Attentional control: the role of task-expectations in determining attentional selection

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BSc (Hon II A)

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Abstract

The human cognitive system is severely capacity limited. As such, only a select subset of visual input to the retina is fully processed by the cognitive system at any one point in time. To compensate, mechanisms of visual attention allow us to distribute these limited resources throughout the visual field according to properties of the visual input and our goals and intentions. Establishing the exact criteria by which visual input is selected to undergo further processing is central to understanding the processes that determine visual selection; processes that ultimately contribute to our conscious experience of the world. In this thesis, I focus on stimulus novelty and the role that task-expectancies play in determining visual selection. It is well documented that that which is new and unexpected often appears to standout in the environment and can attract visual attention (Horstmann, 2005; Meyer, Niepel, Rudolph & Schützwohl, 1991; Ranganath & Rainer, 2003; Yantis & Jonides 1990). However, the conditions under which this is the case and the mechanism by which we come to be sensitive to novel stimuli require some elucidation.

Here I present 3 empirical chapters that explore the conditions under which novel and unexpected stimuli attract visual attention. In Chapter 2, I investigated whether attentional capture by unexpected stimuli reflects a form of stimulus driven capture and occurs contrary to the immediate goals on an observer. Across a series of experiments I found that an infrequent (~3-6% of trials) and irrelevant motion cue captured attention when observers had an active set for a specific target color. Critically, this effect was not observed when the same motion stimulus was presented frequently. Thus, task goals appear to modulate capture by stimuli that broadly conform to contextual expectations, while stimuli that violate these expectations appear to guide visual attention involuntarily.

In chapter 3, I examined what it means for a stimulus to be ‘unexpected’. The first presentation of an unexpected stimulus during visual search has been associated with large RT cost. In chapter 3, I independently varied prior exposure to an unexpected and irrelevant motion distractor and explicit knowledge of its occurrence to assess the contributions of each of these factors in determining the unexpectedness of the stimulus. Neither prior exposure, nor knowledge of occurrence served to attenuate the response to the unexpected motion distractor.
These results suggest that the task expectations, which deviant stimuli are evaluated against, are highly context specific and derived from a process of implicit learning about stimulus relevance, and are not shaped by explicit top-down knowledge about the likelihood of occurrence.

In Chapter 4, I examined the time-course of attention shifts to unexpected stimuli. Previous authors (e.g., Horstmann, 2005; 2006) have made the claim that shifts of attention to unexpected stimuli are delayed relative to expected stimuli and that this may suggest a dedicated orienting system for novel and unexpected events. In Chapter 4, I used eye-movements as a proxy for attentional selection to evaluate this claim. Across two experiments I found oculomotor capture by an unannounced colour singleton that was rapid, and large RT costs that emerged once the eyes selected the unexpected colour singleton, but not before. This pattern of eye-movements and RT costs is not consistent with accounts that posit a delay in orienting to explain performance decrements that have been associated with unexpected stimuli. I propose an interference account whereby attention is deployed rapidly to an unexpected stimulus and performance decrements reflect the engagement of decision level processes that are recruited to resolve expectation violations.

In summary, I present 3 empirical chapters that show consistent effects of stimulus novelty on search performance. Based on these results I have proposed that the attentional set reflects a set of contextually specific expectations that describe both the target defining properties and the to-be-ignored properties of distractors. Sensitivity to stimulus novelty is born of a process whereby salient irrelevant stimuli are inhibited over repeated and frequent exposure in order to be ignored. Stimuli that occur infrequently cannot be inhibited and consequently capture visual attention.
Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Conference abstracts


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Retell, J. D., Becker, S. I., & Remington, R. W. (submitted). An effective attentional set for a specific colour does not prevent capture by infrequently presented motion distractors. – Incorporated as Chapter 2

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Contributions by others to the thesis

My advisors, Roger Remington and Stefanie Becker contributed to the conception and design of all the experiments presented in chapters 2 and 3. The experiments presented in Chapter 4 were a collaborative effort between myself, Stefanie Becker, and Dustin Venini.

Statement of parts of the thesis submitted to qualify for the award of another degree

None.
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FoR code: 1701 Psychology (20%)
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List of Abbreviations Used in the Thesis

- ANOVA – Analysis of variance
- Cm – Centimetres
- DMA – Dimension weighting account
- EEG – Electroencephalography
- ERP – Event related potential.
- fMRI – Functional Magnetic Resonance Imaging
- GS – Guided Search
- GS4 – Guided search 4.0
- IB – Inattentional Blindness
- ISI – Inter-stimulus interval
- MMN – Mismatch negativity
- PSD – Post selection delay
- RT – Response time
- SOA – Stimulus onset asynchrony
- TPJ – Temporal Parietal Junction
- TSE – Time’s subjective expansion
- V1 – Primary visual cortex
- V2 – Extrastraite visual cortex area
Chapter 1 – Introduction and Overview
Perhaps the only unsatisfying aspect of a PhD spent studying visual search, is that after nearly four years of doing so, I am no more adept at locating my office keys on my desk as I prepare to head home of an evening. I am consoled, however, by an understanding of why this is the case, which, if you will indulge me, I would like to share with you in the pages that follow.

I will continue for the moment with the clichéd, though apt example of a disorganized graduate student’s desk to outline the problem at hand. My desk is cluttered. It is littered with academic papers, journals, textbooks, coffee mugs, pens and pencils, gym gear, a copy of the New York Times, my phone, my laptop, yesterday’s coke can, last week’s coke can, a Rubik’s Cube and the list goes on. Buried in this sea of objects are my office keys. At this point you could argue that the arduous search task I routinely engage in for my keys is self-inflicted and I’d have little recourse to object. What’s remarkable to me though, and perhaps you agree, is that I’m able to find them at all. Indeed, we all have experience with trying to locate objects of interest from within cluttered environments; whether you’re searching for personal items from amidst the mess that hides your desk or perhaps searching for a friend at a crowded intersection. The visual world throws at the retina a plethora of visual information, much of which is relevant to our immediate goals, however the vast majority of which often is not. The question of how we distinguish and extract relevant information from the sea of distracting and irrelevant information that presents to the visual system in any given scene has been, and remains, a question of principal interest to vision and cognitive scientists. Your ability to locate your favourite sweater in a closet full of clothes is obviously something you can do and probably with relative ease; however, this ability is not trivial.

The problem at hand is that the quantity of visual information that exists in any given scene far exceeds what can be processed by the human cognitive system at any one point in time. Consequently, we are limited to fully processing only a select subset of the available information from moment to moment. One way the brain compensates for this capacity limitation is to “discard” information at very early stages of visual processing. For example, visual acuity drops off markedly as you move from the fovea to peripheral vision. This is thought to be related to decreasing photoreceptor density and an increase in the size of retinal ganglion cell receptive fields as you move from central to peripheral vision (Banks, Sekuler & Anderson,
1991; Curcio, Sloan, Kalina & Hendrickson, 1990). Moreover, the magnification of visual input from central vision continues as it reaches early cortical visual areas such as the primary visual cortex (V1) and extrastriate cortex area V2 (Holmes, 1945; Horton & Hoyt, 1991) – eye-movements allow us to foveate items that require more finely grained discrimination. In addition to these structural ‘filters’, the visual system further compensates for capacity limitations by sampling visual information from the environment selectively. Visual processing is guided by selective attention mechanisms that allow us to prioritise the processing of a restricted number of events or objects in the visual world on the basis of their visual salience and our task goals. For example, the knowledge that your favourite sweater is blue and the fact that it happens to be flanked by white garments in your closet will, among other factors, influence whether the visual input from the sweater is selected to undergo further processing along the visual pathway. To a large degree, our awareness of the world is determined by the objects and events that we come to attend to, thus, how attentional selection mechanisms are controlled and the information they are sensitive to has important consequences for how we interact with our environment. Unsurprisingly then, the question of what determines the events and objects in the world to which we orient and attend has been extensively studied in the fields of perception and cognition, and is the focus of this thesis.

To elaborate on the example used above, your ability to locate your favourite sweater in a closet full of clothes will be related to your knowledge of what the sweater looks like (i.e., its colour, shape and size etc.) and it’s likely location (e.g., Posner, 1980), but also to the context in which it is embedded (e.g., Becker, 2010). For example, if your sweater shares its colour with proximally located garments of similar shape and size, then your search may be slowed due the similarity between items (e.g., Becker, 2010; Duncan & Humphreys, 1989). If your sweater is the only blue item though, then you may find that colour in this instance can be used to rapidly locate your sweater (e.g., Treisman & Gelade, 1980; Wolfe, 1994). This simple and perhaps intuitive observation, that some searches are slow while others are highly efficient, is actually quite revealing about how visual attention is deployed throughout visual scenes and the stimulus properties that guide visual processing. In this thesis I will focus on one particular stimulus property that has received relatively
little attention within the visual search literature - stimulus novelty, or the extent to which a given stimulus can be expected to appear in a given context.

Imagine that your sweater came to be in your refrigerator rather than your closet. You might find that upon opening the refrigerator that you quickly become aware of your oddly placed sweater, despite having a goal at the time of searching for the milk. No doubt we all have encountered objects and events in the world that, at the time, seemed unexpected or out of place in the context in which they were experienced. Anecdotally, such events seem to capture our attention and are often stored in memory; this experience is supported by experimental evidence demonstrating a cascade of physiological and cognitive changes that occur in response to unexpected events (see Ranganath & Rainer, 2003 for a review). Indeed, from an ecological perspective, the ability to detect and respond to unexpected events in the environment would seem fundamental to survival. However, a relatively small amount of experimental work has explicitly explored the sensitivity of attentional control mechanisms to unexpected events and traditional theories of visual search have, to a degree, neglected to model this process.

In this thesis I present three experimental chapters that explore the sensitivity of attentional selection mechanisms to unexpected stimuli across varying search conditions. In Chapter 2, I establish that indeed stimulus novelty can guide visual attention, even when observers are set to search for another salient stimulus property. In Chapter 3, I examine what it might mean to the cognitive system for a stimulus to be novel or unexpected by examining the effect of top-down expectation and prior exposure on the response to an infrequently presented stimulus. Finally, there is a suggestion in the literature that there may be a separate underlying mechanism of control for unexpected and expected events. This is evidenced by an apparent shift in the time course of attentional capture by unexpected events relative to expected events. In Chapter 4, I investigate this claim by studying the temporal profile of attentional capture by unexpected events using eye-movements. The findings from these three chapters are discussed in the context of the ‘attentional control’ literature and converge on the conclusion that early selection mechanisms are sensitive to certain classes of novel stimuli. Moreover, my results suggest that attentional guidance mechanisms prioritize novel stimuli ahead of task relevant information, at least very early on in visual processing. Whether there is a dedicated
selection mechanism for novelty detection remains unclear. I will argue that current models of visual search can accommodate the findings presented here and thus, there may be no need to postulate a dedicated novelty detection system.

Although each of the experimental chapters has a different focus, each is motivated by the same central question - what determines the events in the visual world to which we orient and attend. As such, similar themes and concepts to those discussed in this introductory chapter will reappear at the beginning of subsequent chapters. To minimize redundancy throughout the thesis, in this introductory chapter I will focus on a more general overview of current and influential models of visual search and introduce the broader conceptual questions currently of interest to the field, while leaving some of the more detailed discussion of experimental methodologies and empirical findings to the introduction sections of the respective chapters. I will begin by briefly outlining some of the prominent and influential models of visual search that have been used to frame much of the work in the field over the past few decades.

**Visual Search**

Sensory input to the retina is processed in parallel by the visual system. However, capacity limitations imposed on the visual system mean that not all sensory input can be processed to its full extent at any one point in time. In what manner then are these limited resources distributed across the visual field? It is clear from experience as well as experimental work that the process is not random. Rather, selection mechanisms control the distribution of processing resources based on the properties of visual stimuli (e.g., highly salient stimuli) and the intentions and goals of the observer (e.g., look for red). However, the relative contribution of each of these factors in determining early visual selection has been the focus of much debate. Studying how visual attention is deployed throughout the visual field is central to understanding the processes that determine visual selection and the perceptual units that the human nervous and cognitive systems are tuned to.
**Feature Integration theory**

Treisman and Gelade’s (1980) highly influential *Feature Integration Theory* (FIT) represents one of the earliest attempts to describe the selection mechanisms involved in visual search and the perceptual units that guide visual processing. FIT is conceptually similar to earlier two-stage models of visual processing, specifically, Broadbent’s (1958) filter theory and Neisser’s (1967) proposed division of visual processing into pre-attentive and attentive stages. According to FIT the visual features of a scene such as orientation, colour and spatial frequency are extracted automatically without the need for serial scrutiny (attention) and are represented along separate spatially organized feature maps. Focused attention is then used to serially scan across feature maps and integrate features that share common spatial coordinates. That is, attention serves as the binding agent to integrate initially separate features to form single objects. The serial nature of this second feature binding stage contributes to our inability to perceive in detail an entire scene at once.

Much of the support for FIT has come from visual search experiments which have been used as a tractable adaptation of the real world problem of searching through cluttered environments. The typical visual search experiment involves searching for a target, such as a red ‘T’, embedded amongst an array of non-targets, such as green ‘T’-s, and making a judgment about the target’s presence or absence, or its features. What is typically found in these experiments is that search performance – generally measured using response time (RT) and or response accuracy – varies systematically with the nature of the search stimuli. For example, when the target is defined by a single feature and embedded amongst an array of homogenous non-targets (pop-out search), such as the example above, subjectively, the target can appear to ‘pop out’ of the display and search performance is generally found to be independent of the number of non-targets in the search array (set size) (Treisman, 1982; Treisman & Gelade, 1980). In contrast, if the target is defined as a conjunction of features (conjunction search), such as a red ‘T’ amongst and array of green ‘T’-s and red ‘L’-s, search performance has been shown to vary as a function of set size; as the set size increases search performance tends to decrease, and often linearly (Wolfe, 1994). Such a relationship between search performance and search mode is consistent with the central idea of FIT – that elementary features are
encoded in parallel and used to guide selection, while the integration of features represents a higher-order computation requiring a serial attentive process.

However, despite the ability of this relatively simple two-stage model of early visual processing to account for a number of effects reported in the visual search literature and beyond (see Treisman & Schmidt, 1982 on illusory conjunctions) the strict dichotomy that FIT proposes between parallel and serial search for single features and conjunctions, respectively, has been challenged by a number of studies demonstrating seemingly parallel processing of conjunctions (e.g., Cohen & Ivry, 1991; Egeth, Virzi & Garbart, 1984; Kaptein, Theeuwes & van der Heijden, 1995; Mcleod, Drive & Crisp, 1988; ) as well as other higher order properties of shapes and surfaces (e.g., Davis & Driver, 1994; He & Nakayama, 1992). Critically though, Wolfe, Cave and Franzel (1989) also noted that FIT allows for minimal influence of the parallel stage on the subsequent serial stage of processing. If the parallel stage fails to derive the target location on the basis of a single feature then the serial stage must scrutinize the output of each feature map to locate possible targets. That is, search proceeds in an unguided fashion. However, a number of studies have demonstrated that information accrued during parallel processing can be used to guide the serial mechanism (Bundesen & Pedersen, 1983; Egeth et al., 1984; Farmer & Taylor, 1980; Kaptein et al., 1995). For example, Egeth et al. (1984) found that when searching for a red ‘O’ amongst red ‘N’s and black ‘O’s, participants who attended to red performed the search more efficiently than participants who were told to attended to ‘O’, demonstrating that attending to a specific feature (red) could restrict search to items containing the relevant feature. Finally, attention has been shown to affect the perception of simple features, casting doubt on the notion that attention is not involved at the early stage of feature registration (Prinzmetal, Presti, & Posner, 1986).

**Guided Search**

It is a testament to the influence of FIT that many of the subsequent and current theories of visual search have retained a number of its key insights, namely the separate coding of different feature domains and the serial selection mechanism that integrates over the output of early parallel processes. One of the most successful derivatives of FIT is Wolfe et al.’s (1989) Guided Search (GS) model of visual search. Since its inception the theory has undergone a number of revisions
(see Wolfe, 2007), though at its core the theory has remained relatively unchanged. Similar in its structure to FIT and other two-stage models of visual processing (Neisser's, 1967; Hoffman, 1979), GS proposes that visual input is initially coded in parallel by the visual system then fed through to object recognition centres of the brain via a mandatory selection bottleneck. Access to the selection bottleneck is governed by selective attention (Wolfe, 2007). At the core of GS models (1.0 to 4.0) though is the notion that the output of early parallel processes can be used to guide the selective attention mechanism. For example, if the target is a red ‘O’ amongst red ‘N’s and black ‘O’s, then selective attention can be tuned to the output of early colour processes and guided, in this instance, to the red stimuli in the display (Egeth et al. 1984). That is, GS was the first model of visual search to describe explicitly how top-down processes that prioritize visual input according to the goals or intentions of an observer and bottom-up factors such as stimulus salience, or feature contrast interact to guide visual attention (see also, Duncan & Humphreys, 1989; Itti & Koch, 2000; Treisman & Sato, 1990); processes that were earlier identified by Posner (1980).

More specifically, GS proposes that the output from early visual processes is filtered through coarse categorical channels and represented along spatially organized feature specific maps. Top-down selectivity works by tuning attention toward a particular channel (e.g., red or horizontal) and modifying its gain. The activation along specific feature maps reflects a weighted sum of the bottom-up signal and any top-down activity through the channels plus some noise (Wolfe, 2007). The guidance signal is derived from integrating over all feature maps to form an overall saliency map, otherwise referred to as the “activation map”. The selection mechanism is then guided serially to the highest peak activations along the saliency map and selects input for processing through the bottleneck. Whether these peak activations correspond to highly salient inputs (e.g., a rose in a bed of weeds) or features that match the goals of the observer (e.g., your blue sweater amongst a rainbow of different coloured garments) depends on the weights applied to the respective channels. In the latest iteration of the GS, GS4, the weights are constrained to values between zero and one, such that a weight of one for a given feature or dimension means that all others will have a weight of zero. A bottom-up weight of zero is the formal version of the claim that salient but irrelevant stimuli do
not determine attentional selection independent of top-down processes. Although GS does not actually allow the bottom-up weight to be set to zero, it remains a topic of debate as to whether or not stimuli can capture attention involuntarily by virtue of their saliency alone. In the next section I will examine and summarize the existing literature concerning this debate.

Attentional Control

Although not all models of visual search adhere to the two-stage architecture found in models such as FIT (Treisman & Gelade, 1980) and GS (Cave & Wolfe, 1990; Wolfe, 1994, Wolfe 2007) (see Duncan & Humphreys, 1989), most theories of visual search model visual selection as an interaction between bottom-up factors, namely stimulus salience or local feature contrast, and top-down processes that prioritize inputs in accordance with the goals or intentions of the observer (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Itti & Koch, 2000; Treisman & Sato, 1990). However, the extent to which either of these factors predominates over attentional selection has been widely debated.

It is generally well accepted that visual selective attention can be shifted to locations in space while keeping the eyes fixated (Hoffman, 1975; Posner, 1980). This ability to prioritize input on the basis of spatial information is referred to as spatial attention and reflects the enhancement of performance for signals presented at a restricted region in space at the expense of other locations (Posner, 1980). Most theories of visual attention recognize that the deployment of spatial attention across the visual field can be controlled in one of two ways, either endogenously — voluntarily and in accordance with the immediate goals of an observer — or exogenously — involuntarily and in response to stimuli in the environment that may be of potential importance, though not necessarily related to ongoing tasks.

Support for the endogenous control of spatial attention comes from spatial cueing experiments demonstrating improved search performance when observers are given information about the location of an upcoming target or stimulus (Carrasco, Ling, & Read, 2004; Erikson & Hoffman, 1973; Posner, 1980; Posner, Snyder, & Davidson, 1980; Remington, 1980; Remington, Johnston, & Yantis, 1992). For example, Posner et al. (1980) showed that observers were faster to detect the
presence of a stimulus when they were cued correctly (80% valid) in advance to its likely location by a centrally presented arrow relative to when they were cued away from the location of the target. A similar pattern of results was observed when a task was to report the location (above or below fixation) of the stimulus. These results are consistent with the idea that the locus of visual attention can be shifted in a top-down fashion in accordance with the intentions of the observer and can result in enhanced signal processing at the attended location.

Posner et al. (1980) also demonstrated that a peripheral cue with no predictive value as to the target location could attract spatial attention when it was presented briefly and prior to the target presentation (see also, Jonides, 1981; Yantis, 1993; Yantis & Hillstrom, 1994; Yantis & Jonides 1988; Yantis & Jonides 1990; Theeuwes, 1991). In this case, responses to the target were impaired when a luminance onset appeared at a location that did not correspond with the subsequent target and were facilitated when the onset occurred at the same location as the subsequent target. This result demonstrates that spatial attention can also be shifted in an involuntary manner to visual stimuli in the environment. A question that has intrigued those interested in the structure and functionality of attentional selection processes is what happens when the demands of these two control mechanisms conflict?

Yantis and Jonides (1990) showed that when participants had accurate information about the location of an upcoming target, a peripheral luminance change, which otherwise was found to interfere with search (slow RTs), had no effect on search performance (see also Theeuwes, 1991; see though Christ & Abrams, 2006). However, the effect was abolished when the information given to participants about the target location was probabilistic rather than certain (Muller & Rabbitt, 1989; Yantis & Jonides, 1990). These results represent an example of how top-down information can negate the influence of bottom-up processes on attentional selection. Although there is general agreement that the efficiency of early selection is enhanced by spatial information about a stimulus, there is less agreement regarding the extent to which the visual system can take advantage of non-spatial information about a stimulus to enhance selection efficiency. More specifically, there has been considerable debate regarding the extent to which exogenous shifts of attention are modulated by top-down processes that reflect the goals and intentions
of an observer (e.g., looking for ‘red’). Indeed, implicit in most models of the visual attention - if not stated explicitly - is the notion that highly salient and irrelevant stimuli can guide selection (Duncan & Humphreys, 1989; Itti & Koch, 2000; Theeuwes, 2007; Wolfe, 1994), however, the conditions under which this can be the case have been debated. Resolving this issue is central to understanding how visual input is treated by early visual processes prior to attentional selection.

The ability of a non-predictive cue to attract spatial attention in the absence of reliable target location information has been interpreted by some as evidence that exogenous cueing reflects a bottom-up process that occurs automatically and largely independent of top-down processes (Theeuwes, 1991, 1992; Yantis & Jonides 1988). Such an interpretation is consistent with models of visual attention which propose that early selection is determined by the initial feed-forward sweep of information through the visual system, where only saliency information (e.g., feature contrast) is extracted and represented along a saliency map. Top-down processes are modelled as re-entrant signals that modulate inputs only after saliency information has been extracted from a scene and used to guide early visual processes (Itti & Koch, 2000; Theeuwes 1991; 2007). Proponents of bottom-up models of visual attention have traditionally cited two key observations to support the claim that early selection is governed by saliency-based mechanisms: The first is the observation that targets that are sufficiently dissimilar from their non-targets (e.g., have a high feature contrast) can appear to ‘pop-out’ of the display and produce efficient search (Treisman, 1985; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Duncan & Humphreys, 1989; Wolfe, 1994). As Yantis and Egeth (1999) and others have pointed out though (see also Folk, Remington, & Johnston, 1992; Yantis, 1996), efficient search for salient targets (i.e., feature singletons) does not necessarily imply that salient items guide attention automatically and in a stimulus-driven fashion. When an item or feature is task relevant (i.e., relates to or defines the target) then it is likely that any resulting attentional effects elicited by the target are, at least in part, related to top-down or task driven processes. To warrant the conclusion that salient items capture attention automatically, they must do so in a way that is independent of the task demands (Yantis & Egeth, 1999).

This criticism is thought to be addressed by the second observation that salient distractors can interfere with search performance even when they are
seemingly unrelated to the immediate task at hand (e.g., *colour singletons*:
Theeuwes, 1991, 1992; 1994, 2004; *abrupt onsets*: Jonides & Yantis, 1988; Yantis & Jonides 1984; Yantis & Jonides 1990; Lamy & Egeth, 2003; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinsky, 1999; *motion onset*: Abrams & Christ, 2006; *new objects*: Hillstrom & Yantis, 1994). For example, Theeuwes (1992) showed that when searching for a shape amongst a circular array of homogenous non-targets, response times (RTs) were elevated by a colour singleton presented on 50% of trials. The same was not true when the roles of the colour and shape singletons were reversed (i.e., a colour singleton target and a shape singleton distractor). Theeuwes (1992) reasoned that this asymmetric result pattern reflects the perceptual experience of pop-out for colour singletons that is attenuated for form singletons and concluded that selection primarily depends on the bottom-up activations produced by feature contrast, irrespective of whether the input relates to the target or an irrelevant distractor.

In contrast to bottom-up models of visual attention are top-down models that place a degree of emphasis on the task demands and the intentions of the observer in determining attentional guidance (Ansorge & Heumann, 2003; Becker, 2010; Duncan & Humphreys, 1989; Folk & Remington, 1998; Folk et al., 1992; Treisman & Sato, 1990; Wolfe, 1994, 2007). Top-down models of visual attention propose that the selection mechanism can be tuned in a top-down manner to specific non-spatial properties of a stimulus (e.g., ‘red’ or ‘bright’) biasing the selection mechanism toward stimuli that possess task relevant features (see earlier discussion of Wolfe’s Guided Search model). Proponents of top-down models point to the observation that irrelevant distractors appear to capture attention to the extent that they resemble the target (Ansorge & Heumann, 2003; Becker, Ansorge, & Horstmann, 2009; Eimer, Kiss, Press & Sauter, 2009; Folk et al., 1992; Folk & Remington, 1998; Folk, Remington & Wright, 1994; Ludwig & Gilchrist, 2002, 2003). For example, Folk & Remington (1998) found that a non-predictive colour singleton presented prior to the target in a spatial cueing paradigm had a differential effect on search performance depending on its featural relationship with the target. When the colour singleton matched the colour of the search target (e.g., both were red) search performance was found to vary as a function of the location of the colour singleton; when the colour singleton occurred at the same location as the target RTs were short relative
to when it occurred at a non-target location. The same relationship between search performance and cue location was not observed when the colour singleton was not the same colour as the search target (e.g., red target, green colour singleton). This similarity effect suggest that top-down processes can be tuned toward non-spatial properties of a stimulus and the ability to do so can have an effect on the efficiency of visual selection.

One of the more influential top-down accounts is the contingent capture hypothesis proposed by Folk and colleagues (Folk et al., 1992; Folk & Remington, 1998). According to contingent capture, guidance is determined by the configuration of task-driven selection mechanisms that select stimuli according to the task demands. Salient stimuli are predicted to capture attention only to the extent that they match the ‘attentional control settings’ of the observer. Salient features that do not share task defining properties with the target can be ignored, even when they are highly salient. For example, Folk et al. (1992) showed that an abrupt onset presented immediately prior to the target in a spatial cueing paradigm had a differential effect on performance according to the target of search. When the task was to search for a colour singleton, only matching-colour distractors affected search performance; abrupt onsets did not capture attention. These results support the notion of a feature-specific attentional system that guides attention in accordance with the goals of the observers.

How then do we reconcile this similarity effect with bottom-up models of visual attention that cite interference from task irrelevant salient items as evidence for a saliency based guidance mechanism? Proponents of top-down models have suggested that reports of saliency-based guidance may be the result of search strategies that inadvertently render distractors task relevant (Bacon & Egeth, 1994; Wu & Remington, 2003). Indeed, using a similar experimental design to Theeuwes (1992), Bacon and Egeth (1994) found that an irrelevant distractor only interfered with search performance in conditions that encouraged participants to search for an odd-man out (any feature singleton) rather than a specific feature. Consistent with Theeuwes (1992), when the task was to search for a shape singleton (e.g., a square target amongst an array of circle non-targets) an irrelevant colour distractor presented on 50% of trials produced RT interference. However, when participants were forced to search for a specific shape (e.g., a square target amongst an array of
circles and diamonds) an irrelevant colour singleton did not produce RT interference. Bacon and Egeth (1994) argued that when the target of search is a singleton, participants adopt a ‘singleton search’ mode to find the target. In this mode any salient singleton will guide attention, explaining why they observed interference from the irrelevant colour singleton in this condition. The fact that the same interference was not observed when the target was not a singleton demonstrates that participants were able to tune attention in a top-down manner to the specific feature value of the target (see also Wu and Remington, 2003).

