The Effects of Feature-Based and Memory-Driven Attention on Appearance

By

Jason Rajsic

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Abstract

Recent evidence suggests that, in addition to improving performance, spatial attention alters the perceptual experience of visual stimuli. We investigated whether two other forms of attention – feature-based attention, and memory-driven attention – also produce an increase in the perceived contrast of stimuli. Perceived contrast was measured by requiring participants to report which of two Gabor stimuli appeared higher in contrast, under different attentional or memory conditions. In Experiment 1, our results indicated that participants indeed allocated attention in a feature-based manner, but no increase in perceived contrast when attending to a given colour was found. Instead, feature-based attention appears to have produced a response bias, such that a stimulus was selected more often when it was attended. In Experiment 2, no change in perceived contrast due to the memory task was observed. A subsequent experiment indicated that our memory task may not have succeeded in causing an attentional shift, which limits the scope of our conclusions on the relationship of memory to perception, but is informative for the development of effective memory manipulations. Overall, our results have provided evidence that the mechanisms of feature-based attention may not be identical to those of spatial attention, but have left the effects of memory-driven attention to be determined.
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- Assisted in the development of the research question and methodology
- Edited my thesis proposal
- Advised on the analysis of results
- Edited my thesis manuscript

My contributions to this thesis were:

- Found and reviewed relevant literature
- Developed core research question
- Wrote thesis proposal and completed ethics submission
- Programmed experimental stimuli in Matlab
- Collected data, which involved the recruitment and instruction of participants
- Performed data analysis using SPSS and Microsoft Excel
- Wrote thesis
- Prepared presentation for oral defense

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Chapter 1: Introduction

Attention is the mechanism, or mechanisms, that selects or prioritizes the processing of a subset of the potentially processed information that is available. Carrasco and colleagues have shown that attending a location of the visual field alters the reported contrast of stimuli at the attended location (Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco 2009; Liu, Abrams, & Carrasco, 2009; Störmer, McDonald, & Hillyard, 2009). While location is the best-studied form of attentional selection, there are additional ways that attention can be oriented to a stimulus. The present study examines whether attention to a non-spatial stimulus feature (colour) and attention directed by spatial working memory will cause a similar increase in the reported contrast of stimuli. Measuring the effects of feature-based and memory-driven attention on perceived contrast will provide insight into whether these mechanisms of selection are functionally equivalent to the mechanism spatial attention.

Chapter 2: Literature Review

Attention

In order to successfully interact with our environment, we must constantly select which information is relevant to our goals, and which is not. Our immediate environment is often littered with events and objects, and the processing priority given to one or another can determine our subsequent decisions, actions, and memories. Given that the brain does not have unlimited processing resources, intelligent information reduction is critical for adaptive behaviour. The process of selecting this information is referred to as “attention”.

A fundamental issue that has been identified in the attention literature is
determining the extent to which selection is controlled by bottom-up, stimulus-driven processes, versus top-down, knowledge-driven processes. Bottom-up attentional control is described as *involuntary*, such that one’s attention can be unintentionally *captured* by perceptual salient stimuli. In contrast, top-down attention is described as *voluntary*, as it is driven by an individual’s goals and intentions. These two types of attention are respectively referred to as *exogenous* and *endogenous* modes of control, which acknowledges the source of the signals that determine selection in each case. A wide range of research supports the notion that attention can be controlled via both sources. For example, individuals are able to reduce their search latencies when they have advance knowledge of unique target features (e.g., Smith, 1962), suggesting top-down control of the selection process. However, individuals may also have their attention involuntarily captured by salient distractors – those that possess some unique feature (such as a red distractor among homogenous, green items; Theeuwes, 1992) – suggesting that stimulus-driven factors can also influence the allocation of attention.

Research into the neural bases of attentional control provides corroborating evidence that both top-down and bottom-up processes contribute to attentional selection. Top-down selection appears to be accomplished via the modulation of sensory processing by a fronto-parietal network. Although one may use the term “fronto-parietal network” as a catch-all for the observed neural bases of attentional selection, the particular areas within this network that are involved vary depending on the attentional task (Giesbrecht et al., 2003). Broadly speaking, signals from frontal areas (such as the frontal eye fields (FEF), and lateral prefrontal cortex (LPFC)) interact with parietal areas (such as the intraparietal sulcus (IPS), and superior parietal lobule
(SPL)), where a saliency map may exist that enables modulation of sensory processing in visual cortex (Kastner & Ungerleider, 2000; Corbetta & Shulman, 2002; Bressler et al., 2008; Buschman & Miller, 2007). In contrast, the sources of bottom-up attention seem to be less frontal, as they emerge from stimulus characteristics, such as feature contrast (e.g., a single tilted line amongst straight lines, or a unique motion direction) or luminance onsets. Bottom-up visual attention is thus thought to be driven by competition within areas of the visual cortex, with the outcome of this competition affecting the representation of visual saliency in the parietal cortex (Constantinidis & Steinmetz, 2005; Corbetta & Shulman, 2002).

