de-prioritise distractor items en-masse on the basis of a shared feature (i.e., colour). As such the need for separate object-based representations (i.e., as each distractor had its own shape and colour combination) for each item now becomes redundant.

In Experiment 5, I attempted to close the paradigmatic gap further between negative priming and inhibitory filtering in preview search. I did this by investigating whether negative priming could be extended to conditions of selection requiring active visual search through the display. The target in both the current and previous negative priming studies appears centrally in the display, heavily flanked by the surrounding distractor items, (Houghton et al., 1996; Neumann& DeShepper, 1992), which is nothing like the situations typical of visual search where the target location is never known and must be located within an array of possible target items before a response can be made.

In addition, although I have demonstrated a colour-based negative priming effect for displays containing up to 7 items, the target has been a colour singleton within the display, whereas preview-based carry-over effects have been shown to occur during inefficient conjunction search. Therefore, Experiment 5 would provide a more direct comparison of the conditions in which negative priming and preview-search carry-over effects occur. If a cost in search for new targets sharing the previous distractor colour emerges under these new conditions, this would blur the distinction between the conditions in which negative priming can be obtained, and the conditions of selection in preview search, which would challenge further the notion that these separate paradigms necessarily recruit separate processes.

Experiment 5 – Negative Priming during Visual Search

I devised a novel visual search task to investigate whether negative-priming inhibitory effects could occur with a display and procedure that was more akin to visual search. This new task borrowed elements of visual search and negative priming procedures. In terms of visual search components, Experiment 5 involved presenting inefficient visual search stimuli items (heterogeneous letters: as opposed to the feature pop-out search used in negative priming) and manipulating display size. In terms of components from negative priming procedures, the displays consisted of two equally sized, partially overlaying sets of items. These items were presented in two colour-groups: a background set (containing the target), and the foreground set (containing irrelevant distractors). In both the prime and probe displays the target had to be located within the background set of items, and in the probe display, the background set could either be presented in a new colour (Control condition) or in the same colour as the preceding prime foreground distractor-set (Repeated condition). The paradigm is depicted in Figure 4.9.

Previous research has posited preview search and negative priming as distinct for several reasons, based largely on their paradigmatic differences. In preview search, a period of time is afforded with which to dedicate attentional resources to inhibiting the irrelevant stimuli. This enables up to 15 items to be inhibited, and to remain inhibited during inefficient visual search through a new set of items. In negative priming, however, distractor suppression occurs during selection of the target. The new paradigm used in Experiment 5 falls somewhere between the two. Consistent with preview search, the selection task requires inefficient search through an array of items, and consistent with negative priming, inhibition of the irrelevant set must occur during selection of the relevant set.

My logic was that, if the costs seen in preview search and negative priming are mediated by a common feature-based inhibitory system, then a task which draws on this system should produce a cost for new targets carrying the colour of the irrelevant distractors. If these new conditions do indeed produce a colour-based cost akin to both negative priming effects and preview-search carry-over effects, this would strongly suggest that these very similar effects, previously demonstrated in very different paradigms may in fact result from a common underlying mechanism that can operate to different degrees under varying conditions of selection.

Method

Participants

Twenty-three undergraduates (4 male) from the University of Birmingham took part for course credits. All reported normal or corrected to normal vision, including colour vision. Ages ranged from 18 to 21, with a mean age of 18.8 years.

Stimuli & Apparatus

The experiment was programmed in E-prime, and run on a Pentium PC. The unrestrained viewing distance was 60 cm. The stimuli consisted of a set of uppercase letters written in Arial font, 6mm in height and 5mm in width, (with a visual angle of 0.57º × 0.48º). In each display there was a background set of items, and a foreground set of items. Each background item was overlapped by a foreground item, by 0.48° × 0.48°, across its top left corner.

The background of the screen was black. The colours of the two sets of items within the prime display were chosen randomly without replacement from a set of eight possible colours (Blue, Red, Yellow, Purple, Green, Grey, Orange, Pink). The colour of the two sets of items within the probe display were then chosen randomly from the remaining 6 colours, except for the repeated condition, where the probe target-set held the same colour as the preceding prime distractor-set. Stimuli appeared randomly in any of 30 possible locations on the screen (with the constraint that the prime and probe stimuli never appeared in the same locations). For the display on any given trial, at each chosen location there was a background and foreground item. The background items were the target carrying display and participants were informed that this was the case. The foreground display items were always irrelevant distractors. The circular presentation window in which the items could fall was 10cm x 10cm, with a visual angle of 9.46° × 9.46°.

As with typical negative priming studies there was a prime display (where the target item was either an ‘X’ or a ‘Z’) which always appeared within the background set of items, and a probe display (where the target item was an ‘N’ or an ‘M’), and always appeared within the background set. For each trial, the distractor letters were chosen randomly without replacement from the remaining 22 letters of the alphabet. See Figure 4.9 for an example of the display used.

Design & Procedure:

A 2 × 3 (Condition × Display Size) within-subjects design was employed. In the Repeated condition, the probe target-set was presented in the same colour as the preceding prime distractor-set. In the Control condition, the probe target-set was presented in a new colour, not present within the prime display. The displays consisted of 2, 6, or 12 letter stimuli (1, 3 or 6 target-set items and 1, 3 or 6 distractor-set items).

Participants were aware that the target would always appear in the background set of items. They were told to search the background-set and ignore the foreground-set in each display. The remaining design and procedure was matched to Experiment 1.

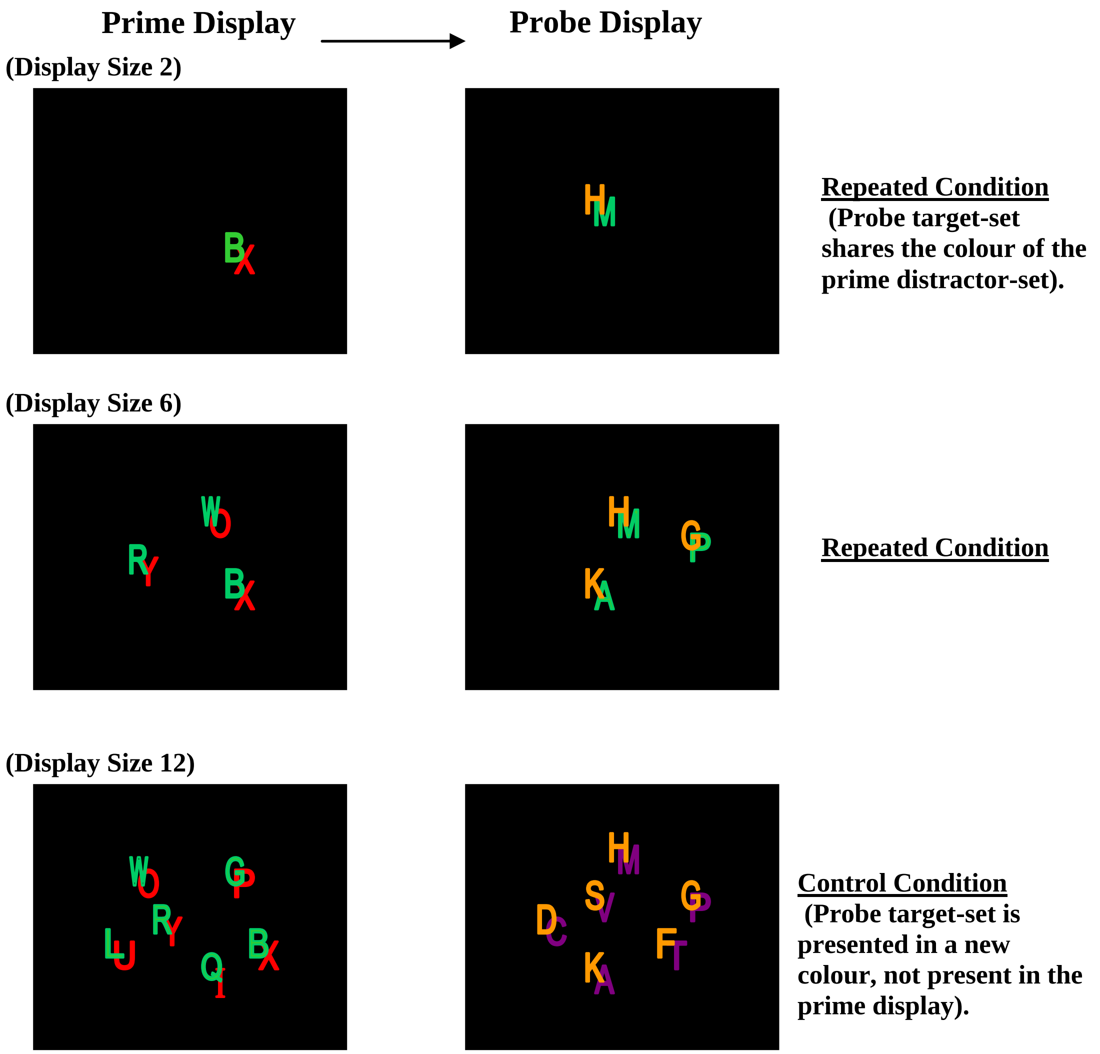

Figure 4.9. An illustration of the displays used in Experiment 5. Each display consisted of a background set of items (the target-set) and a foreground set of items (the distractor-set). The prime target was an ‘X’ or a ‘Z’, and the probe target was an ‘N’ or an ‘M’. In the Repeated condition, the probe target-set was the same colour as the prime distractor-set. In the Control condition, the probe target set held a new colour. The distractor and target sets within each display were always presented in different colours.