Related to this point, Gibson and Kelsey (1998) have noted that other more subtle methodological incentives can lead to effects that resemble stimulus-driven guidance. Often in visual search experiments the appearance of the search array is signaled by a display-wide onset or colour change. Gibson and Kelsey (1998) have suggested that such signals can induce broad display-wide attentional sets that render otherwise irrelevant distractors task-relevant. Gibson and Kelsey (1998) demonstrated this by showing a contingency between display-wide visual features (i.e., features that signal the appearance of the search display) and the features that guide attention. When colour and onset were used to signal the appearance of a search array both task irrelevant colour and onset distractors affected search performance. However, when the search array was signaled only by onset, colour distractors had no effect on search performance (Gibson & Kelsey, 1998).

Finally, claims of stimulus-driven capture are often based on the observation that the presence of an irrelevant distractor can produce a slowing of RTs. However, irrelevant salient distractors have been shown to produce RT interference without producing the pattern of spatial costs and benefits associated with capturing attention (Becker, 2007; Folk & Remington, 1998). Folk and Remington (1998) found that an irrelevant colour distractor produced RT costs (i.e., an elevation of baseline RT) despite not observing a spatial validity effect – an RT difference between valid and invalid presentations of a distractor – associated with the distractor. They attributed this general RT slowing to a filtering cost, a form of distraction that is distinct from orienting attention away from a target toward a distractor (see also Kahneman, Treisman, & Burkell, 1983). Thus, without demonstrating a clear spatially specific effect, such as a validity effect or saccades directed towards the distractor, it can be difficult to make a strong case for attentional capture.
In summary, though stimulus factors clearly play a role in determining visual selection, the claim that attentional guidance reflects a purely bottom-up process where inputs are prioritised, at least initially, on the basis of visual salience has proved difficult to validate experimentally. Conceptually, the position also seems problematic; given the dynamic nature of real-world environments an orienting system at the mercy of bottom-up processes seems poorly suited to executing goal directed behaviours. However, equally problematic is a system that prioritises only those inputs that are immediately relevant to the observer. Environments are often dynamic and occasionally unpredictable, and instances can arise where it becomes necessary to interrupt goal directed behaviours and prioritize signals that fall outside the scope of an observer’s task set. The observation that top-down processes can act to attenuate or even prevent distraction from irrelevant sources suggests the need for an interrupt system that guides visual attention to items and events of potential importance, independent of the immediate priorities of the observer. Many have argued that luminance transients serve this role (e.g., Yantis & Jonides 1990; Theeuwes et al., 1998; Abrams & Christ, 2006), though as I have discussed, in many instances these claims are disputed on methodological grounds (e.g., Bacon & Egeth, 1994; Gibson & Kelsey, 1998) and in other cases transients have been shown not to capture attention when the participant’s goal is to search for a feature value from another stimulus dimension (e.g., Folk et al, 1992). What then is the mechanism that reliably brings to our awareness stimuli and events that require rapid responding to but that may initially be task-irrelevant?

**Stimulus Novelty**

“A considerable number of writers have expressed, and more or less fully developed, the view that what is heterogeneous, in some respect or another, with the simultaneous or the more immediate foregoing contents of consciousness, with previous experience in general, or with expectation, attracts or holds attention” ~ Wilcocks, R. W. (1928)

The typical visual search experiment requires participants to complete hundreds of search trials in one experimental session. Performance indices such as RT and accuracy scores that are used to compare behaviour across experimental
conditions are generally computed by averaging performance across a large number of experimental trials. Basing an estimate of performance on multiple observations has its obvious benefits, however as Gibson and Jiang (1998) have pointed out, you can lose sensitivity to effects that may vary as a function of time or presentation number. It is also true that over the course of a typical visual search experiment stimuli are presented repeatedly and frequently, and often with a degree of predictability. Gibson and Jiang (1998) suggested that task related expectations may contribute to the control of exogenous attention and that failures to observer saliency based effects in the past might be related to the rapid habituation of orienting processes to salient stimuli across multiple presentations.

Indeed, the view that the human perceptual system has an appetite for the unexpected and novel dates back to the early psychological literature and even before (Darwin, 1872/1965; Descartes, 1649/1984; Wilcocks, 1928) and is expressed by models of perception and cognition that emphasize the role played by expectations in determining our conscious percept of the world (Horstmann, 2005; Meyer, Niepel, Rudolph & Schützwohl, 1991; Sokolov, 1963). One of the earliest theoretical accounts of human orienting behaviour was proposed by Sokolov (1963) who described the behaviour as a reflex that is triggered by objects and events in the world that violate a set of contextually specific expectations labeled the neuronal model. According to Sokolov (1963) a stimulus or event will continue to capture attention and demand the resources of the perceptual system until the neuronal model is updated – a process that occurs over repeated exposure to a novel input. Whether it is accurate to describe attentional orienting as a reflex is perhaps debatable, however, the broader notion of an orienting mechanism that directs processing resources toward stimuli that do not ‘fit’ with some internal predictive model of the world, whether this be nervous or otherwise, is also central to many schematic theories of cognition and perception (Neisser, 1976; Rumelhart, 1984; Rumelhart, Smolensky, McClelland, & Hinton, 1986; Meyer, Niepel, Rudolph & Schützwohl, 1991).

Models of perception and cognition that emphasize the role of expectation and prediction in attentional selection and conscious perception are supported by the observation that unexpected stimuli evoke distinct patterns of neural activity (Asplund, Todd, Snyder, Gilbert & Marois, 2010; Heslenfeld, 2003; Näätänen, 1992
Yamaguchi, Hale, D’Esposito & Knight, 2004; for a review, see Ranganath & Rainer, 2003) and are associated with numerous perceptual and behavioural phenomena (Czigler, Weisz & Winkler, 2006; Horstmann 2005; Meyer, Niepel, Rudolph & Schützwohl, 1991). For example, within the auditory domain, the presentation of an infrequent and physically deviant \textit{(oddball)} auditory stimulus in a sequence of otherwise homogeneous stimuli has been found to evoke an early negative going event related potential (ERP) in the electro-encephalogram (EEG) which coincides with increased memory recall for the oddball stimulus (Näätänen, 1992, 1995). This negative component is referred to as the \textit{mismatch negativity} (MMN) and is thought to reflect a neural mismatch processes that contributes to shifting attention to salient changes in the environment (Näätänen, Paavilainen, Rinne, & Alho, 2007). Critically, the effect arises independent of whether an observer is attending to the audio stream containing the deviant stimulus or not (Näätänen et al., 1993).

An analogous ERP component has been observed in the visual modality in response to visual oddballs (Alho et al., 1992; Tales et al., 1999; Czigler, Balazs, & Pato, 2004; for a review see: Pazo-Alvarez et al., 2003), and visual oddballs have been found to induce robust dilations in time perception (Pariyadath & Egleman, 2007; Tse et al., 2004; Schindel, Rowlands, & Arnold, 2011). For example, Tse et al., (2004) showed that an infrequent red disk presented in an otherwise homogenous sequence of black disks was perceived by observers to be presented for longer than its objective presentation duration. Tse et al., (2004) labelled this effect \textit{time’s subjective expansion} (TSE) and have attributed it to the engagement of attentional processes with the oddball that influence the amount of perceptual information processed per unit time.

Within the visual search literature unexpected stimuli have been associated with increased memory recall (Meyer et al., 1991; Niepel et al., 1994; Meyer, Reisenzein & Schützwohl, 1997; Schützwohl, 1998), behavioural interference (Asplund, Todd, Snyder, Gilbert & Marois, 2010; Geyer, Muller, & Krummenacher, 2008; Horstmann, 2005; Neo & Chua, 2006; Schützwohl, 1998) and increases in discrimination accuracy when an unexpected stimulus coincides with the target location (Horstmann, 2002, 2005, 2006). Taken together, these results are consistent with the notion of a selection mechanism that is sensitive in some capacity to unexpected and novel stimuli. The vast majority of studies that have
demonstrated attention shifts to unexpected items have done so during inefficient, serial search (e.g., search for the letter H or U among heterogeneous non-target letters, S, E, F, P, L; Horstmann, 2005). Hence, it is currently unknown whether attentional capture by novel, unexpected stimuli would still dominate visual selection when we are engaged in ‘guided search’ (e.g., searching for a red stimulus), and the target competes for attention with the novel object.

Interestingly, Neo and Chuo (2006) showed that an infrequently presented onset distractor can interfere with search even when participants know in advance where the search target will appear. Using a spatial cuing paradigm, Neo and Chua (2006) had participants report the identity of a target (E or U) that appeared at a prespecified location in the search array. Prior to the target onset an onset distractor could appear at a non-target location on either 75% of trials or just 19% of trials. When the onset distractor was frequent (75% condition) they replicated the results of Yantis and Jonides (1990) by showing that the onset distractor did not slow RTs when participants knew with certainty the location of the target. However, when the distractor was infrequent (19% condition) RTs on the distractors trials were significantly elevated relative to the no distractor trials. This result is important because it demonstrates that presentation frequency can influence search efficiency even when participants are able to shift spatial attention in advance to the location of the target; whether this is also true when observers have a top-down set for non-spatial features (e.g., red) is not known. That is, can an attentional set for a specific feature prevent distraction from a salient task-irrelevant but unexpected stimulus or do unexpected events represent a true form of saliency based capture that occurs independent of top-down processes?

Determining the answer to this question has important consequences for models of visual selection that seek to explain how we are able to ignore much of the irrelevant information that presents to the visual system while simultaneously guiding the selection mechanism to task relevant input. In Chapter 2 I focus on establishing that indeed unexpected and salient task-irrelevant distractors can guide visual attention independent of an observer’s goals or intentions. In Chapters 3 and 4 I present work that is focused on revealing the mechanism by which we come to be to be sensitive to unexpected events in the world. My results are discussed in the context of contemporary models of visual attention.
Chapter 2 - An Effective Attentional Set for a Specific Colour Does Not Prevent Capture by Infrequently Presented Motion Distractors
Summary

In Chapter 2, I investigate the extent to which task-expectancies can modulate attentional capture and the role of top-down control in this process. Several studies have demonstrated that unexpected salient stimuli can draw attention involuntarily and that this form of capture is distinct from purely stimulus driven capture. Yet, the extent to which top-down control can modulate capture by this class of stimulus remains unclear. What follows is a series of experiments that test whether an attentional set for a specific colour can prevent capture by an infrequently presented motion distractor.

Abstract

An organism’s survival depends on the ability to rapidly orient attention to unanticipated events in the world. Yet, the conditions needed to elicit such involuntary capture remain in doubt. Especially puzzling are spatial cueing experiments, which have consistently shown that involuntary shifts of attention to highly salient distractors are not determined by stimulus properties, but instead are contingent on attentional control settings induced by task demands. Do we always need to be set for an event to be captured by it, or is there a class of events that draw attention involuntary even when unconnected to task goals? Recent results suggest that a task-irrelevant event will capture attention on first presentation, suggesting that salient stimuli that violate contextual expectations might automatically capture attention. Here, we investigated the role of contextual expectation by examining if an irrelevant motion cue that was presented only rarely (~3-6% of trials) would capture attention when observers had an active set for a specific target colour. The motion cue had no effect when presented frequently, but when rare produced a pattern of interference consistent with attentional capture. The critical dependence on the frequency with which the irrelevant motion singleton was presented is consistent with early theories of involuntary orienting to novel stimuli (Sokolov, 1963). We suggest that attention will be captured by salient stimuli that violate expectations, whereas top-down goals appear to modulate capture by stimuli that broadly conform to contextual expectations.
Lower layers of our visual system receive far more stimulation from the external world than is possible for our cognitive system to fully process. To compensate, mechanisms of selective attention allow us to focus cognitive processing on a small number of events or objects in the world. As a result, our conscious awareness consists primarily of those objects and events to which we have attended, and attended objects come to have a much greater force in determining our behaviour than do unattended items. It is not surprising then that psychologists have devoted much effort to understand how attention is controlled and what determines the events in the visual world to which we orient and attend.

Modern theories of attention recognise two forms of attentional control: endogenous control that allows us to voluntarily direct our attention to task-relevant objects and events, and exogenous control that directs attention involuntarily toward objects and events of possible importance that are not necessarily related to the ongoing task (Posner, 1980; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991; Yantis & Jonides, 1984, 1990). The control mechanisms by which attention is involuntarily directed to objects and events have been the topic of much debate, particularly the degree to which involuntary orienting (attentional capture) can be modulated by top-down mechanisms (Yantis, 1993). Theories positing stimulus-driven (bottom-up) attentional capture argue that salient stimuli can automatically draw attention to their corresponding locations, in virtue of their bottom-up saliency and independent of the goals and intentions of the observers (Theeuwes, 1992; 1994; 2004; Theeuwes & Burger, 1998). Any modulation of attention by top-down mechanisms is presumed to occur late in processing, after attention has been shifted towards a stimulus ("de-allocation hypothesis"; see Belopolsky, Schreij & Theeuwes, 2010; van Zoest, Donk, & Theeuwes, 2004). In contrast, theories positing top-down modulation of attentional capture, such as contingent attentional capture (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994), posit that involuntary attention shifts are contingent on the task demands and the goals of the observer. A salient, task-irrelevant item ("distractor") is presumed to capture attention only when it shares the task-relevant feature(s) of the search target. For example, Folk et al. (1992) showed that when the target was defined by an abrupt-onset, an abrupt-onset cue but not a salient colour cue captured attention. In contrast, in search for a colour target, only a colour cue with the same colour as the
target but not an abrupt-onset cue captured attention. Subsequent studies showed that a red cue captured attention when observers were searching for a red target, but not when they searched for a green target, and vice versa for the green cue (Folk & Remington, 1998; see also Ansorge & Heumann, 2003), indicating that attention can be set for specific feature values within a stimulus dimension. Capture contingent on task goals has been found for eye movements (e.g., Becker, Ansorge & Horstmann, 2009; Ludwig & Gilchrist, 2002; Wu & Remington, 2003) and EEG (e.g., Eimer, Kiss, Press & Sauter, 2009; Lien, Ruthruff, Goodin, & Remington, 2008; Wykowska & Schuboe, 2009). Further support for the role of top-down goals comes from evidence that target-similar distractors are more effective in capturing attention than target-dissimilar distractors across a range of different stimulus dimensions (e.g., size: Becker, 2010; onsets: Ludwig & Gilchrist, 2002).

Evidence for bottom-up saliency capture.

The evidence for top-down modulation of capture raises the question of how we become aware of events that are not tightly bound to ongoing task goals. The need for an interrupt system to protect us against predation, at the very least, suggests that some property of external events should be capable of triggering a purely stimulus-driven shift of attention. Such a claim has been made for stimuli presented with an abrupt luminance onset (Jonides & Yantis, 1988; Ludwig & Gilchrist, 2002; Yantis & Jonides 1984; Yantis & Jonides 1990; Lamy & Egeth, 2003; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinsky, 1999), for the presentation of a new object (Hillstrom & Yantis, 1994), for motion onset (Abrams & Christ, 2003; Pratt, Radulescu, Guo, & Abrams, 2010), and for stimuli that have a high feature contrast in other dimensions, such as colour (Theeuwes, 1991, 1992; Itti & Koch, 2000). However, the evidence for stimulus-driven capture by all of these has been disputed.

Capture is often inferred when the presence of an irrelevant distractor results in elevated visual search times compared to no-distractor studies. It has been shown that such increases can be associated with a broadly defined target template that included the distractor attributes and can be eliminated when care is taken to insure a precise feature set (see Bacon & Egeth, 1994; Wu & Remington, 2003). For example, Bacon and Egeth (1994) found that irrelevant colour singletons only interfered in a visual search paradigm when the task encouraged a strategy of
searching for a singleton. When the task required that observers search for a specific feature (form), irrelevant colour singletons no longer interfered with search performance. Similarly, Wu and Remington, (2003) found that erroneous eye movements to an irrelevant distractor ('oculomotor capture') in visual search are largely contingent on the task demands and the attributes of the search target. When the goal was to saccade to a colour singleton in the display, an irrelevant onset distractor produced oculomotor capture. However, when the task required participants to search for a specific feature (colour), oculomotor capture by the same irrelevant onset was significantly attenuated.

In addition to such strategic biases that arise from explicit task demands, search performance can also be influenced by more subtle incentives of the method that can go unnoticed. Gibson and Kelsey (1998) demonstrated that apparent stimulus-driven effects in visual search paradigms can be explained by a match between the visual characteristics of distractors and display-wide attentional settings. They argued that the onset of the visual search display can serve as a trigger to begin searching and thus, induce an attentional set for onsets. Indeed, Gibson and Kelsey (1998) found that onset distractors could capture attention when the search display was abruptly onset, but not otherwise.

Interference by task-irrelevant distractors in visual search has also been shown to arise from general, non-spatial forms interference without eliciting an attention shift to its location ('filtering hypothesis'; e.g., Folk & Remington, 1998; see also Becker, 2007). Critically, these studies identify an issue with inferring attentional capture solely from a general slowing of response times to the presence of a task-irrelevant distractor. The possibility of non-spatial interference not associated with attention highlights the need for a measure that more clearly reflects the spatial locus of attention. In spatial cueing studies, for example, cues that cause a spatial reallocation of attention will lead to faster response times in conditions in which the cue occurs at the subsequent location of the target (valid) compared to those that occur at a non-target location (invalid).

**Novelty and unexpected stimuli.**

A characteristic of virtually all disputed findings is that distractors, like targets and non-targets occurred regularly and could be said to conform to contextual
expectations. That is, even though distractors do not occur on every trial, nor is their location predictable, they occur frequently enough to be part of the contextual expectancies of the sequence of events. This raises the possibility that top-down control might be restricted to stimuli conforming to contextual expectancies and, correspondingly, that stimulus-driven capture may be a product of stimulus expectations, rather than its specific physical properties. The role of expectations, including the importance of novelty, is a central feature of the Orienting Reflex proposed by Sokolov (1963). The Orienting Reflex refers to a constellation of physiological and cognitive changes in response to novel stimuli whose appearance violates contextual expectations (Sokolov, 1963). According to the theory a stimulus will elicit a reflexive orienting response only when it generates a sufficient mismatch between the input from the environment and the established neuronal model or schema of that environment. Repeated exposure to a stimulus adjusts the neuronal model to incorporate the once-novel stimulus and it no longer causes reflexive orienting.

The idea a neural model that ultimately governs orienting behaviour is consistent with the observation that novel and unexpected stimuli elicit distinct patterns neural activity (Asplund, Todd, Snyder, Gilbert & Marois, 2010; Friedman, Cycowicz & Gaeta, 2001; Heslenfeld, 2003; Näätänen, 1992 Yamaguchi, Hale, D'Esposito & Knight, 2004; for a review, see Polich, 2007; Ranganath & Rainer, 2003). Specifically, the P300 - a positive going ERP component thought to reflect numerous brain processes associated with memory and attention – has a robust association with the detection of new or rare events/stimuli (Friedman, Cycowicz & Gaeta, 2001; Knight & Nakada, 1998; Polich, 2007). Often referred to as the P3 novelty potential, it is thought to be a signature of neural processes involved in updating the contents of working memory following the detection of a new or unexpected stimulus. Furthermore, functional Magnetic Resonance Imaging (fMRI) and electrophysiology studies have mapped these signals to a distributed network in the brain which includes areas such as the hippocampus (Kiehl et al., 2001; Strange & Dolan, 2001; Yamaguchi et al., 2004), the temporal parietal junction (TPJ) (Asplund, Todd, Snyder & Marois, 2010; Halgren et al., 1995; Yamaguchi et al., 2004) and select regions of the pre-frontal cortex (Asplund et al., 2010; Clark et al.,
2500; Baudena, Halgren, Heit, & Clarke, 1995; Yamaguchi et al., 2004) - regions which are important for memory and learning (Ranganath & Rainer, 2003).

One plausible inference from the Orienting Reflex is that contingent capture only extends to events within a given schema or set of task-expectancies. That is, our ability to ignore irrelevant salient distractors could depend on contextual expectations that describe the characteristics of distractors to be inhibited (e.g., Becker, 2007; Folk & Remington, 1998; Treisman & Sato, 1990). Support for this comes from a study by Horstmann (2005) who had observers search for the letter L or R in an array of 4 or 12 different letters. After familiarization trials, the target letter was unexpectedly presented in a different colour (e.g., red, among all-green items). Search times for these “changed” targets were very fast and independent of the number of non-targets (3 or 11), suggesting that the first presentation of an unexpected salient item attracted attention in the absence of any intentions to either attend to the item or ignore it. After repeated presentations of the unannounced stimulus, observers will quickly adapt their search strategy; viz. they will actively attend to the unannounced salient stimulus when it is predictive of the target location, and ignore it when it is not predictive (e.g., Horstmann & Becker, 2008). Horstmann (2005) accounted for the elevation of visual search times for the first occurrence of an unexpected stimulus by a new mechanism of surprise capture, distinct from capture by the salience or feature value of the new object.

Further evidence for the ability of unexpected items to capture attention comes from spatial cueing experiments by Neo and Chua (2006) who examined whether irrelevant distractors would interfere with search when observers had prior knowledge of the target location. Participants reported the identity of a target letter (E or U) in a search display, the location of which was pre-specified by a central arrow cue. In separate blocks, an irrelevant onset distractor was presented either frequently (75%) or infrequently (~19%) 200 ms prior to the onset of the target. Performance on the letter identification task was impaired when the onset distractor was presented infrequently, but no effect of the distractor was observed when it was presented frequently. Neo and Chua (2006) argued that the onset distractor captured attention when it was presented infrequently because it was not integrated into the neuronal model or schema expectations. Though suggesting that unexpected stimuli can capture attention, these results are at odds with the findings of Yantis and Egeth.
that rare singletons (20% and 4%, respectively) are attended when they are predictive of the target location, whereas singletons that are non-predictive are ignored. Moreover, the design used by Neo & Chua left open the possibility of display-wide settings for abrupt onsets, as subjects could not set for a specific property of the target, but could only monitor for the luminance change that signalled the presentation of the target display. Similarly, it is not entirely clear whether the onset distractor indeed captured attention, or whether it interfered in a spatially non-specific way with later processes, concerning, for example, target identification, or the response.

An effect of distractor frequency has also been observed on the number of erroneous first saccades to distractors in visual search, referred to as oculomotor capture. Geyer et al. (2008) monitored observers’ fixation pattern as they searched for a shape singleton (diamond embedded amongst circle non-targets; see Theeuwes, 1991) in distractor and no-distractor conditions. The proportion of first saccades to a colour singleton distractor presented at a non-target location was greatest when the distractor was presented on 20% of the trials relative to conditions in which the same distractor was presented on 50% and 80% of trials. However, a consequence of varying the distractor presentation frequency in separate blocks was to also vary the percentage of trials in which the target was a singleton in each block. When the distractor was presented on 20% of trials, the target was a singleton on the remaining 80% of trials, and vice versa (see also Sayim, Grubert, Herzog, & Krummenacher, 2010). Therefore it is possible, if not probable, that observers’ task-set varied across conditions, such that in the low frequency condition observers adopted a strategy to search for any singleton item (e.g., singleton detection mode; Bacon & Egeth, 1994) rather than to a feature-specific set, leading to capture by more salient colour distractor (e.g., Theeuwes, 1991).

**Aim of the present study.**

The studies of Horstmann (2005), Neo & Chua (2006), and Geyer et al. (2008) support the principle assumption of the Orienting Reflex of Sokolov (1963) that attention will be involuntarily captured by salient events that violate contextual expectations. However, to demonstrate that a stimulus attribute, even its novelty, is sufficient to produce stimulus-driven involuntary capture attention it is necessary to satisfy two conditions: 1) that attention is in fact reallocated to the location of the
stimulus; and, 2) that there are no incentives in the design that would have led subjects to adopt strategies for singletons or properties other than the desired set for the target feature. As discussed above, the existing demonstrations of the effects of infrequent distractors are open to criticism in failing to satisfy one or both of these two conditions. In particular, the Geyer et al. (2008) study, which does show spatial reallocation, leaves open the possibility of a singleton detection mode strategy.

The aim of the present study was to examine the ability of unexpected events to involuntarily capture attention under conditions that satisfy both the requirement of spatial reallocation and the requirement that subjects are set for a specific feature property. To do this we used the modified spatial cueing paradigm of Folk et al. (1992), in which an irrelevant distractor (’cue’) is presented prior to the target display. If the cue captures attention, response times (RTs) will be faster when the target is presented at the cued location (valid trials) than on when it is presented at a non-cued location (invalid trials), as on valid trials attention will already be at the target location. This cueing effect is positive evidence that the cue has drawn attention to a specific spatial location. In our spatial cueing paradigm, participants searched for a red target embedded among three white non-targets and were instructed to ignore irrelevant red and green cues presented prior to the target frame. Cue location was independent of target location and, thus, uninformative as to target location. Previous studies have shown a cueing effect for red cues – faster RTs to valid than invalid red cues – when participants search for a red target, but not for green cues, evidence for contingent capture by target-matching red cues, but not by green cues (e.g., Ansorge & Heumann, 2003; Folk & Remington, 1998). An effect of cue validity to cues that match the target, but not those that do not, suggests an active set for the target property. If a corresponding pattern can be observed in the present study, we can infer that attention was biased to the target feature value (red), not to other attributes of the target or search display (e.g., singleton status or display-wide features; Bacon & Egeth, 1994; Gibson & Kelsey, 1998). By showing such an effect, we can ensure that any capture associated with infrequent cues takes place in the presence of an active set for the target property.

To examine the effects of contextual expectations we included a motion cue that was presented frequently (Exp. 1) or infrequently (Exp. 2–5). The motion cue was created by rotating four white dots around a placeholder box in a clock-wise
fashion. Motion cues have been shown to capture attention in the spatial cueing paradigm when they are similar to the target but not when they were dissimilar to the target (e.g., Remington, Folk & McLean, 2001; Folk, Remington, & Wright, 1994). In Experiment 1, we presented the red, green and motion cue equally often, on 1/3 of all trials. To examine contextual expectations subsequent experiments limited the presentation of the motion cue to a small fraction of trials. The underlying logic is that frequently presented motion cues would be incorporated into the general experimental context and thus not constitute a violation of expectations, whereas rarely observed motions cues would violate expectations. Involuntary capture by salient stimuli that violate contextual expectations predicts two important outcomes: 1) a cueing effect for red, but not for green cues; and, 2) a cueing effect for infrequent motion cues, but not for frequently presented motion cues.

**Experiment 1**

Before a claim can be made about the role of stimulus novelty in driving shifts of spatial attention, it is necessary to establish that the same stimulus presented regularly does not capture attention. In Experiment 1 subjects responded to a red target in the search display. A cue frame preceding the target frame consisted of either a red, green or motion cue presented with three white non-cues at the other locations. According to contingent orienting (Folk & Remington, 1998) the red cue should capture attention, but not the others. This should be reflected in the presence of a *cueing effect* for red, but not for the green or motion cues (Folk et al., 1992, Folk et al., 1994).

**Method**

**Participants**

Fifteen participants (9 female) aged 17 - 24 (M = 19.6, SD = 2.3) from the introductory psychology course at the University of Queensland participated for course credit. All reported normal or corrected to normal vision.

**Apparatus**
Experiments 1 - 4 were conducted using the computer software package Presentation (Neurobehavioural Systems). Stimuli were presented on a 19-inch CRT monitor attached to a (Pentium 4) personal computer. Responses were recorded using a two-button mouse.