**Spatial and Feature-Based Selection**

Attention can select stimuli based on a number of known stimulus attributes. The most well-studied type of selection is spatial selection, or spatial attention. When the location of a target is known in advance of its presentation, visual processing is prioritized at that location (Jonides, 1983). Behavioural, neuroimaging, and neurophysiological data indicate that the control of spatial attention is closely tied to the control of saccades. Attending or ignoring a location will interfere with the trajectory of a saccade; warping it away from ignored locations and towards attended locations (Doyle & Walker, 2001), and exogenously cueing attention to a location produces reduced saccade latencies to targets appearing in that location (Crawford & Muller, 1992). Covert (non-saccadic) and overt (saccadic) shifts of spatial attention appear to be controlled by overlapping brain regions (Noudoost, Chang, Steinmetz, & Moore, 2010). Microstimulation studies have implicated saccadic control areas such as the FEF and superior colliculus as being also involved in the shifting of covert spatial attention. These
areas contain neurons that induce saccades to particular locations when their firing rates surpass a threshold. Stimulating such neurons to a sub-threshold level increases visual discrimination performance in the locations that a saccade would be deployed to, given suprathreshold stimulation (Moore & Fallah, 2001; Müller, Philiaides, & Newsome, 2005).

The location of a stimulus is only one of many sources of information that can be used to guide attention. Attention can also be directed to features of a stimulus, such as colour, orientation, or motion direction. This feature-based attention is not restricted to just one location in space, instead it appears to operate globally, across the entire visual field (Saenz, Buracas, & Boynton, 2002; Saenz, Buracas, & Boynton, 2003; Zhang & Luck, 2009, Painter, Travis, Dux, & Mattingley, 2011; Liu & Mance, 2011, Serences et al., 2005). Liu & Mance demonstrated that adaptation to an attended motion at fovea produced a motion after-effect for stimuli at six different peripheral locations, supporting the notion that attention to features is not restricted to a single location. Another line of evidence for global feature-based attention comes from brain imaging research; Serences et al. found that when monitoring a rapid serial visual presentation (RSVP) stream for specifically coloured (e.g., red) letters, the Blood-Oxygen-Level dependent (BOLD) response in extrastriate visual cortex to letters in peripheral, task-irrelevant RSVP streams was stronger when the irrelevant letters matched the attended colour. Such research indicates that when selecting stimuli based on a non-spatial feature, one’s attentional filter is applied to all locations, even if they are task-irrelevant.

**Attention and Memory**

Whether attending to a location or a stimulus feature, some sort of temporary
memory representation of the desired stimulus, or its known attributes, must be created and maintained. Such temporary representations are thought to be held in working memory.

Working memory is a theoretical system that temporarily stores information needed for current neural computations; analogous to random access memory in digital computers. The most influential model of working memory is that of Baddeley and Hitch (1974; Baddeley, 2000) who proposed that working memory is composed of two independent stores and a central executive, which manages the information present in each store. The two stores allow maintenance of different types of perceptual representations: the phonological loop can store information coded in an auditory representation, and the visuo-spatial sketchpad (now more commonly referred to as visual working memory) stores information coded as a visuo-spatial representation. Baddeley has since appended a third store, the episodic buffer, which is able to store episodes, units of experience in a multi-dimensional code. Being a cognitive model, Baddeley’s model makes few predictions about the neural basis of working memory. An alternative formulation of working memory has been proposed by Cowan, who proposed no discrete buffers, but instead that working memories are highly activated subsets of long-term memory (1988). Both accounts preserve the notion of a limited capacity short-term store, but the mechanisms supporting the maintenance of information are quite different. In Baddeley’s model, memory capacity is based on structural limitations (i.e., the amount of information each store may contain), whereas in Cowan’s model, capacity emerges as a signal-noise segregation issue, based on the amount of information activated in long-term memory.
Top-down attention presumably relies on working memory as it requires maintenance of a target template to which incoming sensory information can be matched. This is explicit in Desimone and Duncan’s (1995) model where it is suggested that working memory functions as the source of top-down signals that bias perceptual competition in favour of attended stimuli; this implies that rehearsal in working memory and top-down attention may be supported by the same underlying processes. Knudsen (2007) also implicates working memory in the control of top-down attention, including it as one of the fundamental components of attention. An even stronger view of the link between attention and working memory is presented by Postle (2006), who suggests that storage in working memory is accomplished by attending to the relevant sensory or motor channels. Indeed, D’Esposito (2007) shows that areas dedicated to perceptual processing of a stimulus (e.g., faces, in the fusiform face area) are the areas that are recruited to maintain that same stimulus information in the absence of a perceptual stimulus.