Results

When asked, 5 participants reported the colour repetition and these participants were removed from analysis. Errors and outliers (+/- 3 *SD's* from the mean) from the remaining 18 participants were also removed from analysis. When the descriptive RT and error data were first inspected, there was an indication of a slight speed-accuracy trade-off (speed for accuracy). While RT's did indeed increase with Display Size, errors actually became reduced with Display Size (see Figure 4.10 & Table 4.1). To address this I re-analysed the data using a well-established measure of inverse efficiency, in which both accuracy and speed is taken into account. This is done by dividing the mean RT by the proportion of correct responses, (see Townsend & Ashby, 1978, 1983, for detailed discussion on this procedure) which produces a corrected RT often referred to as a combined measure of 'efficiency'[4].

These corrected RTs were analysed in a 2 × 3 (Condition × Display Size) ANOVA which revealed a main effect of Condition, F(1,17)=25.32, p<.001, and Display Size, F(2,34)=184.42, p<.001. RTs for repeated trials were significantly slower relative to those in the control condition and RTs increased with larger display sizes. The Condition × Display Size interaction was also significant, F(2,34)=3.27, p<.05. The cost for repeated targets relative to control targets increased more at the larger display sizes (see Figure 10). Separate paired t-tests confirmed this effect of condition was significant at all 3 display sizes: Display Size 2, t(17)=2.48, p<.03; Display Size 6, t(17)=2.54, p<.03; Display Size 12, t(17)=4.12, p<.01.

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[4] The term 'efficiency' here is unfortunate as this is also used to describe search slopes in studies of visual search performance. Therefore we prefer to refer to the measure as 'corrected RT' which we feel is more transparent and navigates around any potential of equivocation over the term 'efficiency'.

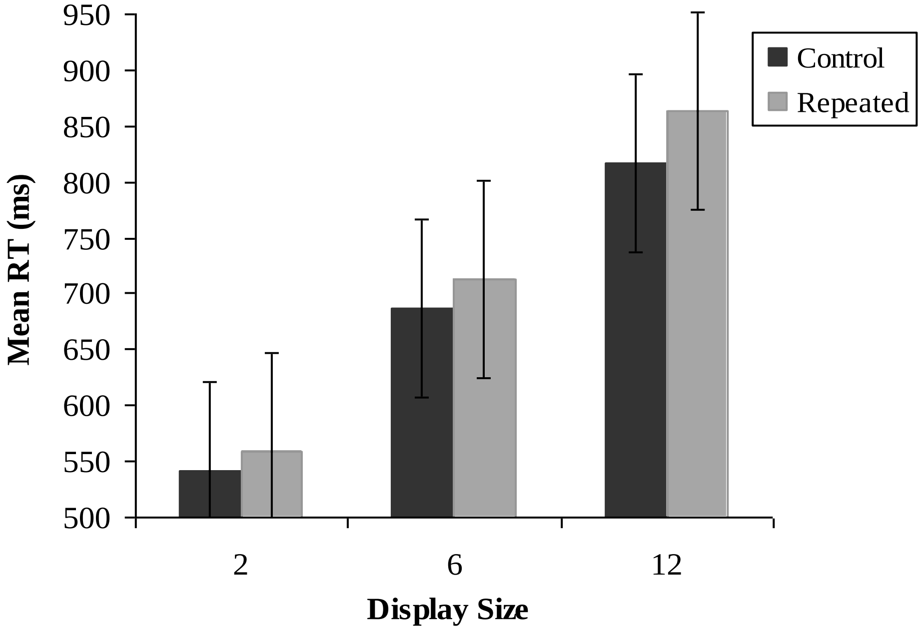

Figure 4.10. Mean probe RTs (corrected) in Experiment 5, across Condition & Display Size, (error bars = 1SE).

Table 4.1. Mean % of probe errors, across Condition & Display Size.

Condition	**Display Size 1**	**Display Size 3**	**Display Size 6**
Control	3.32	3.01	1.69
Repeated	4.32	3.86	2.16

Discussion

Probe responses were significantly slowed when the target-set of items shared the same colour as the preceding distractor-set of items in the prime display (relative to the control condition when colour was not shared across displays). This result is consistent with the view that negative priming effects do extend to these new circumstances of visual search, where the target location is unknown and the observer has to actively search for it. In addition, the present findings also show that such effects are present and clearly impacting on performance at the larger display sizes. Indeed, the reliable Condition × Display size interaction revealed that the effect was increasing as display size increased and as the need to filter irrelevant activations increased.

This pattern may have emerged for a number of reasons. Firstly, it is possible that shared features have a more central role in distractor suppression when the number of distractors stretches beyond the capacity of efficient parallel object-based filtering. This would suggest that when there are just 3 distractors within the irrelevant set items, these may be suppressed via their individual object-based representations as well as their shared feature-map representation. However, when there are 6 items to ignored within the distractor set, inhibition may rely more heavily on their shared representation, enabling these items to be rejected more efficiently than if all 6 items were encoded and inhibited separately.

The increased cost effect with larger displays is also in line with the Houghton & Tipper (1994) reactive inhibition model. They state that the level of inhibition applied to an internal representation (related to distracting information) is directly proportional to the level of initial activation produced by the stimulus. In line with this hypothesis, the onset of six red distractor items would produce a greater level of activation within the red colour map, compared with the onset of just one or three. Therefore, the level of inhibition applied to the red colour-map representation would be increased, accounting for the magnified cost for new targets also appearing within this colour-map. However, regardless of the reason behind the tendency for the colour-based cost effect to become increased with display size, Experiment 5 reveals that a negative priming effect can occur when targets must be located within an array of up to 12 items, and in demonstrating that the cost effect is not limited to the very basic conditions of selection used in the literature to date enables the processes of negative priming to be extended to more realistic visual experience.

The cost for repeated targets in the new context of visual search suggests that guidance *towards* the relevant background target set of items is dependent, at least in part, on feature-based inhibitory filtering directed towards the irrelevant foreground distractor set – guiding search *away* from the distractor set of items. In the same way that the internal representation associated with a single distractor item is inhibited to eliminate it as competition during selection of a target (Houghton & Tipper, 1994), a whole set of irrelevant items may be inhibited via a shared internal representation, reducing the competition produced by these items and improving search through the relevant set of items. This shared feature-map suppression then carries over time to have a detrimental effect on later search when the new relevant set of items holds this inhibited colour. This produces a form of negative priming, where responses are slowed as a result of sharing the feature of previous distractors.

This notion of feature-based inhibition mediating the rejection of multiple distractors via their shared features is in line with attentional models of visual search which posit a role for distractor suppression in target selection (Duncan & Humphreys, 1989; Treisman & Sato, 1990). Performance is greatly improved when distractors can be filtered en-masse from the target item by a common feature, and this is proposed to reflect the spread of suppression throughout the irrelevant feature group. Detailed functional accounts have been proposed for how such inhibition is mediated in both simultaneous visual search presentations (across space: Duncan & Humphreys, 1989; Treisman & Sato, 1990) and over time in studies of carry-over effects in preview search (Braithwaite et al., 2003, 2004, 2007).

The new procedure devised here draws on paradigmatic components of both negative priming and visual search. As a consequence one might argue to what extent the present findings really reflecting negative priming and to what extent are the effects more related to the processes underlying carry-over effects in preview search. This is more of an issue for those accounts which have argued that the processes are distinct than our current revision here (cf. Olivers et al., 1999; Watson & Humphreys, 1997), but nonetheless there is a number of observations worth noting in regard to this question.

In terms of similarity, both negative priming and carry-over effects reflect a selective cost for new targets sharing the colour of an old irrelevant set of distractors that are, or have been filtered from search. However, there are some important differences. The cost for repeated targets here became significantly increased as the display size increased. This is in contrast to previous studies of negative priming where the effect is abolished with increasing display size (Houghton et al., 1996; Neumann & DeShepper, 1992) and my earlier investigations here (Experiment 2 and 4) where the cost was relatively constant across display size. However, previous investigations of the carry-over effect in preview search have shown repeatedly that, in a visual search context, search costs do increase with display size. Indeed, the carry-over is typically characterised as an interaction with search slopes climbing more steeply across display size in the critical conditions (relative to baseline). As the demand increases so does the need to filter the irrelevant items and reduce their competition from selection (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2010a, 2010b). This is also consistent with the Houghton & Tipper (1994) reactive model of negative priming, which posits the level of inhibition in direct proportion to the level of initial activation. The appearance of 6 items red items would produce a greater 'red' activation than just one red item, thus requiring a greater level of inhibition applied against this feature. In this regard, the feature-based cost appears to be similar to preview-search carry-over effects, which also become greatly increased with display size, (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003, 2004). However, carry-over effects are hardly present at smaller display sizes (circa 6 items) and have never been shown to exist at display sizes as small as some of those employed here.