Stimuli

Each trial consisted of a fixation display, a cueing display and a target display. The fixation display was comprised of a central white fixation cross (0.4° x 0.4°) surrounded by four peripheral boxes (2.1° x 2.1°) with white borders positioned (3.3°) above, below, to the left and to the right of fixation. The cueing display was comprised of the same stimuli as the fixation display with the addition of four filled circles (0.4°) in a diamond configuration surrounding each location ('four-dot cue'; e.g., Folk et al., 1992). On every trial the four-dot cue was coloured either red (RGB = 255, 0, 0), green (RGB = 0, 255, 0) or rotated clockwise around the box to create the perception of motion. The motion cue consisted of a 90° rotation of the diamond in three 30° clockwise increments at 40ms intervals (see Figure 1). The circles comprising the motion singleton were coloured white (RGB = 255, 255, 255). All stimuli were displayed on a black background (RGB = 0, 0, 0).

The target display was comprised of the same stimuli as the fixation display with the addition of a tilted bar presented in each of the four peripheral boxes (see Figure 1). The bars were tilted either 45° to the left or to the right and subtended 0.7° of visual angle vertically and 0.7° of visual angle horizontally. On every trial three of the titled bars were white while one, the target, was coloured red (RGB = 255, 0, 0). All stimuli were presented against a black (RGB = 0, 0, 0) background.

Design

Presentation of the cues (red, green and motion) was randomised across the experiment with each cue occurring an equal number of times. The location of the cue was not correlated with the location of the target. On valid trials (25%), the target and the cue were presented at the same location. On invalid trials (75%), they were presented in different locations. Participants were informed of the three cue types prior to commencing the experiment and instructed to do their best to ignore the stimuli in cueing frame as the cue was uncorrelated with the target location. The target and the cue occurred at each location equally often. The orientations of the
non-target tilted bars that appeared at the three non-target locations were randomized.

Figure 1. A) Example trial sequence from Experiment 1. All cues were non-predictive of the target location. B) Time-course of the motion cue. Each frame was presented for 40ms for a total duration of 160ms.

Procedure

Each trial began with the presentation of the fixation display for 500ms. Following this, the fixation cross offset for 50ms. Then the fixation display reappeared for a randomly determined interval of 500, 600, 700, 800 or 900ms. The
cuing display was then presented for 160 ms followed by the fixation display again for 100 ms and then the target display for 50 ms. Following the target display the fixation display was presented and remained on screen until a response was made. Trials ended only when a response was registered. After each response participants were given feedback in the form of a tone. If the response was correct an 800 Hz tone sounded for 100 ms followed by a 900 Hz tone for 100 ms followed by 1000 hertz for 100 ms. Alternatively if the response was incorrect a 600 Hz tone sounded for 150 ms, followed by a 400 Hz tone for 150 ms. The next trial began 1,000 ms after a response had been recorded.

Prior to the experiment, participants were instructed to search for the red target bar and to respond to its orientation by pressing one of two response buttons (left tilted target: left mouse button; right tilted target: right mouse button). Moreover, participants were told that the cues were non-predictive of the target location and were instructed to ignore the cues. Participants were told to respond as quickly as possible whilst minimizing errors. It was emphasized that they should remain fixated on the central fixation cross during the entire trial and that eye movements would be detrimental to their performance.

Participants completed 12 practice trials, followed by 384 experimental trials. The experiment was divided into four blocks of 96 trials and between blocks participants were given the opportunity to rest. See Figure 1 for an illustration of a trial.

Results

Mean RTs and error rates for Experiment 1 are shown in Figure 2 and Table 1 respectively. RTs exceeding 1200 ms and errors were excluded from the RT analysis. One participant was excluded from all analyses due to an unacceptably high average error rate of 19.8%. Across the remaining 14 subjects the exclusion criteria resulted in a loss of 3.8% of experimental trials.

RT analysis

A 2 (cue validity: valid, invalid) x 3 (cue type: red, green, motion) repeated measures ANOVA of RTs revealed a main effect of cue type, $F(2, 13) = 5.52, p = .020, \eta^2 = .48$ as well as a main effect of cue validity, $F(1, 13) = 73.33, p < .001, \eta^2$
Both main effects were qualified by a two-way interaction between cue type and cue validity, $F(2, 13) = 67.94, p < .001, \eta^2 = .92$. This interaction was due to the fact that the red (target matching) cue captured attention more strongly than green (target-non-matching) cue, $F(1, 13) = 146.94, p < .001, \eta^2 = .91$, or motion cue, $F(1, 13) = 57.99, p < .001, \eta^2 = .87$. Importantly, a pairwise comparison revealed no cueing effect for motion cues, with the difference between RTs associated with valid and invalid motion cues failing to reach significance, $t(13) = 1.59, p = .14$. However, there was a small but significant cueing effect associated with the green cue, $t(13) = 4.48, p = .003$, suggesting perhaps a broad set for colour on some trials (see, e.g., Folk & Anderson, 2010).

**Figure 2.** Mean RT as a function of cue type and validity for Experiment 1. Error bars depict the standard error of the mean.

**Error analysis**

The results of an error analysis were consistent with the pattern of results observed for RTs. The same 2 x 3 ANOVA on error rates revealed a main effect cue validity, $F(1, 13) = 27.40, p < .001, \eta^2 = .68$, and a two-way interaction between cue type and cue validity, $F(1, 13) = 6.52, p = .012, \eta^2 = .52$. Pairwise comparisons correcting for multiple comparisons revealed a significant validity effect for the red
cue, $t(13) = 4.60, p < .001$ though not the green cue, $t(13) = 1.30, p = 0.44$ and importantly, not the motion cue $t(13) = 1.20, p = .25$.

**Table 1.** Percent of Errors in each of the conditions in Experiments 1 – 5.

<table>
<thead>
<tr>
<th></th>
<th>Red Cue</th>
<th>Green Cue</th>
<th>Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Invalid</td>
<td>Valid</td>
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<tr>
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<td>2.64</td>
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<td>5.69</td>
<td>4.03</td>
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<tr>
<td>Experiment 4</td>
<td>2.41</td>
<td>5.92</td>
<td>2.31</td>
</tr>
<tr>
<td>Experiment 5</td>
<td>6.29</td>
<td>9.15</td>
<td>2.46</td>
</tr>
</tbody>
</table>

**Discussion**

The results of Experiment 1 were consistent with contingent capture in showing a significant cueing effect for target-matching red cues, less for green cues, and no significant effect for motion cues (e.g., Folk et al., 1992; Folk et al., 1994). Similarly, as shown in Figure 2, the motion cue also did not produce elevated baseline RT that would be indicative of filtering costs or other forms of spatially non-specific interference (e.g., Folk & Remington, 1998). The cueing effect for green is consistent with previous studies showing capture by target non-matching colours, which has been attributed to the adoption of a broader attentional set for the task-relevant dimension on a proportion of trials (dimension-specific setting, e.g., Muller, Heller & Ziegler, 1995; Folk & Anderson, 2010). Nonetheless, the results clearly indicate that the motion cue produced no discernible evidence of capture.
Experiment 2

Experiment 2 tested the role of contextual expectations by presenting the motion cue on only ~3% of all trials. To increase the likelihood that the motion cue would not be part of the contextual expectations, subjects were not informed about its occurrence. To provide the maximum opportunity to adapt to the validity of the infrequent motion cue, one group of participants was always presented with a valid motion cue while another group of participants was always presented with an invalid motion cue. Involuntary capture by stimuli violating contextual expectations would predict a cueing effect for the infrequent motion cues, but not for the green (non-target colour) cues. Because motion-cue validity is between subjects we assessed two measures: the group difference for valid and invalid motion normalized for group differences in overall RT, and comparisons of valid and invalid motion cues with invalid non-target colour cues. If the infrequent motion cue captured attention, then RTs for invalid motion cues would be expected to be slower than those for invalid non-target colour cues while valid motion cues would be expected to be faster than invalid non-target colour cues.

Method

Participants

Forty-three participants (31 female) aged between 17 and 36 years (M = 20.4, SD = 2.3) were recruited from introductory psychology classes at the University of Queensland and received course credit for participation. None of them had participated in Experiment 1 and all participants reported normal or corrected to normal vision.

Apparatus

The apparatus and stimuli used in Experiment 2 were identical to those used in Experiment 1.

Stimuli, Design and Procedure

The stimuli, design and procedure of Experiment 2 were identical to Experiment 1, with the following exceptions: First, the motion cue was presented on only 8 trials (~3%), and second, the validity of the motion cue varied between
subjects. Participants completed twelve practice trials followed by nine blocks of 32 trials. No motion cue was presented in the first block. In each of the subsequent 8 blocks the motion cue occurred once with its position in the block determined randomly, with the limitation that it could not occur within five trials of the preceding motion cue. Across the experiment the motion singleton was presented twice at each location and replaced an equal number of red and green cues, that is, four red and four green. Participants were not informed of the motion cue prior to the experiment. All other aspects of the design and procedure were identical to Experiment 1.

Results

Mean RTs for the valid-motion group are shown in Figure 3a, the invalid-motion group in Figure 3b. Error rates are shown in Table 1. Response times exceeding 1200ms and errors were excluded from the RT analysis. A hard RT cut-off was chosen in favour of one based on standard deviations as we have good reason to suspect that RTs associated with the rare motion cue will cluster towards the top (slow) end of the RT distribution. Given the very small number motion cue presentations we want to avoid excluding these trials. Three participants’ data were excluded from all analyses due to unacceptably high average error rates of 18% or greater in one or multiple conditions. Across the remaining 20 subjects the exclusion criteria resulted in a loss of 4.7% of experimental trials.

RT analysis

Colour Cues

A 2 (motion-cue group: valid motion, invalid motion) x 2 (cue type: red, green) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on mean RTs revealed a main effect of cue type, $F(1, 39) = 4.42, p < .042, partial \eta^2 = .10$ as well as a main effect of cue validity, $F(1, 39) = 164.00, p < .001, partial \eta^2 = .81$. There was no main effect of motion-cue group, nor were there any interactions with motion-cue group. As such, we collapsed across motion-cue group when computing planned follow up comparisons. Pair-wise comparisons revealed that validly cued targets were responded to faster than invalidly cued targets for both red cues, $t(39) = 12.65, p < .001$ and green cues $t(39) = 6.59, p = .03$. However this validity effect was significantly larger for the red cue.
than for the green cue, as reflected by a two-way interaction between cue validity and cue type, $F(1, 39) = 62.92, p < .001, \eta^2 = .62$. These results replicate the findings of Experiment 1 and indicate that participants largely adopted a feature-specific setting in search for the red target (see Figures 3a & 3b).

**Figure 3.** Mean RT as a function of cue type and validity for the valid-motion group (a.) and the invalid motion group (b.) in Experiment 2. Error bars depict the standard error of the mean.

**Motion Cue**

Figures 3a shows RTs on motion cue trials for subjects in the valid-motion group and Figure 3b the invalid-motion group. We asked two questions regarding the effect of the infrequent motion cue; first, whether RTs on trials with a motion cue differed from RTs associated with invalid non-target (green) colour cues, and, second, whether subjects with valid motion cues produced faster RTs than those with invalid motion cues. Unexpectedly, both valid and invalid motion cue RTs were significantly elevated relative to invalid-green RTs, $t(19) = 2.50, p = .022$ and $t(19) = 5.43, p < .001$, respectively. Furthermore, there was no significant difference between valid and invalid motion cue RTs, $t(38) = 0.72, p = .33$.
The elevation of RTs for the invalid rare motion cue is consistent with the hypothesis that novel events capture attention, however, elevated valid motion RTs and the failure to find a validity effect associated with the motion cues challenges the claim that the elevated RTs are due to the reallocation of attention to the location of the motion cue. In his treatment of “Surprise Capture”, Horstmann (2005) identifies the first presentation of a novel event as the trigger for Surprise and notes the habituation of surprise capture over presentations. It is possible, therefore, that the failure to find a validity effect for the rare motion cue arises because our results reflect two convolved effects, surprise and reallocation. In Figure 4 we plot the effect of each of the 8 presentations separately for the valid-motion and invalid-motion cue. Rather than depict raw RTs, we compensate for possible temporal effects (e.g., practice, fatigue) and baseline RT differences between the groups by computing the difference between the RT on motion cue trials and the mean of temporally nearby green cues. The green cues in this case serve as a proxy for a neutral baseline. For each participant we computed the motion effect by subtracting the average RT for (valid and invalid) green cue trials in the 32 trials prior to each presentation of the motion cue from its respective motion cue. That is, we normalised the motion cue RTs to the respective green cue (valid and invalid) RTs. An independent-samples t-test revealed no difference between RTs associated with the first presentation of a valid and invalid motion cue, \( t(36) = .86, p = .40 \).

Two further analyses were conducted to determine if a cueing effect emerged with repeated presentation of the motion cue as Figure 4 might suggest. First, we computed the average effect in Figure 4 separately for the first and second half of the experiment (presentations 1-4, and 5-8). An independent-samples t-test revealed a significant effect of cue validity for presentations 5-8, \( t(38) = 2.41, p = .021 \), but not for presentations 1-4, \( t(38) = .08, p = .94 \). Second, we fit linear functions to the data in Figure 4 separately for the valid and invalid motion cue. Consistent with the split half analysis above, a linear trends analysis revealed a significant linear decrease of the normalised RT for valid motion cue trials, \( F(1, 16) = 15.83, p = .001, \eta^2 = .51 \), but not for the invalid motion cue trials, \( F(1, 15) = 1.99, p = .18, \eta^2 = .12 \).

\[1\] We are not suggesting that the dissipation of RTs across presentations is necessarily linear. In fact, Figure 4 would suggest that there is a non-linear trend in the decline of the valid RTs that may be better characterized by an exponential or power function. This is also true of data presented in subsequent experiments (see Figures 8 & 11). However, our primarily interest was in identifying
Inspection of Figure 4 shows that the RT elevation on valid motion cue trials dropped to the level of performance seen with the green cue, whereas this was not the case with the invalid rare motion cue. A pairwise comparison between the last four occurrences of the invalid motion cue and the average RT to green cues (valid & invalid) from the second half of the experiment revealed a significant interference effect associated with the invalid motion cue, $t(19) = 4.68, p < .001$. These results indicate that the invalid rare motion cue continued to interfere with search throughout the experiment, whereas the valid motion cue showed substantial reduction in RT.

Figure 4. The RT difference score reflects a comparison of motion cue RT to the RT average of valid and invalid green cue trials that preceded the presentation of a given motion cue trial. The results are depicted separately for valid and invalid motion cue trials, together with a linear function fitted to both conditions. Error bars depict the standard error of the mean.

Errors analysis

The results of an error analysis were consistent with the pattern of results seen for RTs (see Table 1). A 2 (motion-cue group: valid motion, invalid motion) x 2 changes in RTs across motion cue presentations. To this end, linear functions are sufficient to illustrate the different trends that are present in the valid and invalid motion cue data.
(cue type: red, green) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on error rates revealed a main effect of cue type, $F(1, 39) = 4.88, p = .033, \eta^2 = .11$, of cue validity, $F(1, 39) = 29.68, p < .001, \eta^2 = .43$, and a significant two-way interaction between cue validity and cue type, $F(1, 30) = 32.59, p < .001, \eta^2 = .45$. There was no main effect of motion-cue group, nor were there any interactions with motion-cue group. Pair-wise comparisons revealed that only when the cue was red did it have an effect on response accuracy, $t(39) = 6.54, p < .001$. There was no effect of validity on error rates when the cue was green, $t(39) = 1.73, p = .09$. Given the pattern of errors across all conditions, the differences in response times reported above are not attributable to any speed accuracy trade-offs.

An independent groups $t$-test revealed no significant difference in error rates associated with valid and invalid rare motion singletons, $t(38) = .31, p = .76$.

**Discussion**

In Experiment 2 observers adopted top-down settings for red, as evidenced by the significantly larger cueing effect for red than green cues (see Figure 3). Despite this set, RTs were significantly elevated by the presentation of an unexpected, irrelevant motion singleton cue. Across the second half of the experiment, RTs associated valid motion cues were significantly faster than RTs associated with invalid motion cues, consistent with the motion cue having captured attention. It is clear from a comparison of Experiments 1 & 2 that the frequency of presentation of the motion cue modulated target RTs, as in all other respects the motion cue was the same as that in Experiment 1. This observation is consistent with previous research demonstrating that frequency-of-presentation modulates distractor inference (Neo & Chua, 2006; Geyer, Muller & Krummenacher, 2008; Horstmann, 2002, 2005) and extends the previous studies by demonstrating that this phenomenon occurs even when participants have an active top-down attentional setting for a specific colour.

Our analyses of the individual presentations revealed significant costs for both valid and invalid cues in the first half of the experiment, which did not differ significantly from each other. Across presentations valid RTs declined linearly,
whereas invalid RTs remained relatively flat and elevated. This difference in pattern led to a significant validity effect in the second half of the experiment. We argue that this pattern cannot be easily explained either by the spatial reallocation of attention or surprise alone. If attention were simply being captured by the motion cue then a validity effect should have been present in all presentations. Conversely, if the interference were due solely to surprise, with no reallocation of attention, then valid and invalid RTs should have shown the same pattern of habituation from surprise over presentations, which was clearly not the case. Instead, our data suggest that the first few presentations of the motion cue gave rise to surprise. As surprise habituated the motion cue retained its ability to capture attention and the cueing effect emerged. We shall deal further with the relationship of surprise to reallocation in subsequent experiments and discuss it at length in the general discussion.

In Experiment 2 we manipulated the validity of the motion cue between subjects. It is possible that the observed differences between valid and invalid motion cue in Figure 4 are due to the development of different strategies specific to the valid and invalid conditions. In Experiment 3 we use a within-subjects manipulation of cue validity to preclude the development of differential strategies for attending to the motion cue. This should provide a more stringent test of whether the validity of the motion cue reflects attention capture.

**Experiment 3**

In Experiment 3 each participant saw both valid and invalid motion cues. Given the small number of motion cues and the potential for sequence effects (see Experiment 2) we alternated the presentation of valid and invalid motion cues and assigned each participant to one of two presentation orders that differed in whether the first motion cue was valid or invalid. This alternating pattern controlled for position within the sequence so that both valid and invalid cues would be presented at equivalent practice levels. Since observers have no incentive to actively attend to or actively inhibit motion, better performance on valid relative to invalid motion cue trials can be safely attributed to involuntary capture by the rare motion singleton. If the motion cue captures attention then we expect to see RTs to valid cues faster than to invalid cues.
Method

Participants

An independent sample of thirty-two participants (21 female) aged 17 – 25 (M = 19.3, SD = 2.1) from the introductory psychology course at the University of Queensland participated for course credit. All reported normal or corrected to normal vision.

Apparatus

The apparatus was identical to the one used in the Experiments reported above.

Stimuli, Design and Procedure

The stimuli, design and procedure of Experiment 3 were identical to Experiment 2, with the exception that valid and invalid cues alternated within subjects. To obtain sufficient observations for a comparison between initial and latter presentations of the rare motion cues, the frequency of rare motion cues was increased to ~6% of trials. Eight valid and eight invalid motion cues were presented either in the order valid-invalid-valid-invalid, etc., or vice versa, in the order invalid-valid-invalid-valid, etc. The order of presentation was counterbalanced across participants. The experiment was divided into nine blocks of 32 trials. No motion cues occurred within the first 32 trials. Each of the eight subsequent blocks contained one valid and one invalid presentation of the motion cue.

After the experiment, participants were probed as to whether they had been aware of any pattern regarding the presentation of the motion cue with the following question – “Did you notice any pattern with respect to where the motion stimulus occurred in the display?” None of the participants reported being aware of an alternating valid-invalid order.

Results

Mean response times and error rates for Experiment 3 are shown in Figures 5 and 6 and Table 1 respectively. RTs exceeding 1200ms and errors were excluded
from the RT analysis. Participant 5 was excluded from all analyses due to an unacceptably high average error rate of 20.8%. Across the remaining 31 participants the exclusion criteria resulted in a loss of 4.8% of experimental trials.

RT analysis

A 3 (cue type: red, green, motion) x 2 (cue validity: valid, invalid) repeated measures of RTs revealed a main effect of cue type, $F(2, 29) = 13.94, p < .001, \eta^2 = .49,$ of cue validity, $F(1, 30) = 54.47, p < .001, \eta^2 = .65,$ and a significant two-way interaction between cue validity and cue type, $F(2, 29) = 38.28, p < .001, \eta^2 = .73.$ The two-way interaction of cue validity and cue type reflected a significantly greater validity effect for the red cue, $t(30) = 12.66, p < .001,$ than for the green cue, which also showed a significant validity effect, $t(30) = 2.90, p = .018$ (see Figure 5). Follow up analyses for the motion cue are presented in the next section.

![Exp. 3: Mixed Motion Cue](image)

**Figure 5.** Mean RT as a function of cue type and validity for Experiment 3. Error bars depict the standard error of the mean.

Motion Cues
In Experiment 3 we again asked whether RTs were elevated on trials with a motion cue, and, secondly whether there was a validity effect associated with the motion cue. Planned pairwise comparison confirmed that RT on both valid and invalid motion cue trials were elevated relative to the target non-matching cue (green), \( t(30) = 2.59, p = .015 \), and \( t(30) = 3.96, p < .001 \), respectively (see Figure 5). Consistent with Experiment 2, an analysis of mean RT across all presentations of the motion cue revealed no cueing effect associated with the motion, \( t(30) = .52, p = .60 \).

As was done in Experiment 2 we conducted two further analyses to determine if a cueing effect emerged with repeated presentation of the motion cue. First, we computed the cueing effect associated with the motion cue separately for the first and second half of the experiment (presentations 1-4, and 5-8). A 2 (exposure: first-half vs. second-half) x 2 (cue validity: valid vs. invalid) repeated measures ANOVA comparing RT on valid versus invalid trials in the first and second half of the experiment revealed a main effect of exposure, \( F(1, 29) = 16.32, p < .003, \eta^2 = .35 \), and a significant two-way interaction between cue validity and exposure, \( F(1, 29) = 5.20, p = .031, \eta^2 = .15 \). The interaction was due to the fact that the motion cue did not produce a significant validity effect in the first half of the experiment, \( t(30) = -1.09, p = .57 \). However, in the second half of the experiment, valid cue RT were significantly faster than invalid cue RTs, \( t(30) = 2.94, p = .015 \), consistent with attentional capture by the motion cue in the second half of the experiment.\(^2\)

Secondly, we fitted linear functions to the data in Figure 6 separately for the valid and invalid motion cue. Consistent with the split-half analysis above, the linear trends analysis revealed a significant linear component to the decrease in RT associated with the valid rare motion cue, \( F(1, 22) = 7.64, p = .011, \eta^2 = .26 \), but not the invalid rare motion cue, \( F(1, 20) = 1.43, p = .25, \eta^2 = .07 \). This result replicates the effect found in Experiment 2.

\(^2\) This spatial validity effect held when the comparison between valid and invalid cues was expanded to include the latter ten presentations (presentations 4-8) of the rare motion cue \( t(30) = 2.17, p = .03 \), as well as when it was restricted to the latter six presentations (presentations 6-8) of the rare motion cue, \( t(30) = 3.24, p = .003 \).
Figure 6. Mean RT for each presentation of the motion cue in Experiment 3. The data have been separated into valid and invalid conditions and a linear function fitted to both.

Errors

The results of an error analysis conformed to the pattern of results observed for RTs. A 3 (cue type: red, green, motion) x 2 (cue validity: valid, invalid) repeated measures ANOVA on error rates revealed a main effect of cue validity, $F(1, 29) = 7.34, p = .011, \eta^2 = .20$, and a significant two-way interaction between cue validity and cue type, $F(2, 28) = 12.61, p < .001, \eta^2 = .47$. Pair-wise comparisons revealed a significant validity effect for the red cue $t(29) = 6.75, p < .001$, but not for the green cue, $t(29) = .16, p = .99$.

A separate ANOVA of the error rates associated with the motion cue condition revealed no main effects or interactions. Given the pattern of errors across all conditions, the differences in response times reported here are not attributable to any speed accuracy trade-offs.
Discussion

The elevated RTs associated with the rare motion cue in Experiment 3 provide further evidence of interference that was not observed in Experiment 1 when the motion cue was presented frequently. Moreover, in Experiment 3, the spatial validity effect associated with the motion cue emerged under conditions that precluded the development of different strategies to attend to motion, evidence of the involuntary capture of attention by rare motion cues. This result supports the contention that frequency-of-presentation is a contributing factor in producing capture from a transient (motion) stimulus. However, it should be noted that the mixed design employed in Experiment 3 did not render the motion cue non-predictive. The motion cue was 50% valid where chance was 25%; it is possible that participants were sensitive to this relationship and biased attention accordingly. However, we suggest that this is highly unlikely for two reasons. Firstly, no participants reported noticing any regularities associated with the presentations of the motion cue when probed after the experiment. That is, there does not appear to be any evidence that participants developed any explicit strategies to attend to motion in response to the predictiveness of the motion cue. Secondly, participants saw only 16 motion cue presentations distributed across 288 trials. It seems unlikely that participants could have learnt, either implicitly or explicitly, the predictive nature of the motion cue over so few and distributed presentations. We discuss this in more detail in the general discussion.

Experiment 4

In Experiments 2 & 3 we found evidence that attention is captured by an unexpected cue with transient properties (i.e., motion). Our data also led us to conclude that initial presentations were dominated by surprise, which only later gave rise to a standard cueing effect. However, surprise has been invoked post hoc to explain this pattern and it remains unclear why the RT interference associated with valid motion cues dissipates across presentations while remaining elevated for invalid motion cues. If our conjecture of surprise habituating to more typical validity effects is correct then we should expect a very specific pattern of results when exposing participants to runs of valid and invalid motion cues. Firstly, we should
observe no surprise (elevated RTs) for valid motion cues following exposure to a series of invalid motion cues. Critically, if habituation is affecting valid and invalid cues equally, then there should be a robust validity effect in the transition from invalid to valid motion cues. Secondly, we should continue to observe interference associated with invalid motion cues following a pattern of habituation to valid motion cues. Alternatively, it remains a possibility that the rare motion cue produces only a non-spatially specific cost which habituates more rapidly for valid than invalid motion cues. In this scenario we would predict no interference from invalid motion cues following habituation to valid motion cues. Additionally we would expect to observe interference associated valid motion following exposure to invalid motions cues.

To test this, in Experiment 4 the presentation order of valid and invalid motion cues was systematically varied, such that one group of the participants was presented first with five valid rare motion cues, followed by five invalid rare motion cues, while a second group of participants received the reverse ordering (i.e., first five invalid rare motion cues, followed by 5 valid motion cues or vice versa). If habituation occurs selectively for valid motion cues but not for invalid motion cues, then RT should be elevated on valid motion cue trials even when these are preceded by a series of invalid motion cues. In this instance, the experiment should also fail to yield any evidence for capture by the motion cue, because RT on valid motion cue trials should be elevated both in the first and second half of the experiment. If, on the other hand, habituation occurs also for invalid motion cues, and elevated RT on invalid motion cue trials were due to attentional capture, then RT on valid motion trials should show an immediate benefit following the presentations of the invalid motion cues. Moreover, we would expect to find evidence for capture by the motion cue in condition in which invalid motion is followed by valid.

Method

Participants

An independent sample of thirty-two participants (23 female) aged 17 – 23 (M = 18.2, SD = 1.89 from the introductory psychology course at the University of Queensland participated for course credit. All participants reported normal or corrected to normal vision.
**Apparatus**

The apparatus and stimuli used in Experiment 4 were identical to those used in the experiments reported above.

**Stimuli, Design and Procedure**

The stimuli, design and procedure of Experiment 4 were identical to those of Experiment 3, with the exception that the frequency of the motion cue was reduced to ~3% of trials, and that the presentation order of valid and invalid motion cues differed. One group of participants were first presented with five valid motion cues, followed by five invalid motion cues, while this presentation order was reversed for the other group of participants. The experiment consisted of 11 blocks of 32 trials and 12 practice trials. Presentation of the motion cue was distributed across blocks two to eleven such that each block contained one presentation of the motion cue. No motion cue was presented in the first block. As in Experiment 3, participants were probed following the experiment as to whether they had been aware of any pattern regarding the presentation of the motion cue, using the same question. As in Experiment 3, none of the participants correctly reported that the motion cues had been presented in a systematic order.