Furthermore, behavioural and neurological research has provided experimental support for a functional coupling of working memory and top-down attention. Downing (2000) has shown that when presented with two faces, one of which is being held in working memory for a later test, attention is drawn to the to-be-remembered face, improving discrimination performance for stimuli presented at that location. Other researchers have shown similar interactions between working memory and attention: spatial working memory performance degrades if attention must be shifted away from a remembered location (Awh & Jonides, 2001), target detection in a visual search task will be slowed if a feature singleton is present that matches an item being remembered for a
later test (but only if the item is encoded visually; Olivers, Meijer, & Theeuwes, 2006), and increasing the amount of task-irrelevant information in working memory causes distractor letters to interfere more with the identification of a target letter on a visual search task (Fockert, Rees, Frith, & Lavie, 2001).

Similar brain regions are recruited for working memory tasks and visual attention tasks as well: LaBar et al. have shown that memory tasks, such as remembering the identity of previously displayed letters, and attention tasks, such as covertly attending a location, activate similar cortical regions, notably in the IPS and FEF (1999). Neuroimaging evidence also shows that rehearsal of locations in working memory causes a similar modulation of perceptual processing to that of spatial attention. Awh et al. (1999) instructed participants to remember the location of letters presented in either their right or left hemifield. During the retention interval, participants saw a six-second flickering checkerboard display, presented to both hemifields. They found that the BOLD response to the checkerboard display in visual areas V1, V2, and V3 was greater for the hemifield that had contained the to-be-remembered stimuli than for the opposite hemifield. Because this hemifield effect was similar to that observed in a lateraled attentional task, it demonstrated that simply holding an item’s location in working memory can lead to attention-like modulations of visual processing.

While considerable evidence exists for functional overlap between attention and working memory, some studies have found evidence for independence of the two systems. For example, Woodman and Luck (2007) found that visual search response times were faster when a distractor matched an item being maintained in working memory. This finding indicates, in contrast to that of Downing (2000), that attention was
oriented away from, not towards, memory-matching stimuli. Olivers (2009) has reviewed a number of working memory studies, and proposed that the key difference lies in whether the memory items can be encoded verbally. When memory items are categorically distinguishable (e.g., red vs. blue shapes, or pictures of familiar objects), the working memory representation may be verbal and not visual, even if articulatory suppression is used to interfere with verbal rehearsal. This highlights a critical aspect of memory-driven attention: the contents of working memory only influence perceptual processing if the memory representation is visual. When a verbal representation is maintained in working memory, no visual areas are recruited for rehearsal, and therefore memory would not be expected to bias visual processing.

The review above describes a variety of methodological approaches for determining the extent to which top-down attention is influenced by the contents of working memory. These approaches include visual search response times (Olivers, Meijer, & Theeuwes, 2006; Woodman & Luck, 2007), perceptual discrimination accuracy (Downing, 2000; Awh & Jonides, 2001), and evoked visual cortical response (Awh, 1999). One goal of the present study is to test the functional overlap of attention and working memory by way of a relatively novel methodology for identifying attentional consequence: its ability to alter the perceived contrast of stimuli.

**Attention and Appearance**

It is clear that there are perceptual consequences to attention: individuals can be completely unaware of the presence of unattended objects (inattentional blindness; Simons, 2000) and miss large changes to unattended visual stimuli (change blindness; Simons & Rensink, 2005). However, whether attention alters the quality of our
perceptual experience is not as clear. Over the past ten years, a number of studies have provided evidence that spatial attention alters the appearance of stimuli. Motivated in part by work showing that the response of neurons in the visual cortex whose receptive fields lie within the locus of attention mirrors the neural response obtained when a physical stimulus contrast is increased (Treue, 2004; Carrasco, Ling, & Read, 2004) developed a psychophysical test to address the question of whether these neurophysiological correlates of attention cause a corresponding change in perceived contrast.