There are also some remaining paradigmatic differences between the procedures for measuring inhibitory filtering. Firstly, in the current experiment the preceding distractors are no longer present when the cost on later search is observed. In contrast, in preview search the preview items remain on the screen during search. Furthermore, in the current experiment distractor suppression occurs *during* search, whereas in preview search, the preview items are inhibited *prior* to search. Irrespective of these differences, I argue that the current paradigm, which brings together aspects of both negative priming and visual search, has revealed a feature-based inhibitory mechanism that may mediate both effects under the varying paradigmatic conditions. I therefore suggest that these effects may well reflect similar or shared processes operating under different conditions of selection. The differences in the magnitude of the effects may be merely paradigmatic. As well as demonstrating that negative priming effects can occur at larger display sizes than previously thought, the current findings also show that such effects can also occur under more extended situations like visual search. Therefore, I argue that the current novel procedure helps to bridge the paradigmatic and functional gap between previously, thought to be, unrelated aspects of visual selection. I will return to explore these issues in more detail in the General Discussion.

General Discussion

The present study provides the first demonstration that negative priming effects can occur when selection involves multiple distractors. Previous research has shown that negative priming is optimal when there is just one distractor present, and becomes diminished as more than distractors are added, leading to the assumption that the effect is strictly limited to displays containing just two stimuli, (Houghton et al., 1996; Neumann & DeShepper, 1992). In contrast to these earlier findings, not only do I show that negative priming occurs when displays contain up to 12 items, but the effect is also preserved when selection requires inefficient visual search.

The previous limitations of negative priming has made it impossible to integrate the processes of negative priming with those involved in other, more complex situations of selection. The current findings therefore, not only extend the phenomenon to conditions of selection more representative of real world selection than previous research, but the data also enables the mechanisms of negative priming to be integrated with the processes of visual search.

Negative Priming with Multiple Distractors

Unlike the previous investigations into negative priming with multiple distractors, which have examined identity-based NP effects (Neumann & DeShepper., 1992), or location-based NP effects (Houghton et al., 1996), the current study examined *colour-based* negative priming effects, where a cost occurs for new targets sharing the colour of a preceding distractor. In Experiment 1, I first replicated previous findings to ensure that the current manipulation would produce a negative priming effect subject to the same constraints as the identity-based effect (Houghton et al., 1996; Neumann & DeShepper., 1992). This replication was confirmed - as the number of distractors within each display was increased above one, the negative priming effect was diminished. Like the previous studies, here I presented displays in which all distractor items were different letters, presented in different colours. Therefore, the repeated targets shared a characteristic of just one of the preceding distractors.

In Experiment 2 I adapted this procedure, presenting displays in which all distractors were, again, different letters, but now all presented in the same colour. The colour-based NP effect was now reflected by a cost for new targets sharing the colour of *all* of the preceding distractors. Here I found the effect was preserved as more distractors were added to the display, and in Experiment 4 I found the negative priming effect was preserved when the display contained up to 6 distractor items.

Experiment 3 provided a test for a low-level perceptual account of the colour-based NP effect found at the larger display sizes. I presented displays in which only the probe display contained a target and required a response. The prime display now contained a set of irrelevant distractor letters and participants merely had to passively ignore this display while it was briefly presented for 300ms. Previous research has shown that negative priming is abolished when the process of selection is removed from either the prime or the probe display (Allport et al., 1985; Guy et al., 2004 Lowe, 1979; Tipper & Cranston, 1985). This has been taken as evidence that the effect occurs due to inhibitory filtering of the distractor during selection of the target.

Under this logic, if the prime display does not require selection of a target there would be no need to inhibit the distractor items, and thus the carry-over of inhibition (i.e. the negative priming effect) would not occur. In contrast, if the colour-based NP effect were simply the result of neural colour adaption to the initial distractor colour (which in the present case is the majority colour at the larger display sizes), then mere perception of this initial colour would be sufficient to produce an adaption effect on new items holding this colour, (Goolsby et al., 2005; Theeuwes & Lucassen, 1993). Clearly this was not the case. The colour-based NP effect was completely abolished by removing the process of selection from the prime display.

In Experiment 5 I extended the complexity of the negative priming task further, by presenting displays containing up to 12 items, consisting of two equally sized colour groups in which the items partially overlapped each other. Instead of the target being a colour singleton within the display, as was the case in Experiments 2-4, the target now had to be located within a set of items containing up to 6 items, whilst ignoring another set of 6 items. This paradigm was developed to bridge the gap somewhat between the conditions in which negative priming and preview-search carry-over effects are shown to occur. I reasoned that if a cost for new items sharing the colour of old distractors could occur under these conditions which could neither be labelled as preview search of negative priming, but contained elements of both paradigms, this would weaken the distinction between the two and the arguments for separate underlying processes. My results confirmed this. Search was impaired when the target-containing set of items held the same colour as the preceding distractor-set of items – the colour-based NP effect is not limited to conditions of selection involving a simply select-and-respond task, the effects also extend to far more complex conditions of selection where inefficient visual search is required.

Perceptual Load Differences?

Perceptual load theory proposes that selection occurs early when the task is hard and late when the task is easy (Lavie, 1995). Under this account, distractors should interfere (and therefore require inhibition) only when the task is easy, predicting that negative priming would be diminished as cognitive load of the task were increased (Lavie & Fox, 2000). Consistent with this, research shows that negative priming is reduced when participants are required to perform a demanding working memory task at the same time, (Engle, Conway, Tuholski & Shisler, 1995; Gibbons & Stahl, 2010), and negative priming effects for a peripheral distractor are removed when the central selection task requires search through 6 items as opposed to selection from 2 items, (Lavie & Fox, 2000), suggesting that irrelevant distractors are only inhibited when 'left over' attention is available to first process these items.

In relation to the current work, Lavie & Fox (2000) suggest that negative priming may become reduced as distractors are added because of an increase in perceptual load as display size is increased. However, there are a number of reasons why I suggest the current pattern of results cannot be explained merely by differences in cognitive load. Firstly, in the final experiment, attentional demand is increased with display size, and reaction times are slowed when the target must be located within a display of 12 items, compared with when the target must be selected from just 2 items. However, the negative priming effect is increased under these more demanding selection conditions rather than diminished, suggesting that distractors interfere *more* when the task becomes harder, therefore requiring a greater degree of inhibition to remove these items from selection.

Secondly, I find no evidence to suggest that the task is easier when all distractors share the same colour, than when they hold different colours. In the former (Exeriment 2), efficiency of selection averages at 29 ms/item, whereas in the latter (Experiment 1) efficiency of selection averages at 30 ms/item. The extent to which the target is crowded by the distractors, the unpredictable location of the target, and the fact that all items hold different shares is likely to make discrimination hard, regardless of whether the distractors share a common colour or not. I therefore suggest that all conditions require a high perceptual load, and the difference in negative priming does not reflect ease of selection.

Finally, perceptual load theory predicts the level of processing undergone by distractors which are irrelevant to the primary selection task. However, according to the inhibitory model, processing of the distracting information is a central component in selection of the target - selection is a direct result of distractor suppression, (Driver & Tipper 1989; Houghton & Tipper, 1994; Tipper, 1985). Investigations into perceptual load typically present irrelevant distractors somewhere in the periphery and these items have no direct involvement in the task of target selection, (Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000). Therefore, it is quite feasible to presume that these irrelevant items are processed only when the main task requires minimal attentional resources. However, in negative priming experiments, the target and distractor often occupy the same location in space, (DeShepper & Treisman, 1996; Tipper, 1985; Tipper & Cranston, 1985; Tipper & Driver, 1988), and in the current study the target is heavily flanked by the distractors, which overlap it considerably. This suggests that distractors here would be less easily ignored and have a more direct involvement in target selection than those used in perceptual load experiments.

To summarise, I suggest that perceptual load theory is more suitable for understanding the level of processing that irrelevant distractors, outside of the primary selection task, receive. The conditions of selection employed in the current study are more consistent with the inhibitory model of NP, where inhibitory processing of the distractor is a central component of target selection, (Driver & Tipper, 1989; Houghton & Tipper, 1994; Tipper, 1985).

A Role for Feature-based Inhibition

The current results support the inhibitory model of negative priming, (Houghton & Tipper, 1994; Neill, 1977; Tipper, 1985). It is proposed that the colour-based NP effect results from the spread of distractor suppression across time, resulting in a cost for new items sharing similarities with the preceding distractors. Previous studies (and the current Experiment 1) show that, when all distractor items must be encoded via separate internal representations (all presented as bounded objects, by distinct colour and shape), the NP effect is limited to displays containing just one distractor. From this it has been proposed that as the number of distractors to be filtered (and the number of individual distractor representations) is increased, the level of inhibition applied to each of these is reduced, (Houghton et al., 1996; Neumann & DeShepper, 1992). However, here I show that when multiple distractors can be grouped, encoded and inhibited via a shared representation (i.e. the shared colour-map), the level of inhibition applied to each distractor does not decay as numbers increased.