**Results**

Mean response times and error rates for Experiment 4 are shown in Figures 7 and 8 and Table 1 respectively. RTs exceeding 1200ms and errors were excluded from the RT analysis. This resulted in a loss of 6.6% of experimental trials across all 30 participants. Again, none of the 30 participants reported identifying any pattern associated with the presentation of the motion cue.

**RT analysis**

**Colour Cues.**

The mean results for the colour cues are shown in Figure 7. A 2 (motion-cue group: valid motion, invalid motion) x 2 (cue type: red, green) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on mean RTs revealed a main effect of cue type, $F(1, 28) = 11.65, p < .002$, partial $\eta^2 = .29$, as well as a main effect of cue validity, $F(1, 28) = 72.44, p < .001$,
partial $\eta^2 = .81$. These main effects were qualified by a significant two-way interaction between cue validity and cue type, $F(1, 2) = 58.87, p < .001, \eta^2 = .68$, reflecting that the red cue showed stronger cueing effects than the green cue. Follow up comparisons confirmed that there was a significant validity effect for the red cue, $t(29) = 9.74, p < .001$, as well as a small but significant validity effect for the green cue, $t(29) = 2.61, p = .014$.

**Motion Cues**

Figure 7 also plots the mean RTs across presentations for the motion cue conditions. As with previous experiments, all within-subjects analyses were computed on the raw RT data while all between-subjects analyses were computed on normalised data. We first report the within-subjects comparisons.

**Within-subject comparisons:** A 2 (exposure-order: valid-first vs. invalid-first) x 2 (cue validity: valid vs. invalid) mixed model ANOVA (exposure-order entered as a between-subjects factor) revealed a significant two-way interaction between exposure and cue validity, $F(1,28) = 30.37, p < .000, \eta^2 = .52$. The interaction was due to the fact that the motion cue produced a significant inverse validity effect when valid motion cues preceded invalid motion cues, $t(14) = -3.22, p = .006$. However, when invalid motion cues were presented first, valid cue RTs were significantly faster than invalid cue RTs, $t(14) = 4.92, p < .001$. The main effect of cue validity was non-significant ($p = .74$). Critically, a pair-wise comparison revealed a significant validity effect between the last invalid cue and the first valid cue in the invalid-first condition, with RTs significantly reduced for the valid cue, $t(14) = 3.33, p = .006$ (see Figure 8 points ‘Invalid 5’ and ‘valid 6’).

Finally, comparing RTs associated with the invalid motion cue trials to RTs associated with the invalid green cue showed that RTs were significantly higher in the presence of the invalid motion cue compared with the invalid green cue, both when invalid motion cues occurred first, $t(14) = 4.60, p < .001$, and second, $t(14) = 3.89, p = .002$. 
Figure 7. Mean RTs as a function of colour cue type and validity for Experiment 4 (valid motion cues followed by invalid motion cues, and vice versa). Mean RTs for colour cues reflect data from both motion conditions. Error bars depict the standard error of the mean.

**Between-subjects comparisons:** To test for the presence of a cue validity effect we conducted a between-subject analysis comparing valid and invalid motion cues. A 2 (exposure: first-half vs. second-half) x 2 (cue validity: valid vs. invalid) revealed a significant two-way interaction, $F(1, 56) = 8.55, p = .005, \eta^2 = .13$. This interaction was qualified by follow up comparisons which revealed a significant between-subjects validity effect associated with valid and invalid motion cues in the second-half condition, $t(28) = 2.34, p = .027$ (see Figure 8 points 6-10). The inverse validity effect associated with the valid and invalid motion cues in the first-half condition did not reach significance ($p = .083$), although on the first unannounced presentation of the motion cue, valid RTs were significantly elevated over invalid RTs (reverse validity effect), $t(28) = 2.45, p = .021$.

A linear trends analysis that revealed a significant linear component to the decline in RTs associated with valid rare motion cues, $F(1, 14) = 15.71, p = .001, \eta^2 = .53$. No such linear decreasing trend was seen for targets cued by invalid rare motion cues, $F(1, 12) = .32, p = .59, \eta^2 = .03$. 
Figure 8. RT difference score reflects a comparison of the motion cue RT to the RT average of valid and invalid green cue trials that preceded the presentation of a given motion cue trial. The data have been separated into valid and invalid conditions and a linear function fitted to both. Error bars depict the standard error of the mean.

Error analysis

Error rates across the different conditions were consistent with the pattern of results seen for RTs. A 2 (motion-cue group: valid motion, invalid motion) x 3 (cue type: red, green, motion) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on error rates revealed a main effect cue, $F(2, 27) = 11.67, p < .001, \eta^2 = .46$, and a main effect of cue validity, $F(1, 28) = 16.69, p < .001, \eta^2 = .37$. These main effects were qualified by a significant two-way interaction between cue validity and cue type, $F(2, 27) = 3.57, p = .049, \eta^2 = .20$, reflecting that the red cue showed stronger cueing effects than the green cue. Pair-wise comparisons revealed that more errors occurred on invalid red cue trials than on valid red cue trials, $t(29) = 3.51, p < .005$, and this was also true of green cue trials, $t(29) = 2.11, p = .043$. There was no difference in error rates between valid and invalid motion cues, $t(29) = 1.00, p = .33$. There was no effect of group.
Discussion

The results of Experiment 4 are consistent with those of Experiment 2 and Experiment 3. Initial presentation of the unexpected motion cue led to elevation of both valid and invalid RTs when compared to the green cue. With subsequent presentations RT to valid cues showed a linear decline, while RT to invalid cues remained elevated. Importantly, there was a significant validity effect for the first presentation of a valid cue when compared to the previous invalid cue. This indicates that adaptation to the motion cue was occurring for both valid and invalid cues, ruling out the possibility that elevated RT on invalid motion cue trials were due to a failure to habituate to the invalid motion cue. These results provide strong support for the view that rare motion captures attention independent of task goals.

An unusual feature of the data was the presence of a reverse validity effect – valid RTs greater than invalid RTs – over the first few presentations. This, in fact, has been a pattern in Experiments 2 & 3 as well, though it is somewhat stronger in Experiment 4. While this appears to conflict with the standard cueing effect observed robustly in spatial cueing studies, it is important to emphasize that our results reflect performance on the first presentation of a new stimulus. In a typical spatial cueing task subjects are given several trials of practice on the exact stimuli they will encounter in the experimental session, or alternatively the first few trials are excluded from analysis. Even if included, the contribution of the first presentations is negligible when data from the entire experiment, or even over a block, is averaged. Our results are showing a new and apparently robust pattern in which valid motion cues produce more interference than invalid when presented first.

The reverse validity effect does seem at odds with results showing additive effects of cue validity and surprise in visual search (Horstmann, 2002, 2005; Horstmann & Becker, 2008; Gibson & Jiang, 1998). Since we have argued that the initial presentations of the motion cue elicit surprise, we investigate the source of the reverse validity effect in Experiment 5 to better understand why our results differ from those of previous surprise capture studies.
Experiment 5

According to current models of surprise capture, surprise-induced costs should be additive with capture (Horstmann, 2002, 2005; Horstmann & Becker, 2008; Gibson & Jiang, 1998), because the RT delay that characterises surprise is thought to reflect a disruption of decision-level processes that are separate from processes responsible for controlling orienting (Horstmann, 2005; Sternberg, 1967). How then can we explain the greater RT elevation for the initial presentations of valid compared to invalid motion cues?

One notable difference between the experiments reported here and previous studies is that in the present experiments the target was always a colour singleton. The presence of a significant cueing effect for colour cues indicates that participants were set for the target colour. Thus, for invalid motion cues the feature for which attention was set was always present in a location other than that of the motion cue. If, as our evidence suggests, the motion cue captures attention, then on invalid trials the presence of the target feature provides a perceptual cue to facilitate disengaging from the motion cue. That is, perceptual processing of the target properties can proceed in parallel with disengagement from the motion cue. For valid trials, on the other hand, there is no spatially distinct perceptual signal to facilitate disengagement. If the process of disengaging from the surprise stimulus involves inhibition of the interfering distractor then it is easy to see this would interfere with parallel perceptual processing of the target, and how the cost could be very high for a valid surprise stimulus.

In contrast, previous studies of surprise capture have used predominately a conjunction search in which the target was not marked by a unique feature (Horstmann, 2002, 2005; Horstmann & Becker, 2008, 2011). Feature singletons are pre-attentively available whereas conjunctions of features are not and mostly require an effortful serial search (e.g., Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, 1994). In conjunction, the target would not compete as strongly for attention with the unexpected singleton as in the target feature in present study.

We examined this in Experiment 5 defining the target to be a conjunction of colour and orientation, more closely mirroring previous studies of surprise capture that observed additive effects of surprise and cue validity. A target defined by a
conjunction of features should not facilitate disengagement from the motion cue. If our reasoning is sound, then Experiment 5 ought to find an RT-elevation that is now additive with attentional capture (as indexed by the cueing effect).

To increase the difficulty of the search task, the number of possible search stimuli was increased to six, and participants were instructed to search for a red bar that could be either horizontal or vertical, among differently coloured bars that were either oriented horizontally, vertically, or tiled left or right by 45°. Each display contained two red bars, two green bars and two blue bars. Targets could only appear on four out of the six possible positions. Eye position was monitored to ensure that participants maintained fixation on the central fixation cross during the entire trial.

**Method**

*Participants*

A new sample of seventy participants (53 female) aged 17 – 47 (M = 20.7, SD = 2.7) from the introductory psychology course at the University of Queensland participated for course credit. All reported normal or corrected to normal vision.

*Apparatus*

Experiment 5 was conducted using the computer software package Matlab (2010a) and the *Psychophysics Toolbox* extension (Brainard, 1997; Pelli, 1997). Participants’ eye movements were measured using a video-based infrared eye-tracking system (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of 0.1 and a temporal resolution of 500 Hz.

*Stimuli*

The fixation display and target display contained six boxes positioned in a circular array around fixation. The size of each box and distance of each from fixation was the same as in the previous experiments. The cueing display consisted of a set of four dots around all six boxes. On colour cue trials one set of four dots around one location was always coloured either red or green (four-dot cue). The motion cue was rendered by a 90° rotation of the diamond cue configuration in six 15° clockwise increments at 22ms intervals.
The target display consisted of an oriented, coloured line in each of the six peripheral boxes. The bars could be oriented horizontally, vertically, or rotated 45° to either the left or right. Three of the bars were oriented either horizontally or vertically and three were oriented either 45° to the left or to the right. Two of the bars in the display were red (RGB = 255, 0, 0), two were green (RGB = 0, 255, 0) and two were blue (RGB = 0, 0, 255). The distribution of colours was such that each orientation (horizontal/vertical and 45° left/right) appeared in each colour. That is, the bars in the display varied across two features, orientation and colour, and no single bar in the display could be differentiated from the other bars by a single feature alone.

**Design and Procedure**

As in Experiment 2 subjects were randomly assigned either to the group that received valid motion cues, or the invalid motion group. Target and singleton cues never appeared at the position directly above or below fixation (see Figure 9), only at the remaining four locations. Participants were required to respond with the left and right arrow key when they saw either a red horizontal or a red vertical bar, respectively. The experiment was divided into six blocks of 32 trials and one block of 32 practice trials. Neither the practice block nor the first block of experimental trials contained a motion cue. Each of the five subsequent blocks contained either one valid or one invalid presentation of the motion cue. Incorrect responses resulted in the word “wrong!” being displayed on the screen for 1000 ms.

![Figure 9. Example target display from Experiment 5. The target in this example is the red horizontal bar.](image)
Results

Mean RTs and error rates for Experiment 5 are shown in Figures 10 and 11 and Table 1, respectively. RT exclusion criteria were relaxed to compensate for the increased difficulty of the search task. RTs exceeding 1500 ms and errors were excluded from the RT analysis. Six participants’ (two from the invalid condition) data were excluded from all analyses due to unacceptably high average error rate of 20% or greater in one or multiple conditions. Across the remaining 64 participants the exclusion criteria resulted in a loss of 8.6% of experimental trials.

Eye movement data were analysed online and trials were aborted if participants did not remain fixated throughout the trial. Participants were deemed to be fixating if their gaze fell within a region of 1.3 degrees of visual angle from the centre of the fixation cross.

RT analysis

Colour Cues

A 2 (motion-cue group: valid motion, invalid motion) x 2 (cue type: red, green) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on mean RTs revealed a main effect of cue validity, $F(1, 62) = 29.30, p < .001, \eta^2 = .32$, and a significant two-way interaction between cue validity and cue type, $F(1, 61) = 46.92, p < .001, \eta^2 = .43$. There was no two-way interaction between motion-cue group and cue type, $p = .23$, or motion-cue group and cue validity, $p = .52$. There was also no three-way interaction between motion-cue group, cue type and cue validity, $p = .43$. As such, we collapsed across motion-cue group when computing planned follow up comparisons. Pairwise comparisons revealed a significant validity effect associated with the red cue, $t(62) = 9.49, p < .001$ and a small but significant inverse validity effect associated with the green cue, $t(62) = -3.75, p < .001$ (see Figure 10).
Motion Cues

To assess the effect of the motion cue we firstly compared RTs associated with the motion cue to the non-target invalid green cue. Pairwise comparisons revealed that both valid and invalid motion cue RTs were significantly elevated relative to invalid-green RTs, $t(29) = 3.04$, $p = .005$ and $t(31) = 6.81$, $p < .001$, respectively. To test for between-subject differences in RT between valid and invalid motion cue trials we first normalised data for valid and invalid motion cues. Normalisation of the motion cue data was computed as before by subtracting RTs from surrounding green cues from the RT to the motion cue. An independent-samples t-test revealed that invalid motion RTs were significantly elevated relative to valid, $t(60) = 2.96$, $p = .004$.

As with previous experiments we looked at the effect of the motion cue across repeated presentations by computing the cueing effect associated with the motion cue separately for the first and second half of the experiment (presentations 1-2, and 4-5). Independent-samples t-tests revealed a significant effect of cue validity for presentations 1-2, $t(60) = 2.76$, $p = .008$, but not for presentations 4-5 though the effect approached significance, $t(60) = 1.97$, $p = .054$. Furthermore, Mean RT on the first unannounced presentation of the motion cue was significantly faster for valid

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3 The effects held when the same comparisons were computed over the raw data
than for invalid cue, $t(55) = 2.28, p = .027$. Note that this pattern of results is in stark contrast to those observed in Experiments 2 – 4.

Figure 11 shows the normalised RT data for each presentation of the motion cue. Linear functions fitted to both the valid and invalid data sets showed a linear trend towards decreasing RT with repeated presentations for both with valid and invalid cues. Due to an increase in the number of errors on motion trials a linear trend analysis on the RT data was not appropriate for either of the rare motion cue conditions. However, comparing RTs across the first two (1st & 2nd) presentations of the motion cue with RTs on the last two (4th & 5th) presentation of the rare motion cue within each condition revealed that RTs were significantly slower across the first two presentation of the motion cue than the last two presentation for invalid motion cues, $t(30) = 3.22, p < .03$ and marginally significant for the valid motion cue condition, $t(28) = 1.90, p = .067$.

**Figure 11.** RT difference score reflects a comparison to the RT average of valid and invalid green cue trials that preceded the presentation of a given motion cue trial.
The data have been separated into valid and invalid conditions and a linear function fitted to both.

**Error analysis**

Error rates across the different conditions were largely consistent with the pattern of results seen for RTs. A 2 (motion-cue group: valid motion, invalid motion) x 2 (cue type: red, green) x 2 (cue validity: valid, invalid) mixed model ANOVA (motion-cue group entered as a between-subjects factor) on error rates revealed a main effect of cue validity, $F(1, 62) = 7.44, p < .008, \eta^2 = .11$, such that more errors were associated with invalid than valid cues. A significant two-way interaction between cue type and cue validity, $F(1, 63) = 8.19, p = .006, \eta^2 = .12$ reflects that there was a validity effect associated with red cue, $t(63) = 3.65, p < .001$, but not the green cue ($p = .65$. A cue type by motion-cue group interaction revealed that error rates were for the red cue condition were slightly high in the invalid motion condition compared to the valid motion condition, $F(1, 62) = 11.59, p = .001, \eta^2 = .16$, (see table 1).

There was no difference in error rates between the valid and invalid motion cue, $t(62) = 1.41, p = .16$.

**Discussion**

Experiment 5 provides the first decisive evidence for the hypothesis that top-down guided search for a pre-attentively available feature markedly changes the dynamics of capture by unexpected and rare stimuli. Standard cueing effects were observed on all presentations. Unlike the Experiments 2-4, Experiment 5 showed significantly elevated RT for the initial presentations of the invalid motion cue that decreased linearly over repeated presentations. The validity effect was observed across repeated presentations of the motion cue, with consistently faster RT for the valid than invalid cues. This pattern of attentional capture and surprise-related RT-elevation is consistent with the two effects having combined in an additive manner.

These results support our hypothesis that the failure to observe additive effects in the previous experiments was due to the fact that the target competed more strongly for attention with the unexpected motion cue, which facilitated disengagement from the motion cue and led to a fast re-allocation of attention to the target. We argue that this reallocation prevented the propagation of surprise to
higher, decision-related processes reducing its impact on invalid RTs. The additive effects of surprise and spatial cueing observed in Experiment 5 conforms to the pattern of results predicted by current models of surprise capture (Horstmann, 2002, 2005; Horstmann & Becker, 2008, 2011; Gibson & Jiang, 1998). The discrepancy between the results of Experiments 2 - 4 and previous reports of surprise hinges on the presence versus absence of a pre-attentively available signal in the target display to guide attention away from the location rare motion cue. According to this explanation, the absence of readily available information to match the top-down controlled attentional settings appears to be critical for the (full) manifestation of surprise. In the absence of strong competition by a preattentive feature and/or an effective bias that draws attention away, the unexpected item is then processed in sufficient depth to modulate decision- and response-related processes.

**General Discussion**

The influence of top-down mechanisms on the orienting of attention has been well documented with the general conclusion that the capture of attention by salient events is modulated by their relevance to ongoing task goals (Bacon & Egeth, 1994; Eimer & Kiss, 2008; Eimer, Kiss, Press, & Sauter, 2009; Folk & Remington, 1998; Folk et al., 1992; Folk et al., 1994; Wu & Remington, 2003). In the present series of experiments, we tested whether unexpected stimuli would capture attention even when attention is demonstrably set for a specific colour. The present series of experiments found that a rare task-irrelevant motion signal captured attention even when observers had adopted a top-down setting for a particular colour (red). As shown by Experiment 1, this effect was not due to the bottom-up saliency of the motion stimulus, as it could be successfully ignored when it was presented frequently. These findings support the view that novelty can override the top-down attentional control settings and prompt an attention shift toward rare and unexpected events. Importantly, these results were obtained in the modified spatial cueing paradigm used by Folk et al. (1992), which allowed us to confirm that participants had indeed adopted a feature-specific attentional bias for the target colour, and not a broader search for a discontinuity in the displays (e.g., singleton search mode or display-wide features; Bacon & Egeth, 1994; Gibson & Kelsey, 1998). In our experiments, the presence of a feature set (red) was demonstrated by the
consistently larger cueing effect for the cue of the target colour (red) than for the non-target colour (green), as well as by a frequently presented motion singleton. The observation of capture by infrequent events under conditions of an active top-down set for a specific target feature provides strong support for capture by novel stimuli and extends previous research showing attentional capture by infrequent task-irrelevant abrupt-transients (Neo & Chua, 2006).

**Top-Down Control of Attention**

Our claim that attentional capture is sensitive to frequency of presentation, not the onset transient itself is supported by the presence of interference from rare motion cues (Experiments 2, 3, & 4) compared to the absence of capture to the same motion cue presented more frequently in Experiment 1. This failure to find capture by motion cues in Experiment 1 is consistent with the results of other spatial cueing studies that have failed to find evidence of capture by onsets or motion cues when attention was set for a specific colour (Folk et al., 1992; Folk et al., 1994). Capture by the same motion cue when it was presented on only a small number of trials is strong evidence that the salient transient of the motion cue per se was not instrumental in capturing attention, as has previously been maintained (Abrams & Christ, 2003; Abrams & Christ, 2006; Lamy & Egeth, 2003; Belopolsky et al., 2010; Franconeri, Simons & Junge, 2004; Theeuwes & Van der Burg, 2007). Evidence supporting theories of stimulus-driven capture by salient onsets or motion come largely from visual search or irrelevant singletons (Theeuwes, 1991; Theeuwes, 1994; Schreij, Owens & Theeuwes, 2008) in which both targets and distractors are presented simultaneously. The simultaneous presentation pits the sensory processing of targets against that of distractors and, as a result, is more sensitive to physical attributes, such as intensity or salience. Evidence supporting the role of top-down modulation has come instead from spatial cueing studies, like ours, in which the distracting stimulus (cue) is presented in isolation prior to the target. The sequential presentation minimizes that perceptual interaction of cue and target, thus allowing more scope for top-down control. In this respect, our finding of capture by unexpected motion stimuli in a spatial cueing paradigm is strong support for the ability of novel events to generate stimulus-driven capture.

Our experiments are the first to demonstrate stimulus-driven capture by infrequent transient stimuli in the presence of an active top-down set for colour. Our
design incorporated measures that not only encouraged a strong set for the target colour, but that also allowed us to detect if that set were active. Previous studies showing capture by infrequent stimuli have not employed such stringent controls on attentional set. Presenting cues in a non-target colour encouraged a strong set for the target colour (red), as witnessed by the consistent and strong cueing effects for target-matching (red) colour cues. The weak but consistent cueing effect for the non-target colour cue (green) suggests that on some trials subjects may have adopted a set for colour rather than a specific colour value (Folk & Anderson, 2010).

The capture by rare motion cues seen in experiments 2, 3 and 4 is, thus, in violation of top-down settings and strong evidence for stimulus-driven capture by novel events. The results force a re-examination of the mechanisms for top-down control described by the theory of contingent capture (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Folk & Remington, 1998). According to a strong version of contingent capture a positive setting for a stimulus property would be necessary for it to capture attention. This cannot be the case in our experiments as subjects could not have a positive set for a stimulus they did not know would be presented. Even after the first presentation the motion cue continued to capture when presented infrequently, suggesting that whatever expectation was generated by each presentation was no longer active on the next presentation. How is it that top-down control can prevent capture by frequently presented events, but not novel events?

One way to account for the range of findings is to consider the neural model of the world posited by Sokolov (1963) to explain the orienting response. According to Sokolov the brain maintains a model of the world that incorporates the recent history of processing. The orienting response is triggered by stimuli that fall outside that model. This suggests that the rare motion cue captured attention because its frequency of presentation did not support incorporation into this world model. When presented frequently, however, the same stimulus was updated regularly and incorporated into the model. This leads to a view of top-down control that is more than simply a positive set for the relevant target feature. Instead, it suggests that effective top-down control is the result of general contextual expectation for the properties of both targets and distractors (see Theeuwes, 1996: A. Kramer, M. Coles, & G. Logan (Eds.), Converging Operations in the Study of Visual Attention.)
This is consistent with classical theories of attention that assume that salient irrelevant stimuli have to be filtered out or inhibited (Becker, 2007; Folk & Remington, 1998; Treisman & Sato, 1990). Such filtering or inhibition of irrelevant features would depend on the prior exposure to these stimuli and implicit learning about their relevance. The effectiveness of inhibition or filtering would depend on an active set for distractor properties maintained by repeated occurrence and the probability that it indicates the target location or misguides attention to a non-target location (e.g., Geyer et al., 2008; Yantis & Egeth, 1999). In fact, Vaterott and Vecera (2012) found that, in search for a shape target, an irrelevant colour singleton interfered with search only in the first half of a block, but not in the second half. This pattern was observed for all blocks in which the colour of the singleton was changed from the previous block. These results show that top-down control included suppression of irrelevant salient stimuli, not just a positive setting for a target feature (which did not change in the study of Vaterott and Vecera, 2012). Alternatively, the present results as well as the results of Vaterott and Vecera (2012) are consistent with the existence of dedicated novelty-detection mechanisms that detect a mismatch between a neuronal model and the visual input, and guide attention to items that violate expectations (e.g., Horstmann, 2002; Sokolov, 1963).

The present experiments cannot distinguish between these two different views: Models proposing a dedicated novelty detection mechanism also predict RT to be elevated, due to fact that an unexpected stimulus elicits surprise (e.g., Horstmann, 2005), or that the visual system has not habituated to the stimulus (e.g., Sokolov, 1963). The new finding of the present study - that the existence of a top-down controlled attentional control setting for the target colour and the pre-attentive availability of the target feature can attenuate the surprise response - also seems consistent with both accounts. Of note, current surprise capture accounts do not deny the existence of top-down controlled attentional mechanisms, or their ability to modulate capture by novel stimuli (e.g., Horstmann 2002, Neo & Chua, 2006). Similarly, classical theories would not deny that top-down controlled attention shifts can interrupt visual processing of a rare motion singleton. Since the two models both propose that attention shifts to rare and unexpected stimuli are governed by a mechanism that is separate from the top-down controlled mechanism that guides attention to the target (i.e., filtering vs. expectation mismatch), it may very well be
impossible to distinguish between the two accounts experimentally. However, one important finding of the present study is that stimulus novelty does not completely dominate early visual processing: when the target feature was pre-attentively accessible and strongly competed for attention with the unexpected stimulus, the unexpected stimulus was apparently not fully processed. Instead, attention was quickly re-allocated to the target, preventing large RT costs when the target was presented at a different location than the motion singleton. These results indicate that task-related attentional settings can alter attentive processing of unexpected items, if the conditions permit immediate localization of the target feature.

**Predictivity of color cues vs. motion cue.**

In Experiment 1, the red and green color cues and the motion cue were all non-predictive of the target location, as they coincided with the target on 25% of all trials. In the subsequent experiments, the colour cues were still non-predictive; however, in most instances (Exp. 3–4), the motion cue coincided with the target location on half of all trials, and thus, was positively correlated with the target. Is it hence possible that attention shifts to the motion cue were not completely involuntary? Yantis and Egeth (1994) showed that the amount of attention allocated to a nominally irrelevant singleton depends on its predictiveness of the target location: Is it possible that a similar mechanism guided attention to the motion singleton in the present experiments? We consider this highly unlikely, for the following reasons: First, in Experiments 3 and 4, participants were probed directly after the experiment regarding whether they had noticed any regularities associated with the presentations of the motion cue, and none of the participants correctly reported that the motion cue had been presented in a regular foreseeable sequence (i.e., of ABAB... or AA.. BB..). This negative result would seem to rule out that participants developed an explicit strategy in response to the predictiveness of the motion cue. More importantly, Experiments 2 and 5 tested effects of motion cues that were always valid versus always invalid for different participants, and the results were very similar to the results of the mixed presentations of the motion cue (Exp. 3) and presenting first all valid and then all invalid motion cues or vice versa (Exp. 4; compare Fig. 4, 6 and 8). The failure to find any differences in response to these manipulations indicates that the predictiveness or non-predictiveness of the motion cue did not change the results.
This negative finding is consistent with previous results with the spatial cueing paradigm, showing that presenting always valid cues and always invalid cues in different blocks yields very similar results patterns as presenting valid and invalid cues mixed within a block of trials (e.g., Folk et al., 1992). Possibly, the predictiveness of the distractor only has an effect in visual search tasks such as used by Yantis and Egeth (1999), where the distractor feature (e.g., color) is an attribute of the target itself and a more salient attribute than the target-defining feature, so that it can aid search when it is predictive. In any case, the finding that capture by the motion cue was not modulated by the cue's predictiveness rules out a top-down strategic account of capture by the motion singleton and indicates that attention shifts to the motion singleton were mediated by a different mechanism than the mechanism that guides attention to the target.