To examine the influence of attention on perceived contrast, the procedure used by Carrasco et al. combined a psychophysical forced-choice discrimination task with exogenous attentional cueing to control the location of an individual's attention as he or she viewed the discrimination stimuli. Each trial began with a brief presentation of a peripheral cue (a small white dot) in one of two locations (left and right side of fixation), or a neutral cue at fixation. Next, two peripheral Gabor patches (stimuli whose brightness varied sinusoidally from side-to-side and were presented through a Gaussian filter), were briefly presented. The observer's task was to report the orientation of the Gabor that was perceived to be of higher contrast. Importantly, the peripheral cues were not predictive of either the stimulus contrast or the stimulus orientation, but directed attention in an involuntary, bottom-up fashion. Using this procedure, Carrasco et al. were able to measure perceived stimulus contrast for Gabor stimuli that appeared at the attended location (same as peripheral cue location), the unattended location (opposite location from the peripheral cue), and under neutral conditions (central cue). The authors discovered that Gabor patches that had been cued immediately before
presentation were reported to be higher in contrast than Gabor patches that had not been cued, which indicates that attention increases the perceived contrast of stimuli.

This paradigm is flexible, allowing for the examination of the influence of attention on the perception of a variety of quantifiable stimulus properties. Using this paradigm, Carrasco’s lab, along with others, have demonstrated attention-induced shifts in the perception of contrast (Carrasco, Ling, & Read, 2004; Liu, Abrams, & Carrasco, 2009), spatial frequency, spatial resolution (Gobell & Carrasco, 2005), motion coherence, flicker rate (Liu, Fuller, & Carrasco, 2006), colour saturation (Fuller & Carrasco, 2006), speed (Turatto, Vescovi, & Valsecchi, 2007), and size (Anton-Erxleben, Henrich, & Treue, 2007). The increase of perceived contrast by attention has also been replicated with auditory cues (Störmer, McDonald, & Hillyard, 2009) and using cues of differing intensity (Fuller, Park, & Carrasco, 2009).

Debate still exists as to whether the reported change in contrast is truly a perceptual change, or whether attention produces biases to preferentially report the attended stimulus (Schneider & Komlos, 2008; Valsecchi, Vescovi, & Turatto, 2010). Simple response biases, in which attention makes a stimulus more likely to be chosen regardless of task, have been largely ruled out by using a control experiment that requires participants to report the stimulus with less, rather than more, of a visual attribute (Carrasco, Ling, & Read, 2004; Gobell & Carrasco, 2005; Fuller & Carrasco, 2006; Anton-Erxleben, Henrich, & Treue, 2007; Turatto, Vescovi, & Valsecchi, 2007). If a simple response bias did underlie the results of a perceptual experience study, then such a control experiment (report the stimulus with less of the attribute) would be expected to produce the opposite result to the standard experiment (report the stimulus
with more of the attribute). However, the simple response bias account is not typically observed; instead results of the standard and control experiments typically converge on the same conclusion that there is a genuine increase in perceived contrast. This control experiment does not, however, control for more complicated decision biases, which will be discussed later.

**Visual Working Memory and Appearance**

Thus far, only one study has explored whether the contents of working memory can produce the shift in appearance that occurs when attention is cued to a stimulus location. Turatto, Vescovi, and Valsecchi (2008) combined the Carrasco paradigm with a working memory manipulation to determine whether the contents of working memory could alter perceptual experience. Over three experiments, the authors instructed participants to hold either the orientation or colour of a Gabor patch in memory, and then required participants to judge the speed of two coloured Gabor patches that each moved in a perpendicular direction to the sinusoidal Gabor within a fixed viewing window. The memory item could match either of the two Gabor patches in either orientation or colour, or neither. If attention was deployed to the Gabor with a feature matching the feature being held in working memory, then the speed of that Gabor should be judged to be faster – in accordance with the findings of Turrato et al. (2007) who demonstrated that attentionally cued, moving Gabors are reported to be faster than uncued, moving Gabors. Although a control experiment provided evidence that attention was biased towards stimuli matching the contents of memory, there was no evidence that stimulus-memory compatibility influenced judgments of speed, and thus no evidence that the contents of memory can bias the perception of stimuli.
The Present Study