Houghton et al (1996) suggest that the level of inhibition is reduced as distractors are added simply because less inhibition is needed. They propose that the level of initial activation becomes diffuse over multiple distractors, compared with the activation associated with just one competing stimulus, and as the inhibitory mechanism is proposed as reactive, a reduced initial activation requires a smaller degree of inhibition. Under this account, my results can be explained as follows: the appearance of just one distractor colour would produce a greater activation within that colour-map, compared with the activation associated with each individual colour-map when several become activated in response to the same set of distractor items. Therefore, a greater level of inhibition would be required to keep the items appearing within this shared colour-map from competing for attention. In contrast to this, Neumann & DeShepper (1992) suggest that when there are multiple distractor representations to be suppressed, the level of inhibition applied to each of these is reduced simply because there is less inhibition to go around. My findings are also consistent with this notion. With a limited capacity inhibitory process, when it must be spread over multiple colour-map representations, the level of inhibition would be reduced compared with when inhibition can focus on just one colour-map.

Although these models hold some discrepancies, both agree that negative priming is decreased for multiple distractors because the level of inhibition applied to each distractor representation is reduced as more are added to the display. The current findings are completely consistent with this proposal. I first replicate the previous demonstrations that, when distractors must be encoded and inhibited via separate internal representation the effect is diminished with display size. However, I also reveal that when multiple distractors can be inhibited via a shared internal representation, the capacity limits of negative priming are lifted.

The notion of shared feature-map suppression is in line with the revised Feature Integration Theory of attention and selection, (Treisman, 1993; Treisman & Sato, 1990). This model posits that inhibitory connections exist between the activated feature-maps and the location-based master-map which enable all activations that do not possess the target feature to be inhibited and rejected in parallel. The current findings are consistent with the notion that the irrelevant distractors are rejected from selection via the colour-map in which they are activated. This colour-map suppression then spreads across time so that new activations occurring within this colour-map are also attenuated. As a consequence, responses to new items appearing within this colour-map are impaired

While my results are mostly consistent with an inhibitory view, the current data are not completely consistent with the notion of *selective inhibition***,** put forward by Tipper et al., (1994). This model proposes that, while a distractor is represented on various levels, (associated with perceptual features, spatial location, semantic meaning etc.), only those representations specifically competing for a response are inhibited. For example, if the task requires a response to be made to the location of the target, then only the distractor location will be inhibited, leaving the representations associated with other elements of this item in a state of activation. However, in the current study I find evidence to suggest that distractors are inhibited via their colour properties during a task in which the target colour is irrelevant and a response is made to the identity of the target letter.

Despite this contradiction my research findings may be explained under this account of selective inhibition. Firstly, research suggests that inhibition is more diffuse across multiple representational levels under ambiguous conditions of selection, than when attention can be directed towards a specific target feature. For example, Tipper et al (1994) found that when the target colour was pre-cued prior to the onset of the stimuli, the negative priming effect was specific to the task-related feature. However, when the cue was presented at the same time as the stimuli there was a negative priming effect found across all distractor dimensions. In the current experiment, the target colour, identity and location are all ambiguous prior to the stimulus presentation, which may account for why inhibition spreads across non-task specific representations of the distractor stimuli.

Secondly, although the task did not require a response to the target’s colour property per se, colour nevertheless played an important part in the task, as this feature distinguished the target from the distractors. Therefore, it is likely that colour played an important role in the selection. Finally, when distractor items share the same colour, shared feature-map suppression would be a far more efficient method of filtering multiple distractor items en-mass, than inhibiting each distractor via its separate semantic representation. This would support the notion of a highly flexible inhibitory mechanism (Tipper et al., 1994), and extends the current models to suggest that inhibition not only adapts to the current task demands and attentional-set, but it also adapts to the most efficient and effective method of filtering in any given situation.

Links Between Negative Priming and Preview Search

Preview-search studies have also been used extensively to examine inhibitory filtering during selection, and like negative priming, also demonstrate a carry-over cost for new targets sharing feature with old distractors (Braithwaite & Humphreys, 2003, 2007; Braithwaite et al., 2003, 2007, 2010a, 2010b). Despite the similarities, it has been impossible to integrate the process of negative priming and preview-search carry-over effects due to the presumed capacity differences. However, the current findings shed new light on the capacity limits of negative priming, leading us to reconsider whether these effects may, in fact, share some functional overlap.

In preview search tasks, half of the distractors items are presented early, before the remaining distractors and the target item are added to the display (Watson & Humphreys, 1997). This greatly improves search performance compared with when all items are presented together (the *preview benefit*). However, if the new target shares the colour of the preview set of items, search is impaired and the preview benefit is removed. To account for these effects, Braithwaite and colleagues (Braithwaite & Humphreys, 2003, Braithwaite et al, 2003) proposed that the initial set of irrelevant items are inhibited, in part, via their shared features (i.e. colour). This enables the old items to be excluded from search, leading to more efficient search through the relevant new set (producing a preview benefit). However, this suppression spreads across time, carrying over to new items sharing the critical feature. As a consequence, these new items suffer an attentional cost and search is impaired, relative to new items not holding the old inhibited feature.

To date, the processes of preview search and negative priming have been assumed to be distinct, (Braithwaite & Humphreys, 2003; Olivers et al., 1999; Watson & Humphreys, 1997), a notion supported by their apparent capacity differences. While negative priming has previously been limited to conditions of selection involving just two items (Neumann & DeShepper, 1992; Houghton et al, 1996), preview search carry-over effects occur for up to 12 items, (eg., Braithwaite et al, 2003, 2007). However, previously investigations into the capacities of negative priming have used displays in which distractor items shared no common feature, whereas in preview search the old distractor items can typically be grouped into one or two colour groups (Braithwaite et al., 2003, 2007; Watson & Humphreys, 1997). In the current study I examined negative priming effects under similar conditions of selection, where multiple distractor items were present, but these could be encoded and suppressed via a shared colour-map, and here I found the effects were preserved.

Not only have I demonstrated here that negative priming can extend to multiple distractors when they share a common feature, but I find the cost effect occurs when active visual search is required. These novel findings suggest that the previous capacity differences between preview search and negative priming may be, in part, due to paradigmatic differences rather than being due to different underlying mechanisms. The current demonstrations that a colour-based cost effect occurs under conditions in which visual search is required (akin to preview search), but where inhibition must occur during, not prior to selection (akin to negative priming) suggests there may well be an overlap between the underlying mechanisms involved in these different conditions of selection.

However, despite the similarities between the preview search carry-over effects and the present colour-based effects, there remain a number of important differences between negative priming and preview search which require further address. Firstly are the effects of an off-set. The preview benefit is abolished when the preview display is removed during the preview period and then replaced with the onset of the search display, (Watson & Humphreys, 1997). Therefore, such luminance changes occurring at the old locations are thought to disrupt inhibition at that location, (Watson & Humphreys, 1997, 2002). In contrast, negative priming survives such luminance changes. For example, in the case of location-based negative priming, the prime distractor is removed and replaced by a new item (the probe target) yet an inhibitory cost at this location remains. This discrepancy suggests that location-based visual marking in preview search and location-based inhibition in negative priming tasks may not reflect the same inhibitory processes. However, these results do not necessarily speak to the feature-based inhibitory components.

In static preview search filtering of the old items is proposed to occur predominantly via their locations, and features are used to aid the grouping and segmentation process. In dynamic preview search, however, feature-based inhibition becomes central to guidance (Kunar et al., 2003; Watson & Humphreys, 1998; Watson, 2001), and these dynamic preview benefits survive luminance changes to the old items (Kunar et al., 2003), suggesting that feature inhibition is not subject to the same constraints as location-based inhibition.

Negative priming research also implicates multiple inhibitory components where distractors can be filtered either via their spatial location, identity or colour, dependent on the current task, (Milliken et al., 1994; Tipper et al., 1994), and research suggests the processes underlying these different types of carry-over effects may be separable. For example, both elderly and infant populations fail to show identity-based negative priming effects, (Hasher et al., 1991; Tipper, 1991; Tipper et al., 1989) whereas these groups show normal location-based NP, (Connelly & Hasher, 1993; Tipper & McLaren, 1990). In contrast, schizophrenia appears to disrupt location-based NP but not identity NP (Hoenig et al., 2002). Together, the findings from both preview search and negative priming suggest that these selection tasks can recruit multiple inhibitory components, and the suggestion that there may be an overlap between feature-based element and the resulting colour-based carry-over effects does have to infer an overlap between the space-based inhibitory components of these different types of selection tasks. This remains a topic for future investigation.

Negative Priming & Preview Search: A Common Mechanism?

The current study demonstrates that a colour-based cost effect can occur during visual search through displays consisting of up to 12 items, where inhibition of the irrelevant set must occur at the same time as search through the relevant set of items. This new paradigm recruits elements from both the preview paradigm and the negative priming paradigm, revealing costs of around 50ms at the largest display size. In preview search, inhibition develops prior to search, and carry-over costs for displays containing up to 24 items can grow to around 200ms or more (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003). In negative priming, the distractor is filtered during selection of the target, and the cost of feature sharing is typically around 10-20ms (e.g., Neumann & DeShepper, 1992). Therefore, it would appear that the current paradigm produces a cost effect somewhere in between the two, and this may well become increased further and more closely resemble the preview-search carry-over effect if display size were increased beyond 12 items.

These findings suggest that rather than reflecting separate processes, feature-based negative priming and carry-over effects of preview search may reflect the same process, operating to different degrees under different conditions, dependent on the availability of attentional resources. Under this account, I propose that the current colour-based cost effect may well reflect a moderated version of the greatly magnified cost found in preview search, which develops when additional time and attention is allocated to the development of inhibition.