**Surprise Capture**

In discussing the experiments we made the point that our results appear to reflect the presence of both a standard cueing effect and surprise. There was clearly something about the initial presentations of a *valid* motion cue that elevated RTs more significantly than an invalid motion cue, resulting in a reverse validity effect in the case of Experiment 4. In all our studies save Experiment 5 RTs for valid motion cue trials decreases linearly over presentations, whereas RTs for invalid trials remained relatively constant. A standard cueing effect emerged around the third or fourth presentation and was significant in the last half of all experiments. We hypothesized that RTs for the first few presentations reflected both an orienting of attention to the cue as well as initial surprise effect, which resulted in attention dwelling at the location and engaging response selection mechanisms for the cue. As surprise diminished over presentations the orienting of attention remained and a cueing effect emerged. Further, in Experiment 5 we provided evidence that the greater elevation with valid motion cue RTs resulted from the presence of a feature singleton with invalid cues that facilitated disengagement from the motion cue. In the absence of a singleton target feature in Experiment 5 RTs for both were elevated on first presentation with valid RTs faster than invalid, as expected. The effect of surprise was additive with the cueing effect as has been previously found. Our results are also consistent with the hypothesis that the effect of surprise is not only to draw attention to the cue, but to engage response and decision mechanisms as well.
Theoretical Implications

The principle theoretical implication of the present study is that a top-down setting for a particular colour does not prevent the capture of attention by a novel or rare salient stimulus\(^4\). The present study provided the first evidence that unexpected stimuli can capture attention even when attention is firmly biased to the target feature value. This finding is inconsistent with the original contingent capture hypothesis that a stimulus has to be similar to task-relevant features in order to capture attention (Folk et al., 1992). We conclude that salient (transient) novel stimuli, by which we mean stimuli outside the current neural model of the world, will capture attention regardless of top-down attentional control settings. A second implication is that top-down modulation of capture is not accomplished simply by setting for a target property. In our account, both target and distractor properties must be actively in mind. Together with the study of Vaterott and Vecera (2012), the present study provides the compelling evidence that top-down control involves both target and distractor modulation.

The present results also extend on our knowledge of capture by unexpected and rare stimuli. Here we show, for the first time, that surprise capture and a surprise-induced RT elevation can also be obtained in the spatial cueing paradigm, in a task similar to Folk and Remington (1998), where the target is identified by a unique, constant feature. Although the present experiments yielded results similar to those found previously in difficult visual search tasks, they also showed some deviations from previous results; specifically, the non-additively of RTs for the first (few) presentation(s) of the unannounced motion cue. This results pattern deviates from previous reports where surprise-induced RT elevation has been reported to be additive with capture effects (e.g., Horstmann, 2005). Naturally, it is possible that the invalid motion cue did not capture attention and therefore did not lead to a surprise-induced RT-elevation. However, this hypothesis is difficult to reconcile with the facts (1) that we found significant capture by motion in the second halves of the experiments, and (2) that RT to valid motion cues were not elevated when they were presented after a series of invalid motion cues (see Exp. 4). The latter finding was

\(^{4}\text{Note that this does not rule out the possibility of some other type of top-down attentional setting that may be effective in preventing capture by novel stimuli.}\)
taken to show that participants had habituated to the invalid motion cue, which is difficult to explain if we assume that it was never attended.

We noted in Experiment 5 that a key feature distinguishing our displays in Experiments 2 - 4 from earlier studies of surprise is that on invalid trials the critical target feature is visible at an uncued location immediately following the briefly presented cue. Indeed when the target was defined as a conjunction of features and consequently rendered less distinguishable from the non-targets in Experiment 5, the observed RT costs appeared to combine with attentional capture in an additive manner. We have suggested that the under-additively observed in Experiments 2-4 is the result of an ability to disengage with the motion cue when it was invalid due to the presence of a the feature singleton (the target) in subsequent target display. Such an account is consistent with previous reports showing a slowed time-course of surprise. A signature of Surprise Capture, at least with respect to colour singletons, is that surprise does not appear to propagate in the system until at least ~300 ms after stimulus onset, with pronounced effects found for targets 400 and 600 ms following the surprise stimulus (Horstmann, 2002, 2005, 2006). Furthermore, surprise capture has not been observed at SOAs of 200ms or less (Horstmann, 2006; Horstmann & Becker, 2008). As we employed an SOA of 210ms, it may be that in the case of the invalid rare motion cue attention was not held at the location of the surprising stimulus long enough for surprise to manifest and affect RTs. In Experiment 5 spatial attention was able to linger at the location of an invalid rare motion cue due to the attenuated target signal in the proceeding target frame. This additional time may have been sufficient for surprise to propagate through the system. In the case of the valid rare motion cue, attention is drawn to the location of the motion cue and is held at that location by the presentation of the target. The time for which attention is focused at the location of a valid rare motion cue is thus lengthened sufficiently to allow for further processing of the motion cue, which interferes with the task. Note that an implication of this interpretation is that surprise not only requires just ‘time’ to manifest but some sustained period of spatial attention directed at the location of surprising stimulus. There is some evidence to suggest that this is indeed the case (see Horstmann, 2008).

Although our disengagement hypothesis certainly warrants further investigation, it is clear that the involvement of effective top-down attentional
guidance significantly alters the results for unexpected and rare irrelevant singletons. Specifically, the ability to quickly locate the target in the spatial cueing paradigm interrupts further processing of the motion singleton, which in turn causes these costs to combine with capture effects in an under-additive manner. These results are important, in that they show that top-down controlled processes can dominate attention and alter our response to the unexpected.

Our account of the inverse cueing effect observed for initial presentations is also consistent with the theory of ‘biased competition’ (Desimone & Duncan, 1995). According to the biased competition model, stimuli within in the same receptive field of neurons compete more strongly with one another than stimuli that are represented by different neuronal populations (Moran & Duncan, 1985; Desimone & Duncan, 1995; Desimone, 1998). The novel and/or unexpected stimuli would have a competitive advantage over the subsequent target given evidence of increased neural responses observed for novel and or unexpected stimuli (Fahy, Riches & Brown, 1993; Li, Miller & Desimone, 1993). The invalid motion cue is outside the receptive field of the neurons processing the target and therefore would not directly compete with it for attention. The two explanations are not mutually exclusive. The absence of a target feature at a location outside the receptive field encompassing the motion cue would fail to provide the necessary trigger for disengaging attention from the novel stimulus, allowing surprise to develop, giving the rare motion cue its competitive advantage over the target. It is worth noting that such an account would explain the decline in response time on valid trials with successive presentations of the motion cue as a reduced neural response to the unexpected, but no longer novel motion cue.
Chapter 3 - Previously Seen and Expected Stimuli Elicit Surprise in the Context of Visual Search
Summary

The series of experiments presented in chapter 2 show that an unexpected salient task-irrelevant stimulus can capture attention even when there is an established attentional set for a specific feature (colour). Based in this observation, I proposed an account of attentional control whereby top-down goals modulate capture by stimuli that conform to contextual expectations, whereas stimuli that violate these expectations involuntarily attract attention. In this view, the "attentional set" is not simply a setting for relevant target properties, but rather the result of expectations / a neuronal model that forms for both target and distractor properties. The ability to ignore task-irrelevant distractors reflects an active set for distractor properties that is learned and maintained through repeated exposure.

In Chapter 3, I explore in more detail the factors that determine the formation of task-expectancies. Specifically, how context specific is the learning of distractor properties and to what extent task-expectancies are shaped by top-down knowledge about the likelihood of a given event or stimulus. To address these questions I focus predominately on the initial presentation of an unexpected visual stimulus which has been shown to induce a surprise response during visual search (Hortsmann, 2002; Meyer, Niepel, Rudolph & Schützwohl, 1991). Here I test whether the magnitude of the surprise response can be modulated by pre-exposing participants to an unexpected stimulus and / or explicitly informing participants about an impending unexpected stimulus. Modulation of the surprise response to either of these manipulations would suggest a shift in the underlying task-expectancies / neuronal model that govern orienting toward novel stimuli.

Abstract

In the context of visual search surprise is the phenomenon by which a previously unseen and unexpected stimulus exogenously attracts spatial attention. Capture by such a stimulus occurs, by definition, independent of tasks goals and is thought to be dependent on the extent to which the stimulus deviates from expectations (Horstmann, 2005). However, the relative contributions of prior-exposure and explicit knowledge of an unexpected event to the surprise response have not yet been systematically investigated. Here observers searched for a
specific colour while ignoring irrelevant colour cues presented prior to the target display. After a brief familiarization period, we presented an irrelevant motion cue to elicit surprise. Across conditions we varied prior exposure to the motion stimulus – seen versus unseen - and top-down expectations of occurrence – expected versus unexpected - to assess the extent to which each of these factors contributes to surprise. We found no attenuation of the surprise response when observers were pre-exposed to the motion cue and or had explicit knowledge of its occurrence. Our results show that it is neither sufficient nor necessary that a stimulus be new and unannounced to elicit surprise and suggest that the expectations that determine the surprise response are highly context specific.
There is more information present in any given visual scene than the human cognitive system is capable of fully processing at any one point in time. A challenge for the human visual system then is to construct a stable and functional percept of the world from only a select subset of the available visual input. Mechanisms of selective attention allow us to prioritise the processing of certain visual input so that our conscious percept is one constructed from information in the environment that is functionally pertinent. How these selection mechanisms are controlled and the information they are sensitive to has important consequences for how we interact with our environment. In everyday life, the visual system is frequently challenged to decide whether to attend to information that is relevant to our immediate goals or to prioritize signals that might be unexpected and signal a threat.

Much of the debate in the literature over attentional control has focussed on the nature of control of the exogenous attentional system – a system that reflexively shifts the focus of attention to signals of potential importance in the environment. At issue is the degree to which bottom-up factors, namely stimulus saliency, automatically capture attention and to what degree top-down, namely task goals, modulate the effect of salient stimuli (Jonides & Yantis, 1988; Posner, 1980; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991; Yantis & Jonides, 1984). Previous studies investigating orienting, especially in natural scenes, suggest that salience may in fact be a weak determinant of attentional selection: Although stimuli may need to be salient in order to attract attention, saliency in and of itself is not always sufficient to guide attention. In contrast, top-down models of attentional guidance propose that shifts of attention are contingent on the configuration of task-driven selection mechanisms, that select stimuli according to the current task (e.g., Einhäuser, Rutishauser, & Koch, 2008; Einhäuser, Spain & Perona, 2008; Foulsham & Underwood, 2008; Stirk & Underwood, 2007; Tatler, Hayhoe, Land & Ballard, 2011; Valuch, Becker & Ansorge, 2013). Whether a stimulus will attract attention has been shown to depend on whether the stimulus matches the ‘attentional set’ of the observer, which describes the set of relevant stimuli or features that we need to attend to in order to successfully complete the current task (Folk, Remington & Johnston, 1992; Folk, Remington & Wright, 1994; Folk & Remington, 1998). Indeed there are examples in the literature where task-driven processes have been shown to modulate attentional capture even when highly salient stimuli are presented. Folk,
Remington & Johnston (1992) showed that a salient distractor presented immediately prior to the target in a spatial cueing paradigm produced differential effects on performance according to its relationship with the target. When participants' task was to search for a colour singleton in the display, only matching-colour distractors and not abrupt onset distractors had an effect on search performance. The opposite was true when the target of search was an abrupt onset (though see Belopolsky, Schreij & Theeuwes, 2010; van Zoest, Donk, & Theeuwes, 2004). The equivocal support in the literature for purely bottom-up capture leaves open the question of how we become aware of stimuli and events in the world that are not directly relevant to our immediate tasks and or goals.

A commonality across much the research that informs the debate over attentional control is that stimuli in these paradigms are presented repeatedly, frequently and often with a degree of predictability. Yet outside of the laboratory the environments we encounter are rarely static and predictable in this way; rather, they are typically dynamic and can be unpredictable. Critical to the function and ultimately to the survival of any organism is the ability to effectively respond to and adapt to changes in its environment signaled by these unexpected events. This ability requires a mechanism for detecting new information (novelty) in the environment that operates largely independently of task-driven control and an observer's attentional set.

Several researchers have proposed that humans possess an orienting mechanism tuned to detecting novelty in the environment. An early theoretical account by Sokolov (1963) proposes that our tendency to reflexively orient towards stimuli in the environment is dependent on a mismatch between stimulus input and a set of contextual expectations that he labeled the 'neuronal model'. Over repeated exposure to a novel stimulus the neuronal model is updated to incorporate the novel stimulus, consequently dampening the orienting response to subsequent presentations of the stimulus ('habituation'). A similar mechanism for responding to novelty in the environment is derived from schema theories of perception and cognition where a schema is conceptualized as an organized knowledge structure used to generate predictions about the nature of objects and events in the environment (Rumelhart, 1984; Rumelhart, Smolensky, McClelland, & Hinton, 1986; Meyer, Niepel, Rudolph & Schützwohl, 1991). Unexpected events in the environment
generate prediction errors due to the mismatch that arises between the stimulus input and a set of expectations generated by the schema. Prediction errors signal that there is new information in the environment and the system responds by interrupting ongoing processes and devoting attentional resources to process this new information. This process is presumed to underlie the subjective impression of surprise (Meyer et al., 1991; Niepel, Rudolph, Schützwohl and Meyer, 1994; Meyer, Reisenzein & Schützwohl, 1997). Once an unexpected stimulus has been reconciled and incorporated into a schema it will no longer elicit surprise as it is no longer expectation discrepant (Niepel et al., 1994). It is through this mechanism that schemas are thought to be updated and maintained as accurate accounts of one’s environment. Indeed, a novelty selection mechanism has been proposed as the necessary complement to dynamic and efficient goal-driven selection mechanisms to ensure adaptive action in natural environments (Horstmann, 2006).

The role of task-expectancies in determining the allocation of cognitive resources is supported by experimental evidence demonstrating numerous physiological and behavioural changes in response to unexpected events (Asplund, Todd, Snyder, Gilbert & Marois, 2010; Becker & Horstmann, 2011; Czigler, Weisz & Winkler, 2006; Forster & Lavie, 2011; Horstmann, 2002, 2005, 2006; Horstmann & Becker, 2008; Kazmerski & Friedman, 1995; Meyer, et al., 1991; Niepel et al., 1994; Schützwohl, 1998; Neo & Chua, 2006). For example, in a study by Meyer et al. (1991) participants had to respond to the location of a dot that appeared briefly (0.1 secs) either above or below two vertically arranged words. For the first 29 pre-critical trials of the experiment the words appeared as black against a white background. On the 30th ‘surprise’ trial, the colour of one of the words and its background was inverted (white letters on a black background). Recall for the inverted word on the surprise trial was significantly better relative to a control condition in which the word was presented in the same way as in the pre-critical trials, suggesting that the expectation-discrepant word had attracted attention. Furthermore, RTs to the dot on the surprise trial were significantly elevated relative to a control condition, suggesting that additional processing resources were recruited to process and integrate the expectation-discrepant event.

Subsequent work by Schützwohl (1998) and more recently by Horstmann (2005) has demonstrated that the magnitude of the surprise response to a new and
unannounced stimulus indeed varies with varying task-expectancies. Using the same paradigm as Meyer et al. (1991), Schützwohl (1998) varied the number of pre-critical trials between 3, 13, 23 and 33 to modulate the strength of stimulus expectations prior to the exposure to the surprising stimulus. In line with the predictions, the four conditions showed a differential response to the surprising stimulus. RTs on the surprise trial were significantly longer in the 13 trials condition than the 3 trials condition and significantly longer again in the 23 trials condition relative to the 13 trials condition. No difference in RTs was found between the 23 and 33 trials conditions. These results indicate that more practice leads to the formation of stronger expectancies, which, when violated, produce a heightened surprise response.

In a separate experiment Schützwohl (1998) established that the variability of the stimulus array presented in the pre-critical trials can also modulate the surprise response. In one condition the word stimuli in the pre-surprise trials were presented in a uniform font (homogenous stimulus array) while in a second condition the font of one of the two words was varied in each of the pre-critical trials (heterogeneous stimulus array). Presenting a novel combination of font colours in the surprise trial led to RTs that were significantly shorter in the heterogeneous condition relative to the homogenous condition. These results show that the formation of task-expectancies are influenced by experience and the distribution of events and objects that occur prior to a novel stimulus. When a set of expectations is weakly established and/or broadly defined, broad expectations are formed and new and unannounced stimuli are less likely to violate them. Conversely, repeated exposure to relatively homogenous stimulus arrays leads to narrowly defined task-expectancies with seemingly less tolerance for new unannounced deviants.

Common across all the experiments investigating surprise is that the surprising stimulus is always new and unannounced. It is clear from the work of Schützwohl (1998) and Horstmann (2005) that novelty or “unexpectedness” per se are not sufficient to elicit a strong surprise response, because the context plays an important role in shaping our expectancies, which in turn determine the surprise response. However, it is less clear to what proportions prior exposure versus top-down expectations shape our task-expectancies and whether either one of them or both are necessary to elicit surprise. That is, if participants have prior exposure to a
stimulus and/or are informed about its occurrence, would it still be unexpected in the sense that it still elicits surprise? We know that both the behavioural and neurophysiological markers of surprise dissipate across successive presentations of an unexpected stimulus within the visual domain (Retell, Becker & Remington, in press; Horstmann 2002, 2005, 2006; Schützwohl, 1998; Asplund et al., 2010; Kazmerski & Friedman, 1995). In certain instances the surprise effect occurs on only the first presentation of a novel stimulus (Horstmann 2002, 2005, 2006). However, it is an open question whether the surprise response would be attenuated if participants had been exposed to the stimulus prior to performing a specific experimental task. Presumably, any exposure to a stimulus will render it familiar, and will therefore affect, almost by definition, its novelty. Thus, if surprise is related to the novelty of a stimulus in this sense then we should expect an attenuation of the surprise response when participants are pre-exposed to an “unexpected” stimulus. Similarly, if task-expectancies can be shaped by explicit knowledge about the nature of events and objects in an environment then we might expect that knowledge of a forthcoming “unexpected” stimulus should also result in an attenuation of the surprise response. An alternatively possibility is that task-expectancies are highly task- or context-specific and formed strictly through a processes of implicit learning. If this is the case, pre-exposure to and or explicit knowledge of an “unexpected” stimulus should have no effect on the subsequent response to such a stimulus.

The present study addressed these open questions, by examining responses to an otherwise surprising stimulus when participants a) were instructed to expect it, b) had been pre-exposed to it, c) were exposed to both of these manipulations, or d) none (standard).

**Experiment 1**

We used a variant of the spatial cueing paradigm used by Folk and Remington (1998) to test surprise with respect to a task-irrelevant motion singleton distractor (cue). Participants had to report the orientation of a specific red target (e.g., red horizontal bar) that was embedded amongst six differently coloured and oriented non-target bars (i.e., red, green, blue, horizontal and vertical bars). Prior to the target display, a cueing display was presented that contained a to-be-ignored red
or green singleton cue. The red and green cues were either presented at the same location as the target (valid trial) or at a different location (invalid trial), and were included to provide a baseline against which the effects of the surprising motion cue could be compared. According to the Contingent Orienting Hypothesis, the target-similar red cue should attract attention because it is consistent with the goal of searching for red, which should lead to faster response times (RT) on valid than invalid trials. On the other hand, the green cue should not attract attention, because it did not match the task goals of searching for red (Folk, Remington & Wright, 1994; Folk and Remington, 1998), so there should be no effect of cue validity. The motion cue was always presented at an invalid location. Hence, if participants are able to ignore the motion cue in any of the conditions, there should be no performance differences between the invalid green cue and the motion cue in the RTs. On the other hand, if the motion cue attracts attention, RTs should be elevated. Indeed, if rare stimuli elicit a surprise response in addition to spatial reallocation of attention then RT could be elevated even more than on invalid red cue trials, due to the extra time needed to process the surprising stimulus (e.g., see Horstmann, 2005).

If presenting an irrelevant motion cue generates surprise, then the RT elevation should moreover dissipate with repeated presentations of the motion cue. To gauge the RT elevation due to surprise, we presented the motion cue infrequently during the experiment (once every ~30 trials) after the first presentation, to a total number of eight motion cue trials. The core question of the present experiment was whether providing participants with prior information and/or exposing them to the “unexpected” stimulus prior to the experiment would modulate their surprise response. To that aim, we varied the amount of prior information and exposure to the motion singleton between different groups of participants.

In the ‘expected’ condition participants were told immediately prior to the experiment that at some point during the experiment a new and unexpected stimulus would be presented but not what that stimulus would be. Additionally, they were told that the unexpected stimulus would occur at an invalid location and that it was designed to distract them from searching for the target and therefore they should do their best to ignore it. Moreover, participants in the ‘expected’ condition were informed that the fixation dot would turn blue when the new stimulus was about to occur, as a reminder to them that they were about to see a potentially distracting
new stimulus and that they should do their best to ignore it. To summarise, participants in the ‘expected’ condition knew that an “unexpected” stimulus would be presented, but were naive to the specific attributes of the stimulus.

In contrast, in the ‘exposed’ condition participants were shown an example of the motion cue immediately prior to the start of the experiment. However, participants were told a cover story to explain the presence of the motion cue, but were given no information regarding the presentation of this stimulus in the experiment. Participants in the ‘expected and exposed’ condition received the ‘expected’ and the ‘exposed’ manipulations. Critically though, the two were linked. That is, participants were shown the motion cue prior the experiment and told that that would be the “unexpected” stimulus that would occur later in the experiment. Again, participants in this condition knew that the motion distractor would roughly be predicted by the fixation dot turning blue, and were instructed that attending to the motion cue would be detrimental to performance.

Finally, in the ‘standard’ condition, participants were not informed about the appearance of the motion cue and not shown any stimulus examples of it. This condition served as a baseline condition to which the other three experimental conditions were compared.

To ensure that RT elevations in response to the motion cue were not due to participants’ gaze shifts instead of attention shifts, we used an eye tracker to monitor central fixation. All eye-movement analyses were conducted online and trials in which participants broke fixation during the cueing frame were coded as an error.

Method

Participants

Two-hundred participants (137 female) aged 17 – 42 (M = 19.9, SD = 3.1) from an introductory psychology course at the University of Queensland were assigned to one of the four conditions (standard, expected, exposed, expected and exposed) and participated for course credit. All participants reported normal or corrected-to-normal vision.
Apparatus

All experiments were conducted using the computer software package Matlab (2010a) and the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 19-inch CRT monitor attached to a (Pentium 4) personal computer. Stimuli were presented with a resolution of 1280 * 1024 pixels and a refresh rate of 75Hz. Responses were recorded using a keyboard. Participants’ eye-movements were measured using a video-based infrared eye-tracking system (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of 0.1 and a temporal resolution of 500 Hz and the Eyelink Toolbox extension (Cornelissen, Peters & Palmer, 2002).

Stimuli

Each trial consisted of a fixation display, a cueing display and a target display. All displays contained a central fixation circle (0.2° x 0.2°) surrounded by six peripheral circular placeholders (2.6° x 2.6°) positioned in a circular array around fixation and subtending 5° of visual angle from fixation. The cueing display consisted of a set of four filled circles (0.3°) in a diamond configuration surrounding all six placeholders (see Figure 1). With the exception of motion cue trials, one set of four dots around one location was always coloured either red or green (four-dot cue). The motion cue was rendered by a 90° rotation of the diamond configuration in eight 11.25 ° clockwise increments at 13.33ms intervals.

The target display was comprised of the same stimuli as the fixation display with the addition of six bars presented at each of the six placeholder locations. The bars could be oriented horizontally, vertically or 45° to either the left or to the right. In the target display three of the bars were oriented either horizontally or vertically and three were oriented either 45° to the left or to the right. Two of the bars in the display were coloured red (RGB = 255, 0, 0), two were coloured green (RGB = 0, 255, 0) and two were coloured blue (RGB = 0, 0, 255). The distribution of colours was such that each orientation (horizontal/vertical and 45° left/right) appeared in each colour. The target was the red bar that could appear either horizontally or vertically and participants had to report its orientation (horizontal vs. vertical) with a button press (left arrow key for horizontal; right arrow key for vertical). All stimuli were presented against a black (RGB = 5, 5, 5) background.
Design

Experiment 1 consisted of 32 practice trials and 288 experimental trials, though this structure was not apparent to participants. Presentation of the red and green cues and the target was randomised across the experiment with each occurring at each location equally often. This design rendered the cues non-predictive of the target location, thus providing no incentive to orient to the cues. Participants were informed of this and instructed not to attend to the cue throughout the experiment. On eight of the experimental trials the colour cue was substituted for a motion cue. The motion cue was presented once every 30-35 trials and was only ever presented at an invalid location. The colour cues, the motion cue and the target never appeared at the position directly above or the position directly below fixation (see Figure 1). That is, these stimuli could only occur at four of the six placeholder locations. The motion cue was presented twice at each of four possible locations and replaced an equal number of red and green cues – four of each. Five trials prior to the presentation of the first motion cue the fixation dot was presented as blue for one trial. The relevance of this signal varied across conditions and is explained in more detail below.

We independently varied prior exposure to the surprising motion cue, with instructions to expect a surprising motion cue. This resulted in the four conditions outlined in Figure 2. Due to practical reasons, the first 100 participants were randomly assigned to the either the ‘standard’ condition or the ‘expected’ condition and these two conditions were run first. The second 100 participants were randomly assigned to either the ‘exposed’ or ‘expected and exposed’ condition.
Figure 1. Example trial sequences. Red and Green cues were non-predictive of the target location while the motion cue only ever occurred at invalid locations. The target and cues never occurred at the locations above and below fixation.

Procedure

Prior to the experiment, all participants were informed about the occurrence of the red and green cues and were instructed to ignore them as they were non-predictive of the target. Moreover, all participants were briefed about the eye tracking procedure and instructed to maintain fixation on the central dot, while responding as fast and accurately as possible.

Apart from this, the instructions differed for the 4 groups (standard, expected, exposed, expected and exposed). Participants in the standard condition were not at all informed about the appearance of the motion cue nor shown any examples of it.

Participants in the expected condition were informed that a novel cue would be presented at an invalid stimulus location, of which they would be warned by the fixation dot turning blue, and they were instructed to ignore it. Participants in the exposed condition were presented with an exposure display that presented the motion cue at the location of one of the placeholders (see Figure 3). Participants were told that the motion stimulus in this context was related to the calibration of the eyetracker and were asked to maintain central fixation during its presentation.
Additionally, participants were told that the fixation dot would turn blue on some of the trials but that this was irrelevant for the purposes of the present experiment. In the expected and exposed condition, participants were fully informed about the appearance of the motion cue, shown the same example as the exposed group, and were informed about the significance of the blue fixation dot. Each trial began with a central fixation dot that was presented for 700ms. This was followed by the fixation display for 500ms or until the participant met the fixation criteria of the eye-tracker. Following this, the fixation dot offset for 50ms then the fixation display was presented for a randomly determined 200, 400 or 600ms, after which the cueing display was presented for 120ms. Following the cueing display there was an ISI of 53ms and then the target display was presented for 53ms (see Figure 1). At the offset of the target display, the fixation display was presented and remained on the screen until a response was recorded. That is, the trial ended only when a response was registered. If the response was correct and made in fewer than 1000ms then the next trial started after a 500ms delay. If the response was correct but made in over 1200ms participants received the feedback “Too Slow!” and if the response was incorrect they received the feedback “Wrong!” In both cases the feedback was presented for 1600ms and then the next trial commenced.

The RT deadline of 1200ms with the specific feedback was employed to avoid that participants in the ‘expected’ and ‘exposed & expected’ conditions disengage from the search task and actively searching for the motion cue. By installing a soft response deadline we aimed to ensure that participants’ primary focus was on the search task.
**Figure 2.** Condition matrix for Experiment 1.

**Results**

Mean RTs and accuracies for Experiment 1 are shown in Figures 3 and 4, and Table 1, respectively. RTs exceeding 1,800ms and errors were excluded from RT analyses. Eye movement data were analysed online and trials coded as an error if participants did not remain fixated throughout the trial. Participants were deemed to be fixating if their gaze fell within a region of 1.3 degrees of visual angle from the centre of the fixation cross. This criteria lead to a loss of 7.94% of trials that was uniformly distributed across conditions. Data from four participants (1 Standard; 2 Exposed; 1 Exposed & Expected) were excluded from all analyses due to unacceptably high errors of 25% or greater. In the report of results, we first present the results for the red and green cues, followed by the motion cue data for each condition, followed finally by the results of a between subjects analysis of the motion cue data.