Conclusion

Previous research has suggested that negative priming effects are limited to displays containing just 2 stimuli (Neumann & DeShepper, 1992; Houghton et al., 1996), which has made it impossible to extend the processes of negative priming to real world selection, or to integrate the processes of negative priming and preview search, despite these paradigms demonstrating very similar inhibitory carry-over effects. The present study shows for the first time that negative priming occurs (i) when selection requires filtering of multiple distractor stimuli, and (ii) when selection requires inefficient visual search for the target item. These revelations question the previous assumption that negative priming and preview search recruit separate inhibitory processes, suggesting that they may well functional interdependent. This demands a re-examination of the possible overlap between the mechanisms involved in these separate paradigms.

CHAPTER 5

GENERAL DISCUSSION

In the final chapter the results from each of the experimental chapters are summarised, their implications are explored, and a functional framework is proposed. The current findings are important for understanding the mechanisms of attention and selection across time, in both the preview paradigm and the negative priming paradigm. However, they also have important implications for a wider understanding of real world selection and awareness. The preview search studies (Chapters 2 & 3) are first discussed, and an updated model of flexible inhibition is outlined. The negative priming study (Chapter 4) is then discussed, and its relation to the mechanisms of preview search is examined. Finally, I consider the issues which remain for future research, to further explore the implication of the current thesis.

Summary of Findings {Chapters 2 & 3: Dynamic Preview Search}

The current thesis provides the first investigation of colour-based carry-over effects under dynamic preview search conditions. In Chapter 2, I examined preview benefits and costs for static and dynamic stimuli, where the display items scrolled vertically down the screen. In Chapter 3, this investigation was extended by including a new type of dynamic display, where all items moved in different directions, the trajectories of which were random and unpredictable, changing every time a collision occurred. Together, these investigations produced a number of critical new findings which are summarised below.

- *Preview benefits are equivalent when items are static and when items move, which suggests that moving items can be filtered from attention equally as efficiently as static items, when search is extended over time.*

- *The cost for new items sharing the preview colour (the colour-based carry-over effect) is significantly increased when items move compared with when items remain static, implicating a flexible inhibitory weighting system, which increases the inhibitory strength of features for dynamic stimuli.*

- *The dynamic cost of feature sharing is increased even more when items move in random directions, compared with when items move together in common motion, suggesting that configural coding in common motion search reduces the reliance on feature inhibition.*

- *The dynamic preview benefit and colour-based carry-over effect is abolished following a shortened preview duration, demonstrating that both of these opposing effects reflect a slow-developing mechanism that cannot be explained by fast-acting low-level grouping accounts.*

- *When the preview display and the carry-over target share the same colour for just 100ms, the dynamic carry-over effect is abolished, providing evidence against an automatic colour grouping account (see also the point above).*

- *A colour change to the preview display disrupts the random motion preview benefit but this does not disrupt the common motion preview benefit, suggesting that a stable configuration-based representation enables moving items to remain suppressed even when these items change colour.*

- *When displays are achromatic, the dynamic preview benefit is abolished, demonstrating that, for moving stimuli, colour segmentation is crucial for new items to be effectively prioritised over old.*

- *Dynamic preview search for non carry-over targets is improved by target colour foreknowledge, suggesting that observers do not default to colour-based prioritisation when the target colour is unknown.*

Previous investigations of dynamic preview search have employed situations only where either colour is segmented across displays or is completely removed from them (i.e., achromatic stimuli: Kunar et al., 2003; Olivers et al., 1999; Watson, 2001; Watson & Humphreys, 1998). In addition, when colour was present in these previous studies, the observers always knew the colour of the target in advance of search. Therefore, the preview benefits reported in those investigations could easily be explained in terms of either (i) an increased role of colour-based grouping in dynamic situations and / or (ii) excitatory guidance directed *towards* the new relevant colour. In both cases, these accounts posit no need for any inhibitory guidance *away* from the old items at all.

The current thesis considerably extends these previous investigations by systematically demonstrating both the existence of a negative colour-based carry-over effect (which cannot be fully accounted for via low-level accounts) and that the magnitude of the colour-based carry-over effect becomes increased as the role of other visual information (i.e., location-based and configural processing) is either reduced or abolished. Further experiments show this increased carry-over effect cannot be explained by (i) an increased role for low-level grouping processes in operation under dynamic search conditions, (ii) a reliance on colour-based prioritisation strategies, and neither can the dynamic preview benefit be accounted for purely in terms of luminance onset capture (Donk & Theeuwes, 2001, 2003) or temporal segmentation processes (Jiang et al., 2002).

Instead, the results strongly suggest that feature inhibition becomes more heavily relied upon as location-based inhibition is attenuated. This increased weighting on feature-based guidance subsequently leads to a more severe attentional cost for new items holding the critical, old and inhibited feature. Furthermore, the severe cost of feature sharing under more ecologically valid dynamic visual conditions suggests that this feature-based inhibitory mechanism may contribute towards real world failures of awareness.

What is inhibited in Dynamic Preview Search?

Previous research has implicated a role for location-based (Watson & Humphreys, 1997, 2000, 2002), feature-based (Braithwaite et al., 2003, 2004, 2007), and possibly object-based inhibition in preview search (Kunar et al, 2003; Watson, 2001). As already discussed, the present findings provide strong evidence for a role for feature-based inhibition in both static and dynamic preview search. However, consistent with previous suggestions, inhibition appears to be multifaceted, adapting to the information available in a given situation. I will now consider how my results integrate with previous findings in evidencing a role for additional inhibitory components which are not based on the features of the display.

Location-based Coding and Inhibition

Previous research suggests that the locations of old items are inhibited in static preview search, (Watson & Humphreys, 1997, 2000, 2002), which is supported by a cost for detection of probes falling at the location of an old item, compared with probes falling on background space, (Humphreys et al., 2004), and the disruption to preview search caused by luminance changes occurring at the locations of old items (Watson & Humphreys, 2002). The current demonstration that the static carry-over effect is much smaller than the dynamic carry-over also implicates a role for location-based inhibition, (which is itself ‘feature-blind’). This moderates the extent to which features are relied upon under static search conditions, and subsequently reduces the amount of carry-over feature-based inhibition on new items.

Configuration-based Coding and Inhibition

The current thesis also adds to previous research in implicating a role for configural processing and inhibition in preview search. For static stimuli, Kunar et al (2003) found that achromatic preview benefits survive a location change to the preview items, but only when the configuration of the display remains the same, (and this configuration moves to a new location on the screen). When items are re-presented in new random locations and the configuration of the display is altered, the preview benefit is abolished. Similarly, Watson (2001) has shown that configural processing is also important with moving achromatic stimuli. When items rotated in one direction around the screen, maintaining spatial continuity, a preview benefit was obtained. However, when some items moved clockwise and others moved anticlockwise, the preview benefit was abolished.

The present thesis also reveals two major findings which also implicate a role for configuration-based inhibition in the scrolling common motion displays used in the current studies. Firstly, the colour-based carry-over is significantly reduced in common motion search compared with random motion search, suggesting that the additional configural information reduces the reliance on feature inhibition and the resulting carry-over. Secondly, a colour change to the preview display disrupts the random motion preview benefit but not the common motion preview benefit. This suggests that the relatively stable configuration-based representation of common motion search enables the old items to remain inhibited even when the feature-based component of inhibition is disrupted. If configuration played no role in search through these displays, the same pattern of results would be observed in both motion conditions. It was not.

I suggest that the common motion conditions used in the current study are most typical of local motion in real world vision. Moving information maintains a large degree of spatial continuity, with information filtering out of view and new information appearing, as observers move around a relatively stable visual world. Under these types of circumstances, the present findings show that configuration contributes and reduces the reliance on features, enabling old items to remain filtered across colour and luminance changes which are a common occurrence in real vision.

Objects-based Coding and Inhibition

Multiple Object Tracking (MOT) studies suggest that individual objects can be inhibited, and remain inhibited as they move around in a random and unpredictable manner, (Pylyshyn, 2004, 2006). These experiments use randomly moving displays similar to those used in Chapter 3, and research suggests that participants are able to keep track of the target items, in part, by inhibiting the distractor items. Evidence of this comes from Pylyshyn (2006), by incorporating a dot-probe detection task into MOT. He found that probes were harder to detect when they fell on a distractor item, than when they fell on either a target item or on empty background space. This notion of distractor suppression in MOT has also gained neurological support. A study measured ERP responses to probes appearing on distractors, targets and background space demonstrated an attenuated response to probes falling on distractor items (Doran & Hoffman, 2010).

Although these findings strongly suggest that moving items can be tracked and inhibited, multiple object tracking tends to be limited to 4-5 items at one time, (Pylyshyn & Storm, 1988), suggesting the displays used in the current study (where up to 8 items must be inhibited) are too complex for all preview items to be successfully tracked and inhibited. Although more recent investigations have found that MOT capacity can be increased to 8 items under certain circumstances, this is only the case when items move very slowly, (around 0.5 - 1°/second: Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009), whereas in the current study items move at around 5°/second. Therefore, although individual object-based inhibition may contribute at the smaller display size, where just 4 items must be ignored, this is unlikely to extend to the larger displays where 8 items must be filtered. An additional role for object-based inhibition at the small display size may well account for why the carry-over effect is much smaller here, reducing the reliance on features and the resulting inhibitory carry-over. However, as display size is increased, tracking and inhibition of each individual object is no longer possible and features become more heavily relied upon, resulting in a severe cost for new items holding the inhibited feature.