**Table 1.** Percent of errors for each condition in Experiment 1 and Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>Red Cue</th>
<th>Green Cue</th>
<th>Motion Cue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valid</td>
<td>Invalid</td>
<td>Valid</td>
</tr>
<tr>
<td>Exp 1: Standard</td>
<td>6.12</td>
<td>10.18</td>
<td>8.72</td>
</tr>
<tr>
<td>Exp 1: Expected</td>
<td>5.75</td>
<td>9.58</td>
<td>7.81</td>
</tr>
<tr>
<td>Exp 1: Exposed</td>
<td>5.38</td>
<td>9.71</td>
<td>7.00</td>
</tr>
<tr>
<td>Exp 1: Expected &amp; Exposed</td>
<td>4.59</td>
<td>10.74</td>
<td>9.69</td>
</tr>
<tr>
<td>Exp 2: Control</td>
<td>5.42</td>
<td>11.11</td>
<td>7.92</td>
</tr>
</tbody>
</table>

**Colour cues**

To ascertain whether the red and green cues shows a results pattern consistent with top-down controlled search for the red target, we first conducted four 2 (cue colour: red versus green) x 2 (cue validity: valid versus invalid) repeated
measures ANOVAs and computed planned follow-up comparison. As shown in Figure 3, all four conditions (standard, expected, exposed, expected and exposed) showed significant validity effects for the red cue with faster RTs on valid than invalid trials for the red cue, and the reverse effect (of faster RT on invalid than valid trials) for the green cue.

*Standard:* A main effect of cue validity, $F(2, 47) = 24.47, p < .001, \eta^2 = .34$, was qualified by a significant interaction between cue colour and cue type, $F(2, 44) = 95.58, p < .001, \eta^2 = .67$. Follow-up pairwise comparisons revealed a significant validity effect associated with the red cue, $t(47) = 8.51, p \leq .001$ and a small but significant *inverse* validity effect associated with the green cue, $t(47) = -3.80, p = .001$

*Expected:* A main effect of cue validity, $F(2, 49) = 43.32, p < .001, \eta^2 = .47$, was qualified by a significant interaction between cue colour and cue type, $F(2, 44) = 121.72, p < .001, \eta^2 = .71$. Follow-up pairwise comparisons revealed a significant validity effect associated with the red cue, $t(49) = 11.12, p = <.001$ and a small but significant *inverse* validity effect associated with the green cue, $t(49) = -5.04, p < .001$

*Exposed:* A main effect of cue colour, $F(2, 49) = 5.77, p = .02, \eta^2 = .11$ and a main effect of cue validity, $F(2, 44) = 34.30, p < .001, \eta^2 = .41$, were qualified by a significant interaction between cue colour and cue type, $F(2, 49) = 197.33, p < .001$. Follow up pairwise comparisons revealed a significant validity effect associated with the red cue, $t(49) = 12.51, p = <.001$ and a small but significant *inverse* validity effect associated with the green cue, $t(49) = -3.48, p = .001$.

*Expected and Exposed:* A main effect of cue colour, $F(2, 48) = 4.07, p = .049, \eta^2 = .08$ and a main effect of cue validity, $F(2, 48) = 24.38, p < .001, \eta^2 = .34$, were qualified by a significant interaction between cue colour and cue type, $F(2, 49) = 169.85, p < .001$. Follow up pairwise comparisons revealed a significant validity effect associated with the red cue, $t(48) = 12.04, p = <.001$ and a small but significant *inverse* validity effect associated with the green cue, $t(48) = -6.16, p < .001$. 

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Mean RTs as a function of cue type and validity for Experiment 1. RTs for the motion cue reflect the average of all 8 motion presentations. Error bars depict the standard error of the mean.

**Motion cue**

For each condition we computed the effect of the motion cue relative to the average of valid and invalid green cues trials. The logic of this is as follows: remembering that participants searched for a red target, both motion and green were task irrelevant. Thus, if the novelty of the motion cue had any effect on RTs it ought to be observable above and beyond any effect of the task irrelevant green cue. We chose to use the average of the valid and invalid green cues as a baseline rather than invalid green cues due to the inverse validity effect associated with the green cue. This method resulted in a more conservative estimate of the effect of the motion cue.

To determine the interference effect associated with the first presentation of the motion cue we contrasted RTs on the first motion cue trial to the average of the
RTs associated with the green cue trials that were presented prior to the first presentation of the motion cue (16 observations per participant). In all four conditions we observed a significant interference effect. Four pair-wise comparisons revealed that RTs associated with the first motion cue were significantly slower relative to RTs associated with the relevant green cue trials in the 'standard' condition, $t(39) = 3.43, p = .001$, the 'expected' condition, $t(41) = 5.68, p < .001$, the 'exposed' condition, $t(41) = 3.66, p = .001$, and the 'expected and exposed' condition, $t(41) = 4.76, p < .001$ (see Figure 4).

In addition to computing the interference associated with the first presentation of the motion distractor, we also computed the interference associated with presentations 2-8 of the motion distractor in each condition. Four pair-wise comparisons confirmed that RTs associated with the motion cue (averaged across presentations 2-8) were significantly slowed relative to RTs associated with the green cue in the 'standard' condition, $t(47) = 7.36, p = <.001$, the 'expected' condition, $t(49) = 6.90, p = <.001$, the 'exposed' condition, $t(49) = 6.95, p = <.001$, and the 'expected and exposed' condition, $t(48) = 7.41, p = <.001$.

To assess whether the RT interference associated with the motion cue dissipated with repeated exposure to the motion cue we used we ran the motion cue data from each condition through a Monte Carlo procedure. This involved randomly shuffling the position of the RT data within participants and calculating new group means for each presentation of the motion cue. We performed 10,000 iterations of this step, each time calculating a new group mean for each presentation of the motion cue. From these simulated distributions of means (one for each presentation of the motion cue) we calculated the 95% confidence interval around the mean of each distribution (see Fig. 4). This method allowed us to simulate the pattern of data that would result if exposure were having no effect on RTs. As shown in Figure 4, the empirical data deviated significantly from the simulated pattern of results in all four conditions. That is, in all four conditions we observed an effect of presentation order such that the RT were significantly slower than predicted by the null on the first presentation of the motion cue. Moreover, RT associated with the motion cue

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5 These effects held when RTs on the first motion cue trial were compared to the respective invalid red cue trials for the 'expected' condition, $p = <.001$, the 'exposed' condition, $p = <.001$, and the 'expected and exposed' condition, $p = <.001$. In the 'standard' condition the effect reached $p = .06$. 
dissipated across repeated presentations of the motion cue, with lower-than-predicted RT to the last presentation of the motion cue (8\textsuperscript{th} presentation).

**Figure 4.** Average RT for each presentation of the motion cue in each of the four experimental conditions. The major dashed line in each plot shows the predicted pattern of RTs for the motion cue when presentation order has no effect, as determined by the permutation analysis (see Results section). The minor dashed lines define the 95\% confidence interval around the permuted means, where data outside these boundaries indicate a significant change in RTs across presentations of the motion cue.

**Motion cue: Between-subjects analysis**

Having found significant RT interference associated with the motion cue in each condition we sought to test whether these effects varied across our four conditions. To avoid the possibility that different result patterns could be due to baseline RT differences between the groups (e.g., with participants in one group responding generally faster and/or more accurately than participants in the other
group), the motion cue data were normalised for each participant by subtracting the average RT for (valid and invalid) green cue trials – calculated from the trials prior to each presentation of the motion cue – from the RT associated with the individual presentations of the motion cue. To analyse differences in the surprise response across conditions we compared normalised RTs to only the first motion cue presentation. The normalised data for all motion cue presentations is shown in Figure 5.

A one-way between-subjects ANOVA computed over the first motion cue presentation revealed no significant differences between the four between-subjects conditions, $F(3, 162) = 2.49$, $p = .062$. As shown in Figure 5, however, RTs associated with the first motion cue in the ‘expected surprise’ condition appear elevated relative to the standard surprise condition. Correspondingly, a between-subjects contrast revealed significantly elevated RT in the expected surprise condition compared to the standard surprise condition, $t(80) = 2.48$, $p = .015$.

**Figure 5.** Normalized RTs for the motion cue for all four conditions from Experiment 1. RTs are normalized by subtracting the average RT for green cue (valid and invalid) trials – calculated from the trials prior to each presentation of the motion cue – from the RT associated with the individual presentations of the motion cue.
Discussion

In Experiment 1 we varied the instructions and/or exposure to a motion stimulus to modulate the top-down expectations and/or familiarity with the stimulus. In all four conditions we observed elevated RTs associated with the first presentation of the motion cue indicative of surprise. Following the first presentation, the motion cue continued to produce RT interference, however the magnitude of this interference dissipated across presentations of the motion cue. Critically, interference by the irrelevant motion cue was observed despite the fact that participants adopted a feature specific attentional set for the colour red (reflected by the significant validity effect for the red cue and the lack of capture by the green cue; see Fig. 3). Thus, in the standard and exposed surprise conditions, the motion cue produced interference independent of any top-down strategy or goal to attend to motion or novel stimuli (Folk et al., 1992).

Moreover, the interference associated with the first presentation of the motion cue did not vary across conditions, at least not in the predicted direction. There was no attenuation of the RT interference associated with first presentation of the motion cue in the ‘exposed’ condition, the ‘expected’ condition or the ‘exposed & expected’ condition relative to the ‘standard surprise’ condition (see Figure 5). In fact, in the
‘expected’ condition we observed a trend towards an increase in the interference associated with the first motion presentation. That is, knowledge about the occurrence of an otherwise unknown event appears to have amplified the magnitude of the surprise response. However, this effect was evident only when participants knew to expect the “unexpected” stimulus but not what to expect. Even in the ‘exposed & expected’ condition, where participants knew what to expect and roughly when to expect it, the interference effect was preserved.

To summarise, in all four conditions we found RT interference associated with the first presentation of the motion cue. This interference persisted beyond the first presentation of the motion cue but was attenuated with repeated exposure to the motion cue. Contrary to our predictions, we found no attenuation of the RT interference associated with the first presentation of the motion cue when participants knew to expect something unexpected, were pre-exposed to the unexpected stimulus or were pre-exposed and knew what to expect. One possible, though admittedly unlikely explanation for this pattern of results is that the novelty signal we attempted to manipulate in Experiment 1 might not have been the source of the interference in Experiment 1. That is, it is possible that our results reflect a property of the motion stimulus itself and are unrelated to the novelty of the stimulus. In Experiment 2 we addressed this possibility by presenting the motion stimulus frequently.

**Experiment 2**

Experiment 2 was a control experiment to ensure that the effects reported in Experiment 1 were indeed related to the presentation frequency of the motion stimulus and not the motion stimulus itself. To test this, in Experiment 2 we presented the motion stimulus in the same manner as the colour cues - frequently and at both valid and invalid locations. Under these conditions the motion stimulus is comparable to the green cue – frequently occurring and task irrelevant – and should not produce a validity effect when participants are searching for a red target (Folk et al., 1992; Folk et al., 1994).
Method

Participants

Fifteen participants (8 female) aged 21 – 26 (M = 24.1, SD = 1.9) from an introductory psychology course at the University of Queensland participated for course credit. All reported normal or corrected to normal vision.

Apparatus

The apparatus used in Experiment 2 was identical to that used in Experiment 1.

Stimuli, design and Procedure.

The stimuli, design and procedure of Experiment 2 were identical to the ‘standard surprise’ condition in Experiment 1 with one critical exception: The motion stimulus in Experiment 2 was presented frequently – on one third of trials - and at both valid and invalid locations. As a result, in Experiment 2 there were 48 practice and 288 experimental trials.

Results

Mean RTs and error rates for Experiment 2 are shown in Figures 7 and Table 1, respectively. RTs exceeding 1,800ms and errors were excluded from RT analyses. This led to a loss of 7.74% of experimental trials.

A 3 (cue type: red vs. green vs. motion) x 2 (cue validity: valid versus invalid) repeated measures ANOVA of colour cue RTs revealed a main effect of cue validity, \( F(1, 9) = 5.33, p = .046, \eta^2 = .37 \). This effect was qualified by a significant interaction between cue colour and cue type, \( F(2, 9) = 11.68, p = .004, \eta^2 = .75 \). Follow up pairwise comparisons revealed a significant validity effect associated with the red cue, \( t(9) = 4.71, p = .001 \). No validity effect was observed for the green cue, \( t(9) = -1.15, p = .28 \) or the motion cue, \( t(9) = 0.02, p = .98 \).
Discussion

The results of Experiment 2 demonstrate that when the motion stimulus was presented frequently it had no effect on RTs relative to the task-irrelevant green cue. Consistent with the contingent capture hypothesis we observed a strong validity effect associated with the red cue but no effect of the green and motion cues when participants were searching for a red target (Folk et al., 1992). Additionally, the motion cue did not produce elevated baseline RTs that would be indicative of filtering costs or other forms of spatially non-specific interference (e.g., Becker, 2007; Folk & Remington, 1998). Instead, the results of Experiment 2 indicate that the motion cue produced no discernible evidence of capture or interference. Therefore, the effects of the motion stimulus reported in Experiment 1 relate to the infrequency of its presentation and are not the product of an inherent property of the motion stimulus per se.
General Discussion

The experiments reported here explored the contributions of prior-exposure and explicit knowledge of an “unexpected” event to the surprise response in visual search. Our results suggest that the surprise response may be independent of both of these factors. In Experiment 1 we observed robust RT interference indicative of surprise to the first presentation of a task irrelevant motion cue that was not attenuated when participants were pre-exposed to the motion stimulus and/or when participants had explicit knowledge about the unexpected event. Even when observers had prior experience with the surprising stimulus and knew roughly when to expect it (‘exposed & expected’ condition), the motion stimulus still elicited a surprise response. Only in the ‘expected’ condition was there any evidence of a modulation of the surprise response; here though we observed a trend toward increased RT interference (see Figure 5). That is, when participants knew to expect something unexpected but not what is was, there was a trend toward a larger surprise response.

The results of Experiment 2 demonstrated that stimulus presentation (in)frequency was indeed the source of the interference associated with the motion cue in Experiment 1, rather than some inherent property of the motion stimulus, such as salience or abrupt luminance transients. Consistent with the contingent orienting hypothesis (Folk et. al., 1994; Folk et. al., 1998), when the task-irrelevant motion cue was presented frequently in Experiment 2 we observed no effect of the motion cue relative to the green task-irrelevant cue. It could be argued that the elevation observed in the ‘expected’ and ‘exposed & expected’ conditions was obtained because subjects disengaged from the search task and actively searched for the surprising stimulus given they knew it was coming, consequently inflating RTs on the surprise trial. We suggest this is unlikely for two reasons: First, we employed a response deadline of 1,200ms throughout the experiment to encourage engagement with the task and fast responding. Secondly, performance on the trials between the blue fixation and the surprising stimulus did not differ across conditions (see Figure 6). That is, there is no evidence that participants in either the ‘expected’ or the ‘exposed & expected’ condition changed their search behaviour in response to information about the forthcoming novel stimulus. Thus, we suggest that the RT interferences associated with the first presentation of the motion cue in the
‘expected’ and ‘exposed & expected’ conditions reflects a reflexive redistribution of cognitive resources to the “unexpected” stimulus, which resulted in an increased surprise response.

One possibility is that there was a lower rate of inattentional blindness (IB) in the ‘expected’ condition relative to the other conditions. It is well documented that under attentional demand observers can fail to perceive unexpected seemingly highly salient stimuli (Jensen, Yao, Street, & Simons, 2011; Mack & Rock, 1998; Most, Scholl, Clifford & Simons, 2005; Most et al., 2001). When observers are aware that an unexpected stimulus may occur IB rates are attenuated if not abolished (Jensen et al., 2011). This could account for why we observed large RT cost in the expected condition relative to the other 3 conditions; the expectation manipulation may have attenuated rates of IB and resulted in higher rates of surprise. However, it’s not clear why this would not also have been the case in the expected and exposed condition. Possibly here exposure had an effect, though this speculative and would warrant further investigation. In hindsight it may have been informative to have documented participants’ awareness of the first presentation of the motion cue in order to draw stronger links to the phenomenon of IB.

In addition to finding a robust surprise effect to the first presentation of the motion cue, we also found RT interference associated with presentations 2-8 of the motion cue in all four conditions. These results are consistent with earlier findings showing that an infrequently presented salient distractor in visual search continues to interfere with performance on the task (e.g., Geyer, Mueller & Krummenacher, 2008). In line with previous empirical work (Horstmann 2002, 2005, 2006; Kazmerski & Friedman, 1995; Retell, Becker & Remington, in press; Schützwohl, 1998; Asplund et. al., 2010) and theoretical accounts of surprise and novelty (Meyer, Reisenzein & Schützwohl, 1997; Sokolov, 1963; Sokolov & Vinogradova 1975), this interference dissipated as a function of exposure to the motion cue in all four conditions (see Figure 4). Critically, this pattern of results demonstrates that exposure to the motion cue, though infrequent, led to a reduction in the RT interference produced by the motion cue during the experimental task. However, exposure to the motion cue did not have this effect when it occurred prior to commencing the experimental task as a result of the exposure in the ‘exposed’ and ‘expected & exposed’ conditions.
Thus, the results reported here suggest that surprise is highly context specific. To attenuate the initial surprise response, it is apparently necessary to present an irrelevant stimulus inside the task, or as part of the ongoing task. More strikingly, the failure to obtain a decrease of the surprise response in the expected and exposed condition suggests that a reduction of the surprise response is in some sense independent of top-down knowledge. If we define the "unexpectedness value" of a stimulus as its propensity to elicit surprise then our manipulations show that being fully informed about the impending occurrence of the surprising stimulus did nothing to reduce the unexpectedness value of the stimulus. From previous work we know that for surprise to manifest it is not sufficient that a stimulus is novel and unannounced (Schützwohl, 1998; Horstmann, 2005). Our results indicate that it is also not necessary for a stimulus to be novel and/or unannounced to elicit surprise.

This perhaps counterintuitive result is not inconsistent with classical theories of attention that assume that salient irrelevant stimuli are inhibited / filtered out through a process that depends on prior exposure to irrelevant stimuli and implicit learning about their relevance (Becker, 2007; Folk & Remington, 1998; Treisman & Sato, 1990). Note that our procedure may have provided participants only with explicit knowledge about the infrequent motion stimulus, whereas implicit learning may be highly context-specific and require that the to-be-inhibited stimulus is presented in the context of the task at hand. The implicit learning explanation of the results is also consistent with the finding that the effects of the motion cue were attenuated over the course of multiple presentations, but that it continued to produce interference. Of note, stimuli that occur infrequently provide few opportunities for the system to learn the necessary characteristics that require inhibiting. Consequently, they are not included in the formation of contextual expectations that describe the characteristics of irrelevant, to-be-inhibited stimuli.

Whether or not the implicit learning account above is correct, the results provide new insights into the factors that determine the neuronal model, schemata or expectations which in turn determine orienting to surprising stimuli (e.g., Horstmann, 2005; Meyer et al., 1991, Sokolov, 1963): First, the expectations determining the orienting response are apparently highly task specific or context-specific for exposure to show an effect. Secondly, explicit knowledge of an unexpected event or stimulus apparently does not alter the expectancies that ultimately determine the
surprise response, indicating that the neuronal model or schemata are based on implicit knowledge or predictions about upcoming events. In sum, the present results provide compelling reasons to re-define the notion of surprise – as reflecting the foreseeability of a stimulus or event according to inductive processes that operate largely automatically in the traditional sense (Posner & Snyder, 1975) and independent of other cognitive processes (Green, 1956).
Chapter 4 – Oculomotor Capture by New and Unannounced Colour Singletons During Visual Search
Summary

In chapters 2 and 3 I discussed the possibility that the apparent sensitivity of visual selection mechanisms to stimulus novelty reflects a process whereby our ability to inhibit irrelevant stimuli is dependent on prior exposure and implicit learning about their relevance. In Chapter 4, I focus in more detail on the underlying mechanism by which novelty attracts visual attention. It has previously been noted in the literature that the temporal profile of capture by unexpected stimuli appears distinct from the temporal profile of capture by expected stimuli (Horstmann, 2002; 2006; Horstmann & Becker, 2008). This observation is interesting because it suggests a distinct and dedicated mechanism of control for orienting toward unexpected stimuli. Previous attempts to characterise the temporal profile of capture by unexpected stimuli have done so using RT and response accuracy. However, these measures can be affected by decision and response related processes that may not be directly related to search performance per se. Given the constellation of physiological and cognitive changes that characterise our response to unexpected events, a more direct measure of search performance may provide further insight into the selection mechanisms that govern capture by unexpected events. In Chapter 4, I take advantage of the well-documented coupling between eye-movements and visual attention (e.g., Deubel & Schneider, 1996; Peterson, Kramer, & Irwin, 2004) to investigate the temporal profile of capture by an unexpected stimulus.

Abstract

The surprise capture hypothesis states that a stimulus will capture attention to the extent that it is pre-attentively available and deviates from task-expectancies. Interestingly, it has been noted by Horstmann, (2002; 2005; 2006) that the time course of capture by such classes of stimuli appears distinct from that of capture by expected stimuli. Specifically, attention shifts to an unexpected stimulus are delayed relative to an expected stimulus (delayed onset account). Across two experiments we investigated this claim under conditions of unguided (Exp. 1) and guided (Exp. 2) search using eye-movements as the primary index of attentional selection. In both experiments we found strong evidence of surprise capture for the first presentation of an unannounced colour singleton. However, in both experiments the pattern of eye-
movements was not consistent with a delayed onset account of attention capture. Rather we observed costs associated with the unexpected stimulus only once the target had been selected. We propose an interference account of surprise capture to explain our data and argue that this account can also explain existing patterns of data in the literature.
Mechanisms of selective attention allow us to prioritise the processing of a restricted number of events or objects in the visual world. Consequently, our conscious experience of the world is constructed primarily of visual input originating from information to which we have attended. How these selection mechanisms are controlled and the criteria by which (visual) input is selected for further processing versus input that is “discarded” earlier in the processing hierarchy has important consequences for how we interact with our environment. The decision of whether to attend to information that is relevant to our immediate goals or to prioritise signals that might be unexpected and signal a threat is one we often face. Thus, understanding what determines the events in the visual world to which we orient and attend has been a question of principal interest and importance to researchers in the field of cognitive psychology for decades.

Models of attentional guidance distinguish between two forms of attentional control: endogenous control which is the ability to voluntarily allocate cognitive resources to processing task-relevant information, and exogenous control that directs attention involuntarily towards signals of potential importance - but not necessarily task-relevance - in the environment (Jonides & Yantis, 1988; Posner, 1980; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991; Yantis & Jonides, 1984). Understanding the stimulus conditions to which the exogenous attentional system is sensitive has been a topic of much debate. Specifically, research has focused on understanding the extent to which exogenous shifts of attention are governed by bottom-up factors, namely stimulus saliency versus the extent to which they are modulated by top-down processes. Two broad schools of thought have emerged in the literature: proponents of bottom-up models of attentional guidance argue that the exogenous attentional system responds automatically to salient stimuli irrespective of top-down input. Under these models, modulation of attention by top-down processes is thought to occur late in processing, only after attention has initially been deployed towards the stimulus with the highest saliency value (“de-allocation hypothesis”; see Belopolsky, Schreij & Theeuwes, 2010; van Zoest, Donk, & Theeuwes, 2004). Conversely, according to top-down models of attentional guidance, such as the Contingent Capture hypothesis, shifts of attention are contingent on the goals of the observer. That is, a salient stimulus will only capture attention to the extent that it shares characteristics with the target of search (Folk,
Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). In their seminal paper, Folk, Remington & Johnston (1992) showed that a salient distractor presented immediately prior to the target in a spatial cueing paradigm produced differential effects according to its relationship with the target being searched for. When the target of search was a colour singleton only matching-colour distractors and not abrupt onset distractors had an effect on search performance. The opposite was true when the target of search was an abrupt onset. This result demonstrates that attention can be tuned to certain stimulus properties and that only those stimuli that share the defining features of the target will capture attention, seemingly irrespective of stimulus saliency. Subsequent research has explored this tuning mechanism across and within a range of stimulus dimensions. Greater capture by target-similar than target-dissimilar distractors has now been shown within the colour dimension (Folk, Remington & Johnston, 1998), as well as for onsets (Ludwig & Gilchrist, 2002), for size (Becker, 2010) and with a number of dependent measures (e.g., eye-movements: Becker, Ansorge & Horstmann, 2009; Ludwig & Gilchrist, 2002; Wu & Remington, 2003; EEG: Eimer, Kiss, Press & Sauter, 2009; Lien, Ruthruff, Goodin, & Remington, 2008; Wykowska & Schuboe, 2009).

The fact that top-down selection mechanisms can act, in a sense, as a filter to counteract effects of bottom-up saliency raises the question of how we become aware of stimuli that are not directly relevant to our immediate tasks and/or goals. A commonality across almost all the research that informs the debate over attentional control is that distractors in these paradigms are presented repeatedly and frequently throughout the experiments, and thus, presumably contribute, and importantly, conform to task expectancies that develop over the course of an experiment (Gibson & Jiang, 1998). It is possible then that the top-down control of attention is limited to stimuli that conform to these task expectancies and that task expectancies themselves may in fact play a role in determining how spatial attention is allocated throughout a scene. Indeed, the notion that unexpected and novel events in the world demand the resources of our perceptual system is consistent with early theoretical accounts of orienting and surprise. According to Sokolov’s (1963) *Orienting Reflex*, a stimulus will elicit a reflexive orienting response to the extent that it violates expectations and generates a sufficient mismatch between the input from the environment and the established neuronal model or schema. Over repeated
expose to a novel stimulus the neuronal model is updated, consequently reducing the stimulus’ propensity to elicit an orienting response.

Theoretical models of surprise are supported by experimental work demonstrating a number of physiological and cognitive changes in response to new and announced stimuli in the environment (Meyer, Niepel, Rudolph & Schützwohl, 1991, Horstmann, 2002; Horstmann, 2005; Horstmann, 2006; Horstmann & Becker, 2008; Becker & Horstmann, 2011). Meyer et al. (1991) tested surprise experimentally by having participants respond to the location of a dot that appeared briefly (0.1 secs) either above or below two vertically arranged words. In the experimental group, the words were present for the first 29 trials as black against a white background. On the 30th trial, the colour of one of the words and its background was inverted (white letters on a black background). In the control condition the experimental procedure was identical except that there was no inversion of the colours on the 30th trial. Participants were probed on their experience of the “surprising” trial with a series of questions. Notably, recall for the surprising word was significantly better in the experimental condition than in the control condition suggesting that the novel stimulus was attended to. In addition, RTs to the dot on the surprise trial were elevated relative to the control and pre-surprise trials. Meyer et al. (1991) argued that elevated RTs on the surprise trial reflected the recruitment of additional processing resources used for reconciling the discrepancy between the expected and the actual input that is generated by attending to a novel stimulus.

Further evidence that task expectancies can modulate shifts of spatial attention specifically comes from the surprise capture (Horstmann, 2002; 2005) literature. Horstmann (2005) had observers search for the letter L or R in a circular array of 4 or 12 (varied between subjects) different letters. After a series of expectation congruent trials, the target letter was unexpectedly presented in a different colour (e.g., red, among all-grey items). The logic of the design is as follows: if the target fails to capture attention then a serial search for the target must ensue and thus search latency will be dependent on the set size – as the set size increases it takes on average longer to locate the target, resulting in a steep RT x set size function. Alternatively, if the target captures attention then search latencies should be independent of set size, which ought to result in a flat RT x set size
function. Critically though, RT delays that are due to decision-level processes ought to be constant across set sizes and should not change the relationship between search efficiency and set size. Consistent with attentional capture, Horstmann (2005) found that RTs on the surprise trial were in fact independent of the number of non-targets (3 or 11). Given that observers had no prior knowledge of the unexpected colour singleton, capture in this instance was, by definition, independent of any top-down attentional set for the unexpected item and therefore is difficult to reconcile with strictly top-down models of attentional guidance.

Interestingly, Horstmann (2002; 2005; 2006) has noted that the temporal profile of capture by unexpected stimuli appears distinct from top-down mediated capture and reports of salience based capture in the absence of top-down filtering. In a test of the surprise capture hypothesis, Gibson and Jiang (1998) failed to find an effect of an unexpected colour singleton when it was presented for 86ms and onset with the target display. A critical difference between the Gibson and Jiang (1998) and Meyer et al. (1991) paradigms - noted by Horstmann (2002) - is the presentation duration of the surprising stimulus. Meyer et al. (1991) presented the surprising stimulus for 500ms prior to the onset of the target while the surprising stimulus was presented for only 86ms and onset with the target in the Gibson and Jiang (1998) experiments. Horstmann (2002) proposed that the orienting component of a surprise response might be slowed by additional processing that occurs in response to surprising stimuli and that the absence of a surprise effect reported by Gibson and Jiang (1998) was due to the insensitivity of their measure. That is, the presentation duration of the surprising stimulus was too brief for a surprise response to be observed. Indeed, using the same paradigm as Gibson and Jiang (1998), Horstmann (2002) found that when the surprising stimulus appeared 500ms prior to the onset of the target display, response accuracy was significantly improved on the surprise trial relative to pre-surprise trials - a pattern of results indicative of attentional capture by the surprising colour singleton. Subsequent research into the temporal profile of surprise capture suggests that it takes at least 200ms to manifest with pronounced effects observed 400ms post the surprise stimulus onset (Horstmann, 2006). That is, surprise capture appears to manifest slowly. Critically, the time course of surprise capture has been attributed, in part, to a delay in the onset of the attention shift and
this delay has been used to argue for distinct underlying mechanisms of control for expected and unexpected events (Horstmann, 2005; 2006).

**The present series of experiments**

In the following paper we used eye-movements to further investigate this apparent onset latency differential between capture by expected and unexpected events. To date, much of the work on surprise capture has quantified the effect using RTs and response accuracy; this includes the work suggesting its delayed onset. Disentangling the separate components of surprise using these methods is difficult though due the fact that RTs and response accuracy can be affected by decision and response level processes that are unrelated to search performance – a limitation that is of particular relevance in the study of surprise. More recently, research into attentional guidance has made use of the well-documented coupling between eye-movements and attention shifts and used eye-movements as an index of attentional capture. Though attentional selection does not always result in the execution of an eye-movement (Juan, Shorter-Jacobi, & Schall, 2004; Wu & Remington, 2003), eye-movements are preceded by shifts of attention (Deubel & Schneider, 1996; Peterson, Kramer, & Irwin, 2004.). Using eye-movements to measure search performance can provide insight into the spatial and temporal aspects of visual search that other measures such as RT and response accuracy are less sensitive to. As such, we used eye-movements to address whether the temporal profile of surprise capture reflects delays at an early attentional level – prior to shifting attention to the target; or at a later level – after attention has been shifted to the target. It remains an open question whether unexpected stimuli capture the eyes.

**Experiment 1**

The aim of Experiment 1 was to assess whether and to what extent surprise-induced delays occur prior to shifting attention or the gaze to the target, and after selection of the target. As such, the design of Experiment 1 was similar to Horstmann (2002 exp. 3, 2005 exp. 1) with the exception of the set size manipulation. Since eye-movements may offer a more direct measure of how attention is allocated during search it was not necessary to manipulate set size here. Otherwise, the design was conceptually similar to previous studies: the experiments
consisted of a single block that was sub-divided into three phases; a pre-critical, a critical (surprise trial) and a post-critical phase. All three phases involved a visual search task in which participants were required to report the identity of a target letter (H or U) embedded amongst a circular array of heterogeneous non-target letters (difficult search). The critical and post-critical trials were identical to the pre-critical trials with the exception that a colour singleton (surprise stimulus in the case of the critical trial) was presented at the target location. The colour singleton was always presented at the target location to allow measuring the contributions of early and late processes to the RT delay on surprise trials (without interference from further eye movements that would be required if the colour singleton were presented at a distractor location).

The predictions were as follows: first, if an unexpected colour singleton attracts the gaze then the target should be found significantly faster on the surprise trial than on the pre-critical trials. This should be reflected in a decrease in the number of saccades to find the target and a decrease in the time required to visually select the target (target fixation latency) on the surprise trial relative to the pre-critical trials. Finally, if the slow time course of surprise capture is the result of a delay in the orienting component (early stage) then we should expect to see evidence of this in the saccade latencies on the surprise trial (i.e., the time from the onset of the search display to the start of the saccade). That is, saccade latencies of the first saccade should be longer on the critical trial relative to the post-critical trials. Alternatively, if the delay occurs at a later stage – once attention has shifted to the surprising stimulus – then we should observe the delay once the eyes have selected the target.

Method

Participants

Twenty-four participants (15 female) from Bielefeld University participated for course credit. All reported normal or corrected to normal vision.

Apparatus

Experiment 1 was conducted using the computer software package Presentation (Neurobehavioural Systems). Stimuli were presented on a 19-inch CRT monitor attached to a (Pentium 4) personal computer. Stimuli were presented with a
resolution of 1280 * 1024 pixels and a refresh rate of 75Hz. Responses were recorded using a two-button mouse. Participants’ eye-movements were measured using a video-based infrared eye-tracking system (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of 0.1 and a temporal resolution of 500 Hz.

**Stimuli**

Each trial consisted of a fixation display and a target display. The fixation display was comprised of a central fixation cross which subtended 0.3° of visual angle. The target display consisted of 8 grey disks (RGB = 150) presented on an imaginary circle equidistant – radius = 10° of visual angle - from the central fixation cross. Each disk contained one of eight letters. The target letters were H and U and the non-target letters were C, E, F, L, O, P and S. All stimuli were presented against a white background and at a viewing distance of approximately 60cm.

**Design and Procedure**

Participants completed 24 practice trials followed by 49 experimental trials. The experimental trials were divided in 24 pre-critical trials, 1 critical trial (surprise trial) and 24 post critical trials though this structure was not apparent to participants and the experiment flowed continuously from one phase to the other. On the critical trial the otherwise grey disk at the target location was presented as red. The post-critical trials were identical to the critical trial with the target appearing at the position of the red singleton. Practice trials were excluded from all analyses.

Each trial began with the onset of a central fixation cross for 500ms. This was followed by the target which remained on the screen for a maximum of 3000ms or until a response was made (see Figure 1). Participants task was to saccade to the target and report its identity with a mouse click – left click for U and right click for H. The identity of the target and its location were randomised across trials with each target occurring equally often at each location. The locations of the seven non-targets were also randomised across trials. Participants were instructed to saccade and respond as quickly and as accurately as possible. Following a response, participants were given feedback as to whether they were correct or not – ‘correct’ or ‘incorrect’, respectively.
Figure 1. Example trial sequences from Experiment 1. A) Pre-critical trial. B) Critical and post-critical trial. The location of target and non-targets was randomised on each trial. The red colour singleton always appeared at the location of the target (H/U). The search display was presented for 3000ms or until a response was made.

Results

Mean RTs and accuracy for Experiment 1 are shown in Figure 2. RTs exceeding 4000ms and errors were excluded from RT and eye-movement and analyses. This criteria lead to a loss of 4.25% of trials. Averages for the pre and post-critical trials across all measures were computed over the 5 trials that preceded and succeeded the critical trial, respectively. All contrasts involving performance on the critical trial (RTs & Eye-movements) were computed using these averages. This was done in an attempt to reduce noise in our estimates of performance on the pre- and post-critical trials. Eye movements were parsed into saccades, fixations and blinks using the standard parser configuration of the Eyelink software, which classifies an eye movement as a saccade when it exceeds a velocity of 30º/s or an acceleration of 8000º/s. The first eye movement on a trial was assigned to the target, a non-target or the distractor if the gaze was within 100 pixels (1.0º) of the centre of the search item.
**RT analysis**

To test for an effect of the unexpected colour singleton, we first contrast RTs on the critical trial with RTs on the pre-critical and post-critical trials. Planned pairwise comparisons revealed no RT difference between pre-critical trials and the critical trial, $t(23) = .74, p = .47$. Conversely, RTs on the critical trial were significantly slower than RTs on the post-critical trials, $t(23) = -5.79, p < .001$. As shown in Figure 2, the RT delay for the critical trial was quite substantial (>300ms), consistent with previous reports (e.g., Horstmann, 2005).

![Figure 2](image.png)

**Figure 2.** Mean response times for the pre-critical, critical and post-critical trials from Experiment 1. Error bars depict +/- one standard error of the mean.

**Eye-movement analyses**

To assess whether the unexpected colour singleton attracted attention and the gaze, we compare the average number of fixations on the critical trials to that on the pre- and post-critical trials. A planned pairwise comparison between the critical and pre-critical trials revealed a significant difference such that there were fewer fixations on the critical trial than on the pre-critical trials, $t(23) = 3.17, p = .004$, consistent with the surprise capture view. Due to the lack of variability in the number of fixations on the post critical trials (i.e. floor effects - see Figure 4), a comparison
between the critical trial and the post-critical trials was performed using a Wilcoxon’s signed-rank test. This test revealed there to be significantly more fixations on the critical trial than on the post-critical trials, \( Z = -3.53, p < .001 \).

These results would seem consistent with the view that attention shifts to unexpected singletons can be delayed, leading to more fixations on the surprise trial than on the post critical trials. However, as shown in Figure 4, 16 of the 24 participants made only 1 saccade on the surprise trial. Furthermore, only 2 of the 24 participants made more than 2 saccades on the critical trial. As will be further discussed later, this pattern of results shed doubt on the view that orienting to the unexpected events is necessarily delayed.

![Graph showing fixation data](image)

**Figure 3.** Mean number of fixations per trial for the pre-critical, critical and post-critical trials from Experiment 1. Error bars depict +/- one standard error of the mean.
In addition to analyzing the number of fixations on the critical trial we looked at the percentage of first fixations which went to the target on the pre-critical, critical and post-critical trials. As is shown in Figure 5, 14.9% of first fixations went to the target location during the pre-critical trials (chance = 12.5%). In contrast, 66.7% of first fixations went to the target location on the critical trial (see Figure 5). A Wilcoxon’s signed-rank test revealed this difference to be statistically significant, $Z = 3.57$, $p < .001$. 

**Figure 4.** Number of fixations for the pre-critical, critical and post critical trials for all 24 participants.
Figure 5. The percentage of first fixations that went to the target location on the pre-critical, critical and pos-critical trials.

The data for target fixation latencies (i.e., the time measured from the presentation of the search display to the first fixation on the target) is highly consistent with the pattern of results observed for the number of fixations to the target (see Figure 6). Planned pairwise comparisons revealed that the target fixation latencies were significantly shorter on the critical trial relative to the pre-critical trials, $t(22) = 2.66, p = .015$, while simultaneously being significantly longer relative to the post-critical trials, $t(22) = -2.54, p = .019$. Interesting, inspection of the individual data (see Figure 7.) suggests that a very small increase in target fixation latencies on the critical trial relative to the post-critical trials was systematic and apparent even for participants who made only one saccade on the critical trial.
Figure 6. Mean target fixation latency per trial for the pre-critical, critical and post-critical trials from Experiment 1. Error bars depict +/- one standard error of the mean.

Figure 7. Individual target fixation latencies for the pre-critical, critical and post-critical trials. Note that the target fixation latency on the critical trial for one participant (5) was 2649ms. In the interest of preserving the scale, this data point was omitted from the figure. This data point was not omitted from any analyses.

To test for delays in orienting associated with the unexpected colour singleton we compared saccade latencies for the first saccade on the critical trial to that of the
pre- and post-critical trials. Saccade latencies were defined as the time taken for the participants gaze to leave the fixation region. Planned comparisons revealed a significant difference between the critical trial and the post-critical trials such that saccade latencies on the critical trial were significantly longer than saccade latencies on the post-critical trials, $t(23) = -3.57$, $p = .002$ (see Figure 8). We explored this effect further as a function the number of fixations to test whether this effect might be specific to observers who made fewer saccades on the critical trial i.e. observers who were surprised. Saccade latencies for participants who made only one saccade on the critical trial were compared to saccade latencies for participants who made 2 or more saccades. Though the interaction was non-significant ($p = .12$), the pattern of results suggest that the effect of saccade latencies reported above was largely driven by participants who made only one saccade on the critical trial. This pattern is illustrated in Figure 9. There was no difference in saccade latencies between the pre-critical trials and the critical trial, $p = -.60$.

**Figure 8.** Saccade latencies for the pre-critical, critical and post critical trials. Error bars depict one standard error of the mean.
Figure 9. Difference in saccade latencies between the critical trial and post-critical trials as a function of the number of fixations on the critical trial. Error bars depict one standard error of the mean.

Finally, to estimate the contributions of post-selection processes (i.e., decision and response level processes) to the large RT delay on the critical trial, we subtracted target fixation latencies for each participant from their RTs. We refer to this residual as the ‘post selection delay’ (PSD) and this data is plotted in Figure 10. Planned comparisons revealed that the PSD on the critical trial (777ms) was significantly longer than the PSD on both the pre-critical trials (523ms), $t(22) = 4.28$, $p < .001$ and the post-critical trials (476ms), $t(23) = 4.73$, $p < .001$. 
Figure 10. Post Selection Delay (PSD) for the pre-critical, critical and post-critical conditions in Experiment 1. PSD was calculated by subtracting target fixation latencies from the RTs. Error bars depict one standard error of the mean.

Discussion

The results of Experiment 1 demonstrate that the new and unannounced colour singleton induced surprise on its first presentation. Consistent with previous demonstrations of surprise, RTs on the critical trial were elevated relative to the post-critical trials despite these trial types being identical with respect to their stimulus properties. Most notably, we observed a decrease in the number of fixations and target fixation latencies on the critical trial relative to the pre-critical trials and a large percentage of first fixations towards the target on the critical trial. These results show that search was more efficient on the critical trial than on the pre-critical trials – a hallmark of surprise capture.

Interestingly, there was an increase in the number of fixations and an increase in target fixation latencies on the critical trial relative to the post-critical trials. With respect to the number of fixations, inspection of the data at the participant level revealed that 16 out of 24 participants made only one saccade on the critical trial – which is a hallmark of efficient search – while the remaining eight participants made two or more saccades (see Figure 4). Apparently the data reflects two populations of participants – those who were immediately attracted towards the unannounced colour singleton and those who were not, or for which guidance was delayed (six out
of the remaining eight participants made only two saccades on the critical trial). The significant difference that we observed between the critical trial and the post-critical trials seems mainly to result from the population of participants who did not saccade in the first instance to the unannounced colour singleton. However, given that the majority of participants immediately selected the colour singleton, the observed differences probably do not reflect a qualitative difference in search efficiency for expected and unexpected stimuli. Or to put it differently: it does not seem to be the case that there is necessarily a general delay in the orienting towards unexpected stimuli.

With respect to target fixation latencies, we found a slightly different pattern of results. Inspection of the data at the participant level suggests that target fixation latencies were generally slightly slowed on the critical trial relative to the post-critical trials (see Figure 6). That is, participants were slower to fixate the target on the critical trial relative to the post-critical trials. This comes as no surprise for cases in which participants made multiple saccades on the critical trial; however, it’s noteworthy that this effect was observed for participants who made only one saccade on the critical trial. Interestingly, much of this effect can be accounted for by the saccade latencies. Saccade latencies on the critical trial were significantly longer than on the post-critical trials (see Figure 8). Moreover, this effect appeared to be driven by participants who made only one saccade on the critical trial, i.e. were surprised (see Figure 9), though the interaction was non-significant (p = .12).

The delay in saccade latencies and target fixation latencies we observed on the critical trial is consistent with previous reports of surprise capture to the extent that it is a delay. However, the extent to which the magnitude of this delay is consistent with previous reports of surprise capture is unclear. Horstmann (2002, 2006) and Horstmann and Becker (2008) have reported that surprise capture takes at least 200ms, but more likely closer to 400ms to manifest. Importantly, Horstmann argued that at least some component of this delay reflects a delay in the orienting component of the surprise response – “The results were clear-cut: stimulus duration was a powerful moderator of surprise capture. Apparently, the stimulus must be presented for a minimal duration to exhibit its full effect on the deployment of spatial attention” (Horstmann & Becker, 2008, p 303). In Experiment 1 we observed a delay in saccade latencies on the critical trial of ~40ms, relative to the post-critical trials.
For participants who made only one saccade on the critical trial this delay was ~55ms. This delay cannot account for, in its entirety, the temporal profile of surprise capture previously reported in the literature. Nor can the delay in target fixation latencies, which for participants who made only one saccade, was ~115ms. Interestingly though, the PSD for the critical trial in experiment 1 was ~700ms. That is, once participants saccaded to the target, on average, they took another 700ms to respond to the target. The difference between the PSD on the critical trial and the post-critical trials (~400ms) was ~300ms. That is, we observed a non-spatially specific interference effect specific to the critical trial of ~300ms. Note that if we consider the delays associated with the spatial (saccadic latencies) and non-spatial components together (~40ms + ~300ms), the temporal profile of the surprise effect report in Experiment 1 begins to resemble the temporal profile of surprise capture previously reported in the literature.

How might we explain the delay in spatial orienting on the critical trial? One possibility is that participant may have adopted a narrow attentional focus and pre-programmed a saccade to a stimulus location prior to the appearance of the search display on the critical trial. This seems likely given the serial nature of the search task during the pre-critical trials where the target was not pre-attentively available to participants. We propose that the delay in saccade latencies and consequently the delay in target fixation latencies on the critical trial may reflect the suppression of a pre-programmed saccade and a switch from a narrow to a more diffuse attentional control setting on the critical trial. A failure to suppress the pre-programmed saccade could explain why some participants failed to orient in the first instance to the unannounced colour singleton and made multiple saccades on the critical trial. This could also explain the trend for saccade latencies to be slower for participants who made fewer saccades on the critical trial (i.e. these participants were able to suppress their pre-programmed eye-movement / switch from a focused to a more diffuse attentional set on the critical trial.)

**Experiment 2**

As mentioned above, one possible account for the delay in orienting observed in Experiment 1 is that it reflects a cost associated with switching from a serial
search strategy to a more diffuse attentional control setting, or from a narrow attentional focus to a wide attentional window that allows processing of all items in parallel. To test this hypothesis in Experiment 2 we investigated this saccade latency delay under conditions of parallel search. In Experiment 2, the target was consistently a shape singleton (diamond) that could be found efficiently, that is, without serially scanning the search items. Hence, a switch in search strategy on the critical trial was unnecessary, due to pre-attentive availability of both the target and the unannounced colour singleton.

Additionally, we were interested more broadly in the behavioural profile of surprise in the context of guided search. To date, studies of surprise capture have typically employed difficult search tasks such that the target itself could not guide attention. This raises the question whether an unexpected stimulus will attract attention and the gaze when the target is not pre-attentively available and does not (strongly) compete for attention with the unexpected singleton. There is some evidence to suggest that unexpected stimuli can still capture attention and the gaze even when the target is pre-attentively available and able to compete for early selection. For instance, Godijn and Kramer (2008) found oculomotor capture by an unannounced new onset distractor when participants had the task to saccade to a colour singleton in a visual search paradigm. Consistent with the view that capture can be modulated by stimulus expectancies, the rate of oculomotor capture declined across repeated presentations of the onset distractor. However, the effect on other aspects of the surprise response such as its temporal profile and signature RT increase were not explored. Furthermore, Godijn and Kramer (2008) used onsets as the surprising stimulus and there is evidence to suspect that the pattern of oculomotor capture associated with surprising stimuli may differ for different classes of stimuli (e.g. colour singletons vs. onsets; Wu & Remington, 2003). Hence, it is still an open question whether an unexpected colour singleton could elicit surprise and attract attention when it is forced to compete for selection with a pre-attentively available target. Thus, in Experiment 2 we tested the response to an unannounced colour singleton during guided search.

In order to study surprise in the context of guided search, the design of Experiment 2 had to be modified from Experiment 1. Specifically, in Experiment 2 the surprising colour singleton was presented at a non-target location (invalid location).
This was necessary so that any guidance effects related to the unannounced colour singleton can attract attention and the gaze even when it competes with a pre-attentively available target, then it should interfere with target selection on the critical trial, leading to an increase in RTs and an increase the number of fixations and target fixation latencies. Moreover, if the surprise-induced delay in orienting attention to the surprising item in Experiment 1 was due to participants having to switch from serial search to parallel search, then the saccade latencies of the first eye movements should not differ between the critical trial and the pre-critical trials, because in Experiment 2, no such switch was necessary.

**Method**

**Participants**

Fifteen participants (9 female) from The University of Queensland participated in exchange for $10. All reported normal or corrected to normal vision.

**Apparatus**

Experiment 2 was conducted using the computer software package Presentation (Neurobehavioural Systems). Stimuli were presented on a 19-inch CRT monitor attached to a (Pentium 4) personal computer. Stimuli were presented with a resolution of 1280 * 1024 pixels and a refresh rate of 75Hz. Responses were recorded using a two-button mouse. Participants’ eye-movements were measured using a video-based 36 infrared eye-tracking system (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of 0.1 and a temporal resolution of 500 Hz.

**Stimuli**

The stimuli used in Experiment 2 were similar to those used in Experiment 1. The critical differences being that in Experiment 2 the targets (H or U) always appeared in the centre of a shape singleton (diamond) and the colours of the stimuli varied between participants; stimuli in the pre-critical trials were either all red (RGB = 255 0 0) or green (RGB = 0 255 0) and the distractor in the critical trial and the post-critical trials was always green or red, respectively. All other aspects of the stimuli were identical to Experiment 1 (see Figure 11).
**Design and Procedure**

In Experiment 2 participants completed 55 trials in search for a diamond target among circle non-targets - 5 practice trials, 25 pre-critical, 1 critical and 24 post-critical trials. On the critical trial a non-target was randomly presented as a colour singleton, i.e. a red distractor amongst otherwise green stimuli or vice versa. That is, on the critical trial and the post-critical trials, the colour singleton was always presented at an invalid location. All other aspects of the design and procedure were identical to Experiment 1.

![Figure 11. Example search displays from Experiment 2. A) Pre-critical trial. B) Critical and post-critical trial.](image)

**Results**

Mean RTs and accuracy for Experiment 2 are shown in Figure 12. RTs exceeding 4000ms and errors were excluded from RT and eye-movement and analyses. This criteria lead to a loss of 4.5% of trials. Eye movements were parsed into saccades, fixations and blinks using the same criteria as Experiment 1. As with Experiment 1, averages for the pre and post-critical trials were computed over the 5 trials that preceded and trailed the critical trial, respectively, to arrive at a safer estimate of performance on pre- and post-critical trials. All comparisons were computed using these averages.
**RT analysis**

RTs on the critical trial were contrasted with RTs on the pre-critical and post-critical trials. Planned pairwise comparisons revealed that RTs on the critical trial were significantly slower than RTs on the pre-critical trials, $t(13) = -3.33, p = .005$, and RTs on the post-critical trials, $t(14) = -2.87, p = .01$ (see Figure 12).

**Figure 12.** Mean Response Times for the pre-critical, critical and post-critical trials from Experiment 2. Error bars depict +/- one standard error of the mean.

**Eye-movement analyses**

Due to the distribution of number-of-fixations on the pre-critical trials, a comparison between the critical trial and the pre-critical trials was performed using a Wilcoxon’s signed-rank test - this revealed there to be significantly more fixations on the critical trial than on the pre-critical trials, $(Z = 3.03, p = .002)$. A planned comparison between the critical trial and the post-critical trials revealed a significantly greater number of fixations on the critical trial relative to the post-critical trials, $t(14) = -2.32, p = .04$ (see Figure 13).
First fixations data showed that participants were close to chance (12.5%) at selecting the target with their first fixation on the critical trial (see Figure 14). Additionally, 47% of first fixations went to the colour distractor on the critical trial. Two Wilcoxon’s signed-rank tests revealed there were fewer first fixations to the target on the critical trials relative to the pre-critical, $Z = 2.62$, $p = .009$ and the post-critical trials, $Z = 2.12$, $p = .034$. These results indicate that the colour singleton interfered with search on its first unannounced presentation, despite the fact that the target was pre-attentively available and competed for attention with the distractor.

**Figure 13.** Mean Number of Fixations per trial for the pre-critical, critical and post-critical trials from Experiment 2. Error bars depict +/- one standard error of the mean.
The target fixation latency data show a slightly different pattern of results. Planned comparisons revealed that target fixation latencies on the critical trial were significantly longer relative to the pre-critical trials, $t(14) = 3.47, p = .004$, however, there was no difference between target fixation latencies on the critical trial and the post-critical trials ($p = .15$) (see Figure 15). An analysis of saccade latencies found no significant differences between the critical trial and the pre-critical trials, ($p = .37$), or between the critical trial and the post-critical trials ($p = .61$).

Figure 14. The percentage of first fixations that went to the target location on the pre-critical, critical and pos-critical trials.
Finally, as was done in Experiment 1, we estimated the post-selection delay (PSD) by subtracting target fixation latencies for each participant from their RTs. Planned comparisons revealed that the PSD was significantly longer on the critical trial (852ms) than on both the pre-critical trials (577ms), $t(13) = 2.56, p = .02$ and the post-critical trials (575ms), $t(13) = 3.11, p = .008$ (see Figure 16).

**Figure 15.** Mean Target fixation latencies per trial for the pre-critical, critical and post-critical trials from Experiment 2. Error bars depict +/- one standard error of the mean.

**Figure 16.** Post Selection Delay (PSD) for the pre-critical, critical and post-critical conditions in Experiment 2.
Discussion

In Experiment 2 we presented an unannounced colour singleton at a non-target location during search for a shape singleton. Consistent with the view that unexpected stimuli can attract attention and interfere with search, RTs on the critical trial were elevated relative to both the pre-critical and post-critical trials as was the PSD. Importantly, there was an increase in the number of fixations and an increase in target fixation latencies on the critical trial relative to the pre-critical trials suggesting a spatial component to the observed increase in RTs. Furthermore, selection of the target with the first fixation was close to chance on the critical trial (13.3%) compared with 38% and 37% on the pre- and post-critical trials, respectively, and 47% of first fixations went to the distractor on the critical trial. With respect to the temporal profile of this spatial component, we found no evidence of a delay in orienting on the critical trial. Saccade latencies on the critical trial were no slower than saccade latencies on either the pre-critical or post-critical trials. The absence of an orienting delay on the critical trial during guided search is consistent with our hypothesis that the delay in saccadic latencies observed in Experiment 1 may be related to switching of attentional control settings - from narrow to diffuse - as the task switches from an unguided to a guided search task.

However, it must be pointed out that the shape target was a singleton in Experiment 2, and it’s possible that participants adopted a set for singletons or a set for the stimulus of highest contrast rather than the specific shape feature per se (e.g. Bacon & Egeth, 1994). Remembering that the surprising stimulus was a colour singleton of high feature contrast, it’s possible that the colour singleton in Experiment 2 captured attention by virtue of its “fit” with the task set rather than a “miss-fit” with the task expectancies. That is, the surprising stimulus may have engaged (fast) top-down selection mechanisms before any (slow) novelty detection mechanism could respond. This could also account for why we failed to observe a delay in the spatial component of the surprise response in Experiment 2. Thus, there remains some ambiguity as to whether the orienting delay (~40ms) observed in Experiment 1 is related to a changed in the search conditions, as we have suggested, or a feature of a distinct and dedicated novelty detection mechanism. However, regardless of the orienting mechanism at play, the decrease in RTs and number of fixations on the post-critical trials relative to the critical trial demonstrates that stimulus novelty was
critical to the effects observed in Experiment 2. These results demonstrate that oculomotor capture was modulated by the first presentation of an unannounced colour singleton, a result that has previously been demonstrated with onset transients (Godijn & Kramer, 2008) but not with colour stimuli.