A Flexible Inhibitory Mechanism of Preview Search

Preview research has suggested that preview benefits come about, predominantly, via inhibitory guidance *away* from the old items, and this inhibitory mechanism draws upon both spatial and featural elements. The current thesis adds to current knowledge by highlighting a role for features, locations and configuration in flexible inhibitory filtering, where inhibition adapts to the information available in the current situation. These components appear not to be additive, as old items are de-prioritised effectively regardless of how many inhibitory routes are available. Instead the results suggest that inhibition places differential weighting on each component under different circumstances, dependent on the most reliable information available.

Feature-based Inhibition: Feature-guided vs Feature-map

To account for carry-over effects in static preview search, Braithwaite et al have proposed a feature-guided model of inhibition (Braithwaite et al., 2003, 2004, 2005, 2007, 2010; Braithwaite & Humphreys, 2003, 2007). This model suggests that grouping by colour coordinates the allocation of inhibition to the locations of the irrelevant items. Under this account, the features of the items are not inhibited themselves, but they determine the degree of inhibition applied to the locations of the old items. Suppression is proposed to spread throughout a colour group (and across time) in a multiplicative manner, so that larger colour groups receive a larger degree of inhibition and produces a larger inhibitory carry-over, (Braithwaite & Humphreys, 2007; Braithwaite et al., 2005).

To support this feature-guided account of static-preview search, several experiments have shown that, when preview displays are segmented in two colour groups of unequal size, carry-over effects are much larger for new items holding the same colour as the larger colour group in the preview display, than new items holding the same colour as the smaller colour group in the preview display, (Braithwaite & Humphreys, 2007; Braithwaite et al., 2003, 2005, 2007). Similarly, the costs for probes falling on old items relative to new items, was found to be increased when the probe fell on an old majority colour item compared with when it fell on an old minority colour item, (Braithwaite et al., 2005, 2007), suggesting that a larger colour group within the preview display receives more inhibition than a smaller colour group.

The proposed feature-guided inhibitory process is consistent with the attentional engagement model of visual search, where suppression is proposed to spread throughout a feature group, (Duncan, 1995; Duncan & Humphreys, 1989, 1992). The feature-guided model can also account for why the static preview benefit survives a colour change to the old items, (Braithwaite et al, 2004, 2005), as the locations of the old group remain stable even when this group changes colour, and why feature differences are not crucial for static preview benefits (Olivers et al., 2001; Theeuwes et al., 1998), as they only aid grouping, they are not necessary.

The present thesis suggests that a similar process may occur in common-motion dynamic search conditions, but mediated via configural processing. The current results show that, like static preview benefits, the common motion preview benefit can survive a colour change to the old items prior to the search onset. However, unlike static preview search, no common motion preview benefit is found when displays are achromatic. From this, I suggest that colour coding is crucial for a stable configuration-based representation to become established in the current common motion conditions. However, once this has been formed, the items can be successfully inhibited via the locations in which they fall within this moving configuration. This enables the items to remain inhibited even when this configuration-based group changes colour.

In addition to feature-guided inhibition in dynamic preview search, the results implicate a role for *feature-map* inhibition. Under random-motion conditions, neither location-based nor configuration-based inhibition is possible. Here, I suggest that features take on a more central role, and the whole feature-map in which the moving items are activated may be inhibited, (cf., Braithwaite et al., 2003, 2005; Treisman & Sato, 1990). This notion of feature-map inhibition is consistent with the revised version of the Feature Integration Theory, (Treisman & Sato, 1990), where irrelevant feature-map activations are inhibited to remove all items appearing within this feature-map from selection. In dynamic preview search, inhibition of the old items via their shared feature-map representation would enable these items to remain suppressed even when no fixed spatial-map representation could be maintained.

A reliance on feature-map inhibition under random motion search conditions would also account for the more severe carry-over cost found under these conditions, compared with that found under static and common motion conditions. New items appearing within a colour-map currently being suppressed would also be suppressed to a considerable degree, suffering a severe attentional cost relative to new items appearing within an uninhibited colour-map. In addition, colour-map suppression would account for why the random motion preview benefit is completely abolished by a colour change to the old items. Following the colour change, the old items not longer appear within the inhibited colour-map, and would therefore no longer be de-prioritised from attention.

I suggest that feature-map inhibition may also play a role in the current common motion search conditions, where the configuration experiences disruption as items reach the bottom of the screen and filter off. This may supplement feature-guided inhibition, enabling the preview benefit to survive such configuration changes, but also resulting in a magnified cost for new items sharing the old inhibited feature, compared with the cost found in static search, where location-based and feature-guided inhibition can be relied upon.

Extending the Current Model to Dynamic Preview Search

The present thesis builds upon the current inhibitory model of preview search by evidencing a crucial role for feature-based inhibition under more ecologically valid dynamic circumstances. Furthermore, it reveals that the attentional cost that results from feature-based inhibition is greatly increased for dynamic stimuli, compared with static stimuli. The thesis presents the inhibitory mechanism as a flexible weighting system that adapts to the information available in the current situation. Inhibition can be applied to locations, features and configuration-based representations to produce optimal filtering, and the weighting of these components is dependent on the most stable representations available.

Here I outline the flexible inhibitory model in a set of schematic diagrams. Figures 5.1 and 5.2 illustrate the development of inhibition in preview search, for common and randomly moving displays, respectively. When the preview items are known to be irrelevant to the task, an inhibitory goal state is set against these items. When the configuration of the display remains stable, colour is used to group the items into a single object-based representation, and the individual items are treated as features of this object. Inhibition is then directed towards each element of the object, (taken from the static visual marking model put forward by Watson & Humphreys, 1997). Suppression spreads throughout this group and across time. Therefore, if new items appear within this colour group they also suffer a degree of carry-over suppression.

When the master map detects changes to the location of this object, the application of a transform moves the template with the object. This enables inhibition to remain tied to the elements within this moving object, (taken from the rotating transform, put forward by Watson, 2001). For the rotating displays used by Watson (2001), this object-based inhibition appeared to be sufficient for successful de-prioritisation. However, when the elements of this configuration are briefly occluded (as in the current common motion conditions), inhibition based purely on the locations within this moving object is not sufficient. Here, I propose that additional colour-map inhibition enables the elements of the object to remain inhibited when they are briefly occluded and re-presented in new locations, (see Figure 5.1).

When items move at random and no object-based representation can be formed, inhibition must rely more heavily upon the colour-map in which the items appear in. This enables the items to remain inhibited despite there being no stable spatial or configural representation, (see Figure 5.2). However, this inhibition is sustained across time when search through the new relevant set of items is required. Therefore, new activations occurring within this colour-map are also inhibited, and search for these new (inhibited) items is severely impaired as a result, (see Figure 5.3).

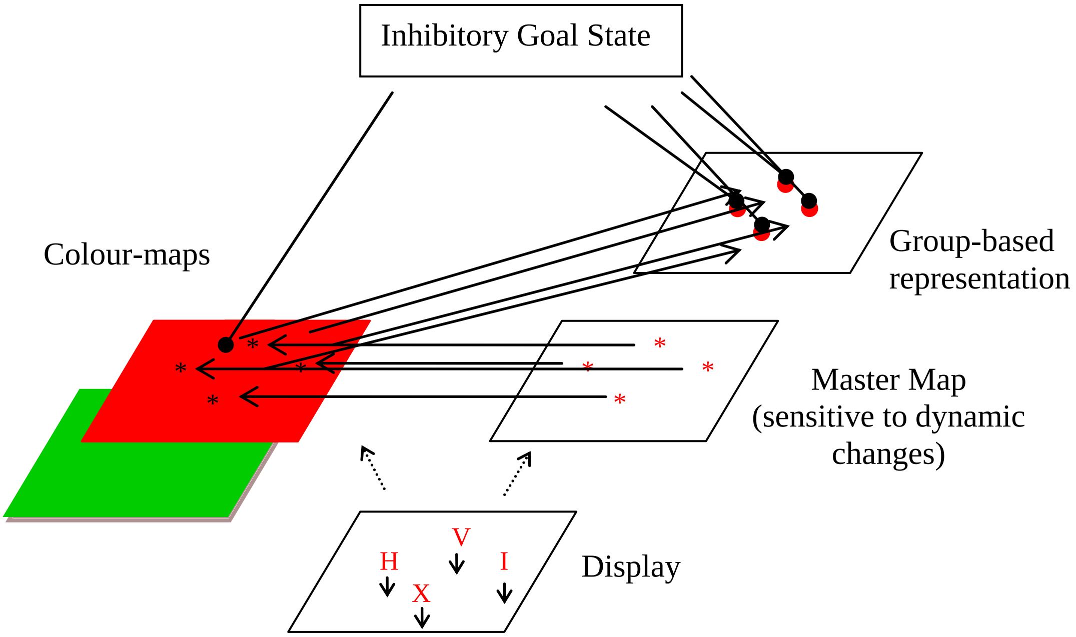

Figure 5.1. Inhibition in common motion search (time = 0 - 1000ms). When the preview display is presented, activations associated with the locations of the items are registered in a master map and the associated colour map. The items are grouped by configuration into a single object-based representation. When this configuration moves, the elements of this object are tracked by the application of a transform to the inhibitory template. Inhibition is then applied to the individual elements of this moving object, and the colour-map in which the items are activated.