**General Discussion**

According to the surprise capture hypothesis, a stimulus will capture attention to the extent that it is pre-attentively available and deviates from task-expectancies. Importantly, capture by unexpected stimuli is thought to be governed by a mechanism separate from the underlying mechanism that governs capture by expected stimuli (Horstmann, 2002, 2005, 2006; Horstmann & Becker, 2008). In the two experiments presented here we explored the phenomenon of surprise capture using eye-movements with the aim of disentangling the various components of the effect, namely the spatial, temporal and decision/response related components, to better understand the mechanisms underlying surprise capture.

In Experiment 1 we presented an unannounced colour singleton at the location of the target during unguided search. Conceptually this experiment was very similar to previous designs employed to study surprise capture (Horstmann, 2002 exp. 3, 2005 exp. 1). Consistent with surprise capture we found strong evidence of attentional capture on the critical trial that was accompanied by a non-spatially specific RT cost (~300ms) related to the engagement of higher order processes recruited to resolve the expectancy violation. However, regarding the temporal profile of the effect, we found evidence in the saccade latencies for only a modest delay in the orienting component of roughly 40ms. In Experiment 2 under conditions of guided search, we again found strong evidence of a shift of attention towards the unannounced colour distractor as well as a large RT cost; however, here we found no modulation of saccade latencies by the unannounced colour distractor.

As discussed previously, surprise capture is thought to manifest relatively slowly. Horstmann (2006) had participants perform an unguided search task for a series of trials before presenting an unannounced colour singleton at the target location. Between subjects the SOA between the presentation of the surprising stimulus and the target display was varied from 0 – 600ms. Only when the surprising
stimulus preceded the target by at least 400ms was an effect of surprise observed. Similar patterns of results have been observed in numerous other reports of surprise capture (Horstmann, 2002, 2005; Horstmann & Becker, 2008; Gibson & Jiang, 1998; Meyer et al., 1991). Critically, this effect has been attributed in part to a delay in the onset of the spatial orienting component of the surprise response – delayed onset model - and used to argue for an underlying mechanism distinct from other forms of capture.

In our view the results of the two experiments presented here are not consistent with a delayed onset model of surprise capture. In Experiment 1 we found a minimal delay in saccade latencies and target fixation latencies on the critical trial but a large RT cost once the target had been selected with the eyes. In Experiment 2 under conditions of guided search we found a similar pattern of results for an invalid colour singleton; here though there was no delay in saccade latencies on the critical trial but again large RT costs once the target had been selected. This pattern of data seems more consistent with an interference model of surprise capture where by attention shifts rapidly to an unexpected feature and the RT delays that characterize surprise reflect computations at a later stage in the system – after attention has been shifted to an unexpected stimulus – dedicated to reconciling the expectation discrepancy (Gibson & Jiang, 1998). It’s possible that the delay in orienting we observed in Experiment 1 reflects an additional operation that is required to detect and or trigger an attention shift towards an expectation discrepancy (Horstmann, 2006). However, we suggest that this cost may reflect a suppression or inhibition of the existing/active serial search strategy on the critical trial as the task switches from an unguided to guided search. The fact that we did not observe the similar delays under conditions of guided search speaks to this account.

Regardless, neither the ~40ms delay in saccade latencies nor the ~115ms delay in target fixation latencies we observed in Experiment 1 can account for time course of surprise capture currently proposed in the literature. What then is the source of the discrepancy between our results and previous reports of surprise capture? One possibility is that there are genuine inconsistencies between the data reported here and previous results, possibly attributable to subtle differences in the methodologies used. Specifically, time-course analyses of surprise capture have in the past used very brief target presentation durations - in the order of 80-90ms so as
to detect variances in accuracy - and looked at covert attention shifts. Here we presented the target display until a response was made and studied eye-movements – necessarily serial processes that take time to be executed. However, it is not clear to us how these methodological differences could produce seemingly different temporal profiles of surprise capture. A second possibility is that the discrepancy lies in our interpretation. We suggest the latter and argue that previous demonstrations of surprise capture can be accounted for by an interference model and that this is a more parsimonious and ecologically valid account of the phenomenon. We discuss this in depth below.

As discussed, the majority of work addressing the time course of surprise capture has used very brief target presentation durations and a feature singleton presented at the location of the target to induce surprise (Horstmann, 2002, 2006; Gibson & Jiang, 1998). These studies invariably find that accuracy on the surprise trial remains close to chance unless the surprising stimulus is presented at least \(~300\text{-}400\text{ms}\) prior to the target presentation. A delayed-onset model accounts for some of this delay by proposing that the orienting component of the surprise response is slow and therefore, for SOAs of less than \(~300\text{-}400\text{ms}\), attention has not yet shifted to the location of the target and thus cannot facilitate identification of the target. On the other hand, an interference model proposes that orienting towards a surprising stimulus is fast, however, central processing resources are devoted to processing the expectation discrepancy ahead of the target. If the target presentation time is shorter than the time required to resolve the expectation discrepancy then target identification will likely be impaired. These two models are not mutually exclusive, however, note that in both Experiment 1 and Experiment 2 we found a spatially non-specific interference effect specific to the critical trial of \(~300\text{ms}\) and \(~280\text{ms}\), respectively; a delay in responding that closely resembles the time course of surprise previously reported (Horstmann, 2002; 2006) but that only manifested in both instances once the eyes had shifted to the target.

We are not the first authors to point out that the delayed-onset account and the interference account make similar predictions with respect to accuracy for valid unannounced singletons. Horstmann and Becker (2008) recognized this and ran a study to distinguish between the two accounts. They argued that the delayed-onset account and the interference account make opposite predictions for an unannounced
distractor i.e. a singleton not presented at the location of the target. Specifically, they reasoned that the delayed-onset account predicts minimal costs at short SOAs (e.g., 100 ms) and large costs at long SOAs (e.g., 400 ms). This is because at short SOAs (100ms) the distractor does not attract attention to its location (away from the target); the opposite is true at long SOAs. The interference account, however, predicts the opposite; large costs at short SOAs that should dissipate as SOA increases. Across two experiments they found results consistent with the delayed-onset prediction showing a minimal decrease in accuracy at the short (100ms) SOA and close to chance performance at the long (400ms) SOA. However, there is a notable difference between the experimental paradigm used by Horstmann and Becker (2008) and previous investigations of the time course of surprise capture (Horstmann, 2002; Horstmann, 2005; Horstmann, 2006; Meyer et al., 1991) which we believe is critical to understanding their results. Specifically, Horstmann and Becker (2008) presented the unannounced distractor for either 100ms or 400ms and offset it when the target display was presented. While in previous experiments, where the unannounced singleton was always valid (Horstmann, 2002; Horstmann, 2005; Horstmann, 2006), the unannounced singleton was presented until a response was made, or until the target display offset but not beforehand. That is, the presentation duration of the surprising stimulus varies substantially across these experiments and we believe this is critical. Indeed so too did Horstmann and Becker (2008) as they went on to demonstrate in the same paper that stimulus duration is critical for surprise to manifest because surprise capture requires a “sufficiently stable stimulus representation” (Horstmann, 2008, p 304). We suggest that the reason there is no effect of the unannounced colour distract at the 100ms duration in the Horstmann and Becker (2008) paper is not because attention is not allocated to the unannounced distractor, but because once attention has shifted to the unexpected stimulus 100ms is not sufficiently long enough for surprise to manifest and interfere with target identification. Finally, the cost observed at the 400ms duration condition can easily be reconciled with an interference account by referring to Horstmann (2006) where he shows that accuracy on the critical trial for a valid unannounced stimulus approaches ceiling at SOAs beyond 400ms (i.e. 600ms). The fact that there were accuracy benefits at an SOA of 600ms demonstrates that participants were continuing to attend to the stimulus at the onset of the target display. Thus based on this data we would not predict that the interference
associated with the unannounced colour distractor in Horstmann (2008) should have fully dissipated by 400ms. Thus, the interference they observe at the 400ms stimulus duration is, to us, not inconsistent with an interference account of surprise capture as Horstmann and Becker (2008) argue.

In summary, the two experiments reported here demonstrate that unannounced colour singletons modulate oculomotor capture and elicit surprise on their first occurrence, both under conditions of guided and unguided search. Saccadic latency data across two experiments suggests there is a small delay in orienting to an unannounced stimulus during unguided search which we suggest may reflect a necessary suppression or inhibition of pre-existing serial search strategies before the unexpected stimulus will guide attention / the eyes. Given we did not observe a saccadic latency delay in Experiment 2 where search was guided to begin with supports this assertion. Interestingly, the temporal profile of saccadic latencies and target fixation latencies we observed is not consistent with accounts of surprise capture that posit a delay in orienting as the primary source of the reduced accuracy at short SOAs. Rather, our data are more consistent with an interference model where by attention shifts rapidly to the location of an unexpected stimulus and central processing resources are diverted to reconciling the expectation discrepancy at the cost of target identification. Distinguishing between these two accounts is important because as Horstmann (2005; 2006) points out, the delayed-onset account points to a separate underlying mechanism for capture by unexpected events while the interference model is not inconsistent with theories of attentional control that propose that salient irrelevant stimuli are filtered out through a process that is dependent on prior exposure to irrelevant stimuli and implicit learning about their relevance (Becker, 2007; Folk & Remington, 1998; Treisman & Sato, 1990).
Chapter 5 – Conclusions
In this thesis I have presented three empirical studies, each motivated by the central question of what determines the events and objects in the visual world to which we orient and attend. Answering this question has important consequences for theories of visual attention that seek to describe the perceptual and cognitive processes that determine visual selection; processes that ultimately contribute to our conscious experience of the world. As I have discussed, contemporary theories of visual attention model visual selection as the outcome of an interaction between bottom-up saliency driven processes and top-down processes that prioritize inputs in accordance with the goals or intentions of the observer (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Itti & Koch, 2000; Treisman & Sato, 1990). The extent to which either of these factors predominates over early visual selection has been a subject of debate.

In response to the equivocal support for purely stimulus driven capture and the observation that task goals can prevent distraction from highly salient but irrelevant stimuli (e.g., Folk et al., 1992), I have proposed that task expectations play an important role in bringing to our awareness objects and events in the visual world that may initially be task irrelevant but that may be of potential importance to the observer. Of course I am by no means the first author to express this view; the notion that the human perceptual system is sensitive to the unexpected and novel is expressed by schema theories of perception and cognition (e.g., Meyer et al., 1991; Neisser, 1976; Rumelhart, 1984). These theories are supported by the observation that infrequent and novel stimuli evoke distinct patterns of neural activity (MMN: Näätänen, 1992; Ranganath & Rainer, 2003) and are associated with a number of well documented behavioural and perceptual phenomena (e.g., TSE: Tse et al., 2004; surprise capture: Horstmann, 2002). My work adds to the existing literature on the role of task expectancies, by rigorously examining how stimulus novelty interacts with top-down feature specific processes. The work herein sheds light on the underlying mechanism by which novelty attracts visual attenuation and the factors that determine the formation of the neuronal model, schemata or task expectations.
Chapter 2: Novelty capture

To date, several studies have shown that infrequent and unexpected salient stimuli can capture attention (e.g., Horstmann, 2002, 2005; Geyer et al., 2008; Neo & Chua, 2006), yet the extent to which top-down processes can modulate capture by this class of stimulus has until now been relatively unexplored. Folk et al., (1992) showed that a task irrelevant onset transient only affected search performance when participants' task was to search for an onset defined target but not when the task was to search for a colour defined target. In Chapter 2, I showed that this contingency between the target of search and the stimuli that guide visual attention may only be true of stimuli that occur repeatedly and frequently, or that can be said to conform to a set of task specific expectancies. Using a variant of the spatial cueing paradigm of Folk et al., (1992), I found that an infrequently presented motion distractor produced a spatial validity effect despite participants adopting a top-down set for a specific feature (red). The fact that the same effect was not observed when the motion stimulus was presented frequently demonstrates that the infrequent motion distractor captured attention by virtue of its novelty, or presentation frequency, and not by virtue of its inherent saliency. Motion cues have previously been shown to capture attention in the spatial cueing paradigm when they are similar to the target but not when they are dissimilar to the target (e.g., Remington, Folk & McLean, 2001; Folk, Remington, & Wright, 1994). The observation that motion captures attention involuntarily when it is dissimilar to the target but infrequent and participants are set for an unrelated stimulus feature is strong support for the ability of novel stimuli to generate stimulus-driven capture.

To explain this result, I have suggested that top-down control reflects more than just a set for specific target features. Rather, my results suggest that top-down control reflects the formation of contextually specific expectations that describe both the target defining properties and the to-be-ignored properties of distractors. This view draws from models of visual attention, specifically Treisman and Satos’ (1990) Feature Inhibition Hypothesis (see all Becker, 2007; Folk & Remington, 1998), that propose that salient irrelevant stimuli must be filtered out or inhibited in order to be ignored and disregarded during search. Indeed, Vatterott and Vecera (2012) showed that an irrelevant colour singleton interfered with search for a shape target in the first half of an experimental block but not in the second. This pattern was observed each
time the colour singleton changed colour across blocks. These results, together with those I presented in Chapter 2, are consistent with the view that effective top-down control involves suppression of salient irrelevant stimuli as well as a positive setting for a specific target feature. Moreover, they suggest that the filtering or inhibition of irrelevant features depends on prior exposure and presumably some learning about their (ir)relevance – whether exposure to irrelevant stimuli must occur within the context in which they are to be ignored for learning to occur (i.e., included in the task-set) and the specific nature of this learning was the focus of Chapter 3.

Critically, the ability to ignore salient distractors likely depends on an active set for distractor properties that is maintained by repeated exposure to a stimulus. The fact that the motion cue here continued to capture attention after repeated but infrequent exposure suggests that task expectancies or the ‘inhibitory set’ is continuously updated across trials and that there is some window in which a stimulus must occur for it to be included in the next “iteration” of the task-set and effectively ignored. Perhaps another way to consider this is that inhibitory signals for a given irrelevant feature are strengthened by repeated and frequent exposure but decay otherwise. Thus, if the interval between successes presentations of a to-be-ignored stimulus is sufficiently great then the stimulus will not be inhibited effectively and will likely capture attention on its next occurrence. Decay of the inhibition signal may occur over time, some number of perceptual events or probably a combination of both of these factors (see Geyer et al., 2008; Sayim et al., 2012) and may depend on the properties of the to-be-ignored stimulus (e.g., stimulus saliency). The exact decay rate or the size of the ‘window’ in which a stimulus must occur for it to be effectively inhibited (i.e., included in the task set) is not clear and was not tested here. However, Sayim et al. (2012) have suggested that short-term memory processes, similar to those implicated in contextual cueing studies (see Chun, 2000; Chun & Jiang, 1998) may mediate the extraction of display probabilities, where ‘display probabilities’ is synonymous with what I have proposed as the formation of ‘task expectancies’. Additionally, the short-term memory processes implicated in feature priming studies may also mediate distractor inhibition and underpin the formation of task expectancies (Huang, Holcombe, & Pashler, 2004; Lamy, Antebi, Aviani, & Carmel, 2008; Maljkovic & Nakayama, 1994; 1996; 2000).
Importantly, the account of distractor inhibition that I have proposed here is a passive one where the inhibitory processes that contribute to the formation of task-expectancies, or the inhibitory-set operate autonomously. Alternative accounts of distractor inhibition such as the *dimension weighting account* (DMA) of Müller and colleagues posits a more active inhibitory mechanism. According to DMA observers can modulate the weights assigned to a particular stimulus dimension in a top-down manner. Modulation is used to enhance saliency signals at the level of the master map (see Chapter 1: guided search) that pertain to the target but also to attenuate those pertaining to distractors. According to this model, infrequent irrelevant stimuli capture attention because there is little incentive to strategically inhibit their inputs (Geyer et al., 2008; Müller, et al., 2009; Müller, Reimann, & Krummernacher, 2003). These accounts are of course not mutually exclusive, it’s possible that both explicit and implicit processes contribute independently to distractor inhibition and the formation of task expectancies (see though Chapter 3). If we accept that the function of a novelty detection mechanism is to facilitate adaptive action by bringing to awareness objects and events that may require immediate action, an implicit autonomous mechanism may serve as a more reliable, albeit possibly less flexible mechanism than an explicit one. However, one can possibly imagine a scenario where the negative consequences a prolonged response might be so severe that observes would indeed keep alive a set that was inefficient for the majority of responses. Such a scenario would presumably benefit from an explicit mechanism responsive to the strategies of the observer.

Perhaps one of the more intriguing results reported in Chapter 2 was the under-additive pattern of RT interference associated with initial presentations of the infrequent motion cue (see Experiments 2 – 4). When the task was to search for a red feature singleton in a spatial cueing paradigm, initial presentations of the infrequent *valid* motion cue were associated with large RT costs which I referred to as ‘surprise’. The same RT costs were either not present or were attenuated for initial presentations of the *invalid* motion cue. Previous reports of capture by new and unannounced stimuli suggest that cueing effects ought to combine in an additive way with the non-spatially specific interference (surprise) that is characteristic of the response to unexpected stimuli (Horstmann, 2002; 2005). However, in Chapter 2 there was clearly something about the initial presentations of a *valid* infrequent
motion cue that elevated RTs significantly more than initial presentations of the invalid motion cue. The results of Experiment 5 suggest that this under-additive pattern relates to the presence of a feature singleton that, when the cue is invalid, facilitates disengagement from the unexpected motion cue. Indeed when the target was not defined as a feature singleton but rather as a conjunction, we observed additivity. This result is important because it demonstrates that the ability to tune attention toward featural information can affect the response to an unexpected and irrelevant singleton. Specifically, the ability to locate the target appears to disrupt further processing of an unexpected stimulus and can lead to a fast recovery of search. This result is also consistent with the view that unexpected stimuli not only to capture attention, but also engage response and decision level processes (Horstmann, 2005; Meyer et al., 1991; Niepel et al., 1994). Importantly, the under-additive effect reported here demonstrates that these two components can be dissociated. This dissociate is consistent with the results reported in Chapter 4 where I observed large RT costs associated with an unexpected colour singleton only once the eyes had selected the target. I discuss this further below.

Chapter 3: What constitutes the unexpected?

It is clear from the work of Schützwohl (1998) and Horstmann (2005) that context plays an important role in shaping task expectancies, and consequently the stimuli that can violate them. The “unexpectedness” of a new and unannounced stimulus is related to the heterogeneity of the stimulus array in which it occurs. As stimulus heterogeneity increases, the extent to which a new and unannounced stimulus will capture attention and elicit surprise decreases (Horstmann, 2005; Schützwohl, 1998). As such, it is not sufficient that a stimulus be new and unannounced for it to be deemed “unexpected” by the perceptual system and capture attention. In Chapter 3, I presented results which suggest that not only is it insufficient, but it is also not necessary that a stimulus be new and unannounced for it to elicit a novelty response. Across four conditions I independently varied prior exposure to an infrequent invalid motion stimulus, with instructions to expect the motion stimulus. Using a modified spatial cueing paradigm participants were either, pre-exposed to the motion stimulus, told about the imminent occurrence of an “unexpected” but irrelevant stimulus or exposed to both of these manipulations.
Relative to a standard condition in which participants received no information about the motion stimulus, there was no attenuation of the response to the infrequent motion distractor across any of the conditions. RT interference was observed for the first presentation of an infrequent motion distractor when observers had prior experience with the motion distractor, and when they had explicit knowledge about the likelihood of an unexpected event. Even when observers had prior experience with motion stimulus and knew roughly when to expect it, it still produced RT interference.

It is intriguing to me that neither explicit knowledge nor prior exposure attenuated the response evoked by an otherwise “unexpected” stimulus. Indeed, as I highlighted in the discussion of Chapter 3, if the “unexpectedness” value of a stimulus or event is to be measured by the response it evokes on its first occurrence, then these results suggest that explicit awareness about an impending deviate stimulus has little bearing on how the stimulus is treated by perceptual processes that determine visual selection. This result is perhaps less surprising when considered in the context of models of visual attention that assume that salient irrelevant stimuli are inhibited via a process that depends on prior exposure to irrelevant stimuli and learning about their relevance (Becker, 2007; Folk & Remington, 1998; Treisman & Sato, 1990). The fact that there was no effect of explicit knowledge suggests that in some sense these effects are independent of top-down knowledge, and rather the ability of ignore task irrelevant stimuli seems to reflect a processes of learning that is implicit.

In summary, these results are consistent with the view expressed earlier that top-down control reflects the formation of contextually specific expectations that describe both the target defining properties and the to-be-ignored properties and adds to this view by demonstrating that learning of distractor relevance appears to be implicit and highly context specific. Based on these results I have proposed that the unexpectedness of a stimulus reflects the foreseeability of its occurrence according to inductive processes that operate largely automatically (Posner & Snyder, 1975) and independent of other cognitive processes (Green, 1956).
Chapter 4: What do the eyes tell us about capture by the unexpected?

In Chapter 4, I investigated the claim that shifts of attention to unexpected stimuli are delayed relative to expected stimuli. Addressing this claim is important as such a delay is not predicted by the inhibitory mechanism I have proposed to account for capture by novel and infrequent stimuli. Horstmann (2002; 2005; 2006) has shown that the first presentation of an unannounced valid colour singleton can capture attention in a visual search paradigm during search for a target letter amongst an array of non-target letters. An interesting aspect of this result is that the effect appears to be contingent on the timing of the onset of the unexpected colour singleton relative to the target display. When the colour singleton occurred at the location of the target less than 400ms prior to the onset of the target display, Horstmann (2006) found that it had no effect on search performance. However, when the colour singleton was presented 400ms or more prior to the onset of the target display, response accuracy significantly improved relative to when the colour singleton was not presented. Based on this observation Horstmann (2006) has argued that shifts of attention toward unexpected stimuli are delayed relative to expected stimuli. Critically, this delay is used to suggest an orienting mechanism for unexpected stimuli that is distinct from that which governs orientating toward expected stimuli.

However, inferring the time course of attention shifts to unexpected stimuli from accuracy scores is problematic. As well as attracting visual attention, unexpected stimuli generate large RT costs during visual search which are thought to be largely separate from the orienting response (see Chapter 2). These RT costs are thought to reflect the engagement of decision level processes that are recruited to reconcile the discrepancy between expected input and the actual input that is generated by attending to a novel stimulus (Meyer et al., 1991). I have argued that it is these non-spatially specific effects that are reflected in the time course analyses reported by Horstmann (2006) and Horstmann and Becker (2008), and not an orienting delay. In Chapter 4, I used eye-movements as a proxy for attentional orienting (Deubel & Schneider, 1996; Peterson, Kramer, & Irwin, 2004) to examine whether in fact shifts of attention and the eyes are delayed when they are exogenously directed toward an unexpected colour singleton.
Consistent with previous reports of oculomotor capture by infrequent stimuli (colour singletons: Geyer et al., 2008; onsets: Godijn & Kramer, 2008; Sayim et al., 2012) I found oculomotor capture by the first presentation of an unannounced colour singleton under conditions of both guided and unguided search. In both instances oculomotor capture was accompanied by large RT costs, consistent with previous reports of surprise capture (Horstmann, 2002; 2005; Meyer et al., 1991) and other results presented in this thesis. However, these RT costs could not be explained by delays in orienting. In Experiment 1 where search was unguided, saccadic latencies were delayed by ~40-50ms and target fixation latencies by ~115ms, while there was an additional ~300ms RT delay that manifest once the eyes selected the target. Furthermore, in Experiment 2 where search was guided, there were no delays associated with either saccadic latencies or target fixations latencies despite large RT costs once the eyes had selected the target (~280ms). I have suggested that the delay in saccadic and target fixation latencies observed when search was unguided (Exp. 1) reflects the suppression of a pre-programmed saccade and a switch from a narrow to a more diffuse attentional control setting at the first presentation of the unexpected colour singleton. Thus, the delays in orienting associated with the first presentation of the unannounced stimulus during unguided search are not specific to stimulus novelty per se, but rather reflect costs associated with interrupting ongoing or planned behaviour. As such, I have proposed an interference model of capture whereby attention is rapidly deployed to unexpected features and central processing resources are recruited to resolve the expectation discrepancy. Due to capacity limitations, processing of the expectation discrepancy comes at the expense of target identification as seen by RT delays (Horstmann, 2005; Meyer et al., 1991) and impaired accuracy (Horstmann, 2002; 2006). Importantly, this view does not invoke a dedicated novelty orienting mechanism to explain visual sensitivity to the unexpected. Instead, I have argue that same underlying orienting mechanisms that guide visual attention to expected and task relevant stimuli are involved in selecting novel and unexpected stimuli. Delays associated with unexpected stimuli arise once attention has been guided by early parallel processes to the location of an unexpected stimulus.

Horstmann (2002; 2005) has labeled attentional capture by a new and unannounced stimulus as ‘surprise capture’. However, based on my results I suggest
that this label is perhaps misleading. ‘Surprise’ describes a certain psychological state that can be induced by attending to an unexpected event; it describes a constellation of physiological and cognitive phenomena that emerge as a consequence of attending to an unexpected event. However, the label ‘surprise capture’ would seem to imply that some separate ‘surprise’ process is instrumental in orienting attention to unexpected stimuli. I have argued that this is unlikely the case and therefore suggest that the label ‘surprise capture’ requires revision. A more appropriate label for these effects would be ‘novelty capture’ or ‘deviant capture’. These terms are useful in that they are descriptive statements about the stimulus conditions / contexts that can produce attentional capture.

Concluding remarks

The three empirical chapters presented in this thesis demonstrate a consistent effect of stimulus novelty on search performance. In Chapter 2, I showed that a task irrelevant motion cue captured attention involuntarily when observers were set for a specific feature value (red). This finding is significant as it represents the first demonstration of capture by an irrelevant stimulus under such search conditions and suggests that capture by the unexpected may represent a true form of stimulus driven capture. As well as this spatial component, initial presentations of the motion cue produced large non-spatially specific costs that dissipated across successive presentations on the rare motion cue. This effect was also observed in Chapter 3 and is consistent with theoretical accounts of surprise which propose that unexpected stimuli engage response and decision level processes as well as drawing attention to their location (Horstmann, 2002; 2005; Meyer et al., 1991; Schützwohl, 1998). Interestingly, when the target of search was a feature singleton (Chapter 2: Experiments 2 – 4), I observed RT costs that were specific to valid presentations of the rare motion cue. The fact the rare motion cue captured attention when it was invalid but did not produce non-spatially specific RT costs suggest that these two components of the surprise response can be dissociated. Furthermore, this result from Chapter 2 is consistent with those of Chapter 4 where we observed oculomotor capture by an unannounced colour singleton and large RT cost that manifested only once the eyes had selected the target. Based on this latter result, I have questioned the need to invoke a distinct mechanism of control for unexpected
stimuli (see Horstmann, 2005; 2006; Horstmann & Becker, 2008). Rather, I have proposed that visual sensitivity to the unexpected and novel reflects a process whereby irrelevant stimuli are inhibited over repeated and frequent exposure (Treisman & Sato, 1990). Sensitivity to stimulus novelty arises because infrequent salient stimuli cannot be inhibited effectively and consequently they are registered by guidance mechanisms that determined visual selection (GS4: Wolfe, 2007; FIT: Treisman & Gelade, 1980). According to this view, the top-down set reflects a set of contextually specific expectations that describe both the target defining properties and the to-be-ignored properties of distractors. Importantly, the results presented in Chapter 3 demonstrate that task expectancies are formed online and implicitly through repeated exposure to targets and distractors.

In conclusion, top-down control of visual attention is critical for executing goal directed behaviours. Equally important is a mechanism that alerts an organism to salient objects and events in the visual world that may require rapid responding to but may not be directly related to ongoing tasks. In this thesis I have proposed an account of attention control whereby the very processes that enable an observer to prioritize task-relevant visual input results in sensitivity to the salient irrelevant stimuli but only when they occur infrequently and cannot be inhibited. This view is supported by three chapters of empirical work demonstrating robust and consistent effects of stimulus novelty on search performance.
References