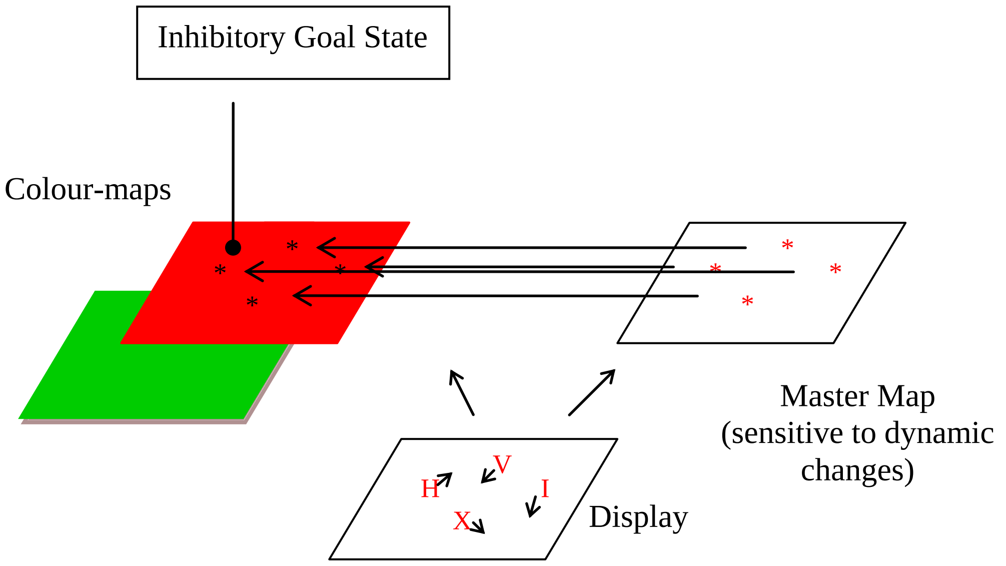

Figure 5.2. Inhibition in random motion search (time = 0 - 1000ms). When the dynamic system detects constant change to the locations and configuration of the display, no group-based representation can be formed. Here, inhibition is applied to the feature-map in which moving items appear in.

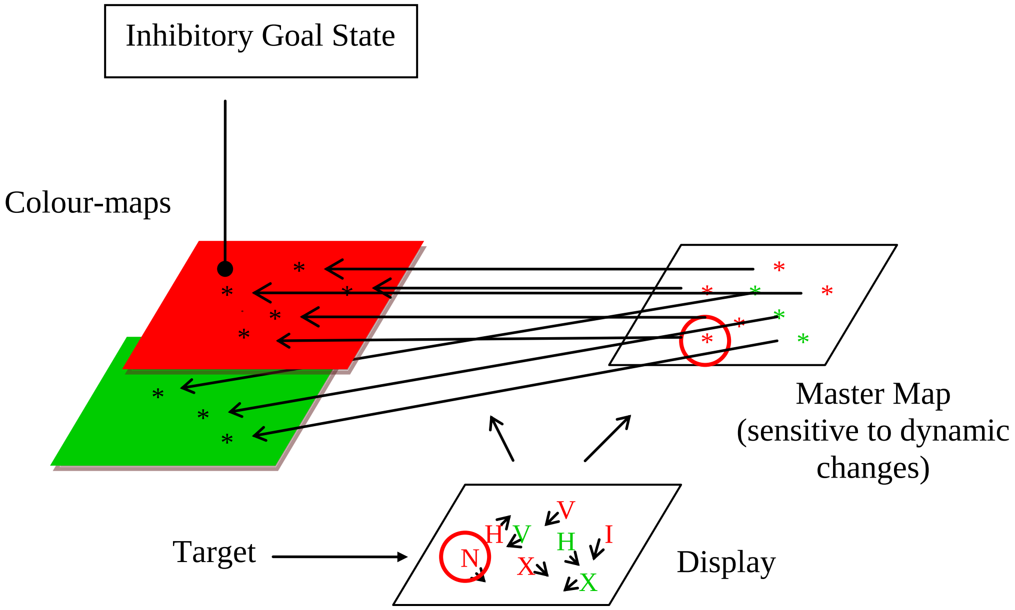

Figure 5.3. Colour-based inhibitory carry-over during random motion search (time = 1000ms+). When the second set of search items appear, the old items are excluded from search by sustained inhibition of the old feature-map (red). Therefore, if new activations occur within this inhibited feature map, they are also suppressed. In this example, the new target (N) is red. This is represented in the red colour-map and it is therefore inhibited. Search here would be impaired, compared with if the target were activated in a different colour-map (i.e. green) not in an inhibitory state.

This flexible model of inhibition enables the system to adapt to the ever changing visual environment, maintaining optimal filtering. Therefore, if one inhibitory component becomes compromised (for example, if items move, or change colour) weighting on another component can be increased. If enough of the system is compromised then the old items will become ‘released’ from filtering and will re-compete for selection (abolishing the preview benefit).

Preview Search & Inattentional Blindness

As discussed in the individual general discussion section of Chapter 3, the likeness between the severe colour-based carry-over effect found under dynamic preview search conditions bares a strong resemblance to the feature-based failures of awareness demonstrated in the selective looking paradigm, (cf. Simons, 2000, for a review of the paradigm). In particular, some of these studies have shown that people are far less likely to notice an unexpected item if it shares features with information being ignored in the primary task, (Most & Astur, 2007; Most et al., 2001, 2005; Simons & Chabris, 1999). For example, Most et al (2001) used visual displays very similar to the current dynamic displays, where two sets of items moved randomly around the screen, and these were defined by colour. One set had to be attended to, and the number of bounces made between the items counted, and the other set of items was irrelevant to the task. They found that an unexpected item moving across the screen during the middle of a trial was far less likely to be noticed when it shared the colour of the irrelevant set of items compared with when it did not, (see also Most & Astur, 2007; Simons & Chabris, 1999, for similar findings).

Like the current results, these instances of blindness demonstrate a selective attentional cost for new items sharing features with old irrelevant items. However, while these studies have produced striking results, no functional account has been proposed, and this is a shortcoming I suggest the present thesis begins to resolve. The work carried out here provides stronger evidence for an overlap between instances of sustained inattentional blindness and preview search carry-over effects, than previous static-based investigations have been able to provide. The current dynamic conditions are far more similar to the conditions in which inattentional blindness has been demonstrated. Furthermore, the cost is greatly magnified under these dynamic conditions, demonstrating a severe attentional *cost*, whereas the static carry-over merely removes the benefit, (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003). Under dynamic preview search conditions functioning is completely disrupted as a result of feature-based inhibition. I propose that this severity makes it entirely feasible to suggest that carry-over effects of feature-based inhibition may also result in unexpected new items going completely unnoticed.

I therefore propose that the feature-based inhibitory process proposed to underlie colour-based carry-over effects in preview search may also contribute towards the feature-based instances of sustained inattentional blindness demonstrated in the selective looking paradigm (Most & Astur, 2007; Most et al., 2001; Simons & Chabris, 1999). Under both of these circumstances, feature-based inhibition may be directed towards the irrelevant set of distractors to enhance the attentional prioritisation of the relevant set of items. However, inhibition spreads across time and as a result new items sharing features with the old inhibited stimuli suffer a severe attentional cost. This carry-over of inhibition can impair functioning when this new information is important and actively searched for, and can result in complete failures of awareness if this new information is unexpected.

Summary of Negative Priming Findings

Chapter 4 re-examined the previous assumption that preview search and negative priming recruit and reflect distinct inhibitory processes. The study re-addressed the capacity constraints of negative priming, and the conditions in which this effect can be obtained.

The main findings of Chapter 4 were as follows:

(i) *The current modified protocol demonstrates a colour-based negative priming effect - when new probe targets share the same colour as the preceding prime distractor, responses are slowed.*

(ii) *This negative priming effect is abolished when the displays contain more than 1 distractor, and the addition of every new distractor includes the addition of a new distractor type (supporting previous findings: Houghton et al., 1996; Neumann & DeShepper, 1992).*

(iii) *Crucially, when the confound between the number of distractors and number of distractor types is removed, a significant negative priming effect is found for up to 6 distractor items.*

(iv) *The cost for probe targets sharing the previous prime distractor colour is removed when the prime display contains no target, and the distractors are presented alone. This is consistent with the effect being based in top-down attentional factors and not low-level grouping factors*

(v) *The effect can be extended to modified visual-search / negative priming paradigms, for displays containing up to 12 items.*

Previous research into negative priming capacity limits have used displays in which all distractor items held different identities, shapes, locations and colours. Therefore, they each had to be encoded and inhibited via a separate internal representation, (Houghton et al., 1996; Neumann & DeShepper, 1992; Neumann et al., 1993). Here I used displays in which all distractors could be encoded and inhibited via a *shared* representation. By addressing this confound I show that negative priming effects can occur when selection involves filtering of multiple distractors, and is no longer limited to displays containing just two stimuli, (Houghton et al., 1996; Neumann & DeShepper, 1992).

The previous limitations of negative priming have made it impossible to (i) extend the mechanisms of negative priming to real world selection where there is a vast amount of irrelevant information available with every fixation, and (ii) integrate the processes of negative priming with those involved in more complex selection tasks, such as visual search. However, the current thesis addresses both of these issues by showing that when distractors share a common feature, negative priming occurs under more complex conditions of selection, more representative of real world experience, and also visual search. Where previous research has shown that a cost is experienced for new stimuli sharing characteristics with a previously ignored stimulus (see Fox, 1995; May, 1995, Tipper, 2001, for reviews), here I show that a cost is experienced when new stimuli share features with previously ignored visual information, be that just 1 old item or several old items. This also highlights the similarity between feature-based negative priming and feature-based carry-over effects of preview search, which was previously masked from their apparent capacity differences. This questions the distinction between the processes underlying these effects.

Distractor Suppression in Negative Priming

Negative priming is proposed to reflect an inhibitory component of selection. In order for the target to be selected and responded to, the internal representation of the competing distractor stimulus must be inhibited. The remaining inhibition associated with this representation is sustained across time, impairing later responses to this item, (Houghton & Tipper, 1994; Tipper, 1985). Previous demonstrations of diminished negative priming with display size have proposed that, as the number of distractors which need to be filtered is increased, the level of inhibition applied to the internal representations associated with each of these distractors is reduced (Neumann et al., 1996 Neumann & DeShepper, 1992). As the negative priming effect is proposed as a direct reflection of the initial suppression applied to this re-activated representation (Houghton & Tipper, 1994; Tipper, 1985), this would explain why the negative priming effect also becomes reduced.

The current results support the suggestion that less inhibition is received by individual distractor representations when more distractor representations require inhibition by showing that, when multiple distractors can be inhibited via one shared internal representation (i.e. the colour-map in which they all appear in) the size of the negative priming effect is equivalent to when just one distractor must be inhibited. This strongly implicates a role for feature-map inhibition (Treisman & Sato, 1990), for the filtering of multiple distractors in the current negative priming selection task. However, this inhibition spreads across time to the following display and the following selection task, resulting in a strong inhibitory carry-over to new items also sharing this feature.

Distractor Suppression in Visual Search

In the final part of my thesis (Chapter 4, Experiment 5), I adapted the standard negative priming task to require inefficient visual search for the target. The display consisted of 2 equally sized colour groups containing up to 6 items each. The group in which the target would fall was known (always in the background set), but its specific location was not. Therefore, the task required the background colour set to be actively searched, while the foreground colour set was ignored. This new paradigm revealed that search was impaired when the new relevant (background) set was presented in the same colour as the previous irrelevant (foreground) set. To explain this cost I suggest that colour is used to group the relevant items and the irrelevant items within each display. Inhibition is then applied to the irrelevant colour group to enhance guidance towards and through the relevant group. However, this suppression spreads across time to new items also appearing within the previously inhibited colour group.

This notion of feature-based grouping and suppression of distractors has received support in the visual search literature (Duncan, 1995; Duncan & Humphreys, 1989; 1992), and is consistent with spreading suppression accounts of preview search carry-over effects, (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003, 2004, 2005). Like preview-search carry-over effects, the negative priming effect found under the new visual search-based selection conditions of the final experiment became significantly increased with display size, suggesting that inhibition is multiplicative, growing in size as it spreads throughout the colour group, (Braithwaite et al., 2005). Therefore, new items receive a greater inhibitory carry-over when the previously inhibited group was large (containing several items) compared to when it was small (containing just one item).

Negative Priming and Preview Search – An Overlapping Process?

In an effort to bridge the explanatory gap between negative priming and preview search, the new paradigm used in Chapter 4, Experiment 5, contained elements of both preview search and negative priming. Consistent with the standard negative priming procedure, filtering of distractors occurred during selection of the target, not before. However, consistent with preview search, selection required inefficient search through one set of items, while another set of irrelevant items were also present. Here I found a cost to search when the new relevant set of items was presented in the same colour as the previous irrelevant set if items.

In terms of the overall size of the cost effect, this most closely resembled the typical negative priming effect. However, in terms of efficiency, this was more akin to the colour-based carry-over effects in preview search - the visual search-based negative priming effects became significantly increased with display size. Furthermore, although carry-over effects can grow to 300-500ms for large displays containing 24 items, (Braithwaite & Humphreys, 2007; Braithwaite et al., 2003, 2004, 2007), the effects found for displays containing 12 items (which is equivalent to the largest display size used here) carry-over effects are much smaller, typically around 100ms (Braithwaite et al., 2003, 2004). Therefore, it is quite possible that, were the current displays to double in size, the negative priming effect may also magnify to become more similar to the size of the carry-over effects found in preview search.

The availability of time and attention in preview search, which is not afforded in negative priming experiments, may also go some way to explain the larger carry-over effects. In preview search, carry-over effects reveal a cost for targets sharing features with a set of distractors which remain present, but that were inhibited previously. Under preview search conditions, a period of time is afforded with which to develop an inhibitory bias against the old items. This suppression is then sustained across time during subsequent search, resulting in a cost to search when the relevant new information shares the inhibited feature (see Braithwaite et al., 2003, 2005; and Chapters 2 & 3 here). In typical negative priming tasks, distractors are inhibited at the same time as target selection. Likewise, in the new paradigm, no time is afforded with which to inhibit the distractor items prior to search through the relevant set of items. I therefore suggest that the apparent capacity differences between negative priming and preview search effects may, in part be due to these paradigmatic differences rather than different mechanisms. Rather than reflecting separate inhibitory processes, I propose that colour-based carry-over effects in preview search and feature-based negative priming effects may reflect the same underlying process, but operating to different degrees under different types of selection conditions.

Location-based Inhibition in Preview Search & Negative Priming

Previous research has suggested that in negative priming selection tasks, a distractor can be inhibited via its location, resulting in a cost for probe targets appearing at the same location as the preceding prime distractor (Park & Kanwisher, 1994; Tipper et al., 1990, 1995). Here, location-based filtering is maintained across luminance changes occurring at this location. In contrast, location-based inhibition in preview search appears not to survive such changes, (Watson & Humphreys, 1997, 2002). Static preview benefits are proposed to occur, predominantly, via inhibition of the locations in which the preview items fall, and these preview benefits are disrupted when the preview items change shape (Watson & Humphreys, 1997, 2002) or are temporarily removed and replaced with the new items, (Watson & Humphreys, 1997). This difference suggests that the mechanisms underlying these location-based effects of negative priming and preview search are not the same, and has been used as crucial evidence of a distinction between the two, (Olivers et al., 1999; Watson & Humphreys, 1997).

However, rather than this difference being due to separate mechanisms, it is possible that the difference lies in the size of the luminance change. Location-based filtering may be able to survive small dynamic changes to the spatial-map representation (i.e. a change occurring at just one location in negative priming) but cannot survive large changes occurring at several different locations (as is the case in preview search). The current thesis investigates feature-based inhibition in negative priming and preview search and does not address the possible overlap between the location-based inhibitory components of these paradigms. This is a remaining question that must be addressed in future research.

Questions for Future Research

The current thesis reveals an overlap between two paradigms which previous research has failed to show. This questions the previous assumption that negative priming and preview search are discrete paradigms tapping into separate processes, and opens up a new line of research. The current research demands the case to be reopened for future investigations into the overlap / distinction between these inhibitory mechanisms. I will conclude with a summation of the questions I feel are particularly important in determining the extent to which inhibitory processing and negative priming and preview search share a common basis.

- *Will the magnitude the negative priming effect increase further for display sizes equivalent to those used to produce optimal preview-search carry-over effects?*

- *Do good preview searchers show the largest negative priming effects?*

- *Is the overlap between negative priming and preview search specific to colour-based effects, or does it extend to location-based inhibition?*
    - *Can other negative priming effects be extended to multiple distractors?*
    - *Like location-based filtering in preview search, is location-based inhibition in negative priming disrupted by large luminance changes to the display?*

- *Are the same brain regions involved in feature / location inhibition in negative priming and preview search?*

- *Is the time course of inhibition in feature / location inhibition in negative priming and preview search equivalent?*

Closing Remarks

To conclude, the current thesis provides a detailed investigation into inhibitory processing during selection. When irrelevant information must be filtered from attention, the inhibitory system recruits location, configural and feature information with which to encode and suppress these items. The weighting on these components depends on what is available in the current situation. When items move and location-based filtering is not possible, the feature properties of the display become more central to filtering. Although a reliance on feature-inhibition enables the irrelevant information to be filtered just as effectively as filtering via locations, this results in a severe cost to functioning. Feature-based inhibition spreads across time to new information in possession of this critical old feature. The severe attentional cost experienced by these new items, even when they are highly important to the task, strongly implicates this feature-based inhibitory process in real world failures of visual awareness. Finally, my research also extends the negative priming to more ecological validity conditions of selection, and strongly implicates an overlap between the inhibitory mechanism of preview search and negative priming. In all, the current findings place feature-based inhibition in a central role of guidance, selection and awareness, producing both positive and negative effects on functioning during real world selection.

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