Although the evidence from Turrato et al. (2008) implies that working memory does not produce the change in appearance that occurs when spatial attention is allocated to a stimulus, it is important to note that the contents of working memory in each of their manipulations were object features, not locations. As described earlier, attention research has distinguished between two modes of attention: spatial attention, and feature-based attention (Vierck & Miller, 2005; Hayden & Gallant, 2005; Liu, Stevens, & Carrasco, 2007). In the former, attention selects stimuli based on locations, and in the latter, attention selects stimuli based on features they possess (such as colour, form, and motion). To date, there have been no studies explicitly testing whether feature-based attention has a similar impact on stimulus appearance as has been found with spatial attention tasks. Therefore, it is possible that the reason that Turatto et al. failed to find an effect of working memory on appearance is because their manipulation of working memory involved features, and not locations.

These considerations have motivated the present study to investigate two questions: (1) whether attention to a feature, rather than a location, produces an increase in perceived contrast, and (2) whether spatial working memory affects perceived contrast in a manner similar to that observed with manipulations of spatial attention. Results indicating that perceived contrast does increase with both modes of attention would provide support for a unitary selection process.

Chapter 3: Experiment 1

In Experiment 1, we explicitly tested whether attention to a stimulus feature (colour) produced shifts in appearance. To accomplish this, we adapted the paradigm
used by Liu, Abrams, and Carrasco (2009), who manipulated voluntary spatial attention by preceding the perceptual judgment by two peripheral RSVP streams. On each trial, participants were cued to attend the left, right, or both RSVP streams, populated by upper-case letters. Participants were told that the cue predicted the location of the target letter (an 'X'), which was present on 20% of trials. On trials where no X was present, participants provided the standard forced-choice judgment on two peripheral Gabor patches, indicating the orientation of the Gabor that appeared to be higher in contrast. Using this paradigm, Liu et al. provided the first evidence that voluntary, spatial attention increased the contrast of stimuli. In Experiment 1, we adapted this paradigm by using colour cues to provide participants with advance information of the colour, rather than the location, of a target letter in an RSVP stream before presenting coloured Gabor patches.

**Experiment 1a**

**Methods.**

**Participants.**

For this experiment, we recruited 17 participants, enrolled in the Psychology program as undergraduate or graduate students at Queen’s University. Participants were required to have normal, or corrected-to-normal, vision. Nine participants participated in Experiment 1a, and eight in Experiment 1b. The results of eight of the nine participants were analyzed for Experiment 1a; one participant’s data was excluded due to incorrect responses for over 95% of trials, resulting from a misunderstanding of the experimental procedure.
**Apparatus.**

Stimuli were presented on a 17” CRT monitor, with a refresh rate of 60 Hz. Experiments were run on a Dell PC in a dimly-lit room. The apparatus was the same for all subsequent experiments.

**Stimuli.**

Experiment stimuli were generated using Matlab 7.04 and version 3 of the Psychophysics Toolbox. Each trial consisted of the sequential presentation of a fixation display, a cue display, an RSVP display, and a perceptual judgment display, as depicted in Figure 1.

The fixation display consisted of a white fixation cross, subtending 1º of visual angle horizontally and vertically, presented at the center of the screen against a uniform, grey background.

The cue display consisted of a small coloured square, subtending approximately 1º X 1º of visual angle. The square appeared in one of three possible colours: blue, yellow, or white.

The RSVP display consisted of one stream of coloured letters, horizontally centered at 1º above the horizontal meridian. Letters in the RSVP stream were chosen from a set of eight distractor letters (N, R, Z, B, A, M, and L), and included (on 20% of trials) a target letter (X) in a random temporal position. All letters were approximately 0.6º in size, and were coloured in one of the seven possible colours (blue, yellow, red, green, pink, brown, and purple). No two letters appearing sequentially had the same colour or identity.

The perceptual judgment display consisted of a central fixation cross, flanked on
either side by the two _judgment stimuli_. The judgment stimuli were two coloured Gabor patches. These Gabor patches were luminance gradients that varied sinusoidally, and were enveloped in a Gaussian window. The Gabor patches were centered at 3° to the left and right of fixation, and were rotated either 15° to the left, or 15° to the right of a vertical orientation. They had a fixed spatial frequency of 4 c/deg, and their Gaussian

**Figure 1.** A sample trial from Experiment 1. The RSVP display contained a variable number of letters, adjusted to the performance of each participant. As such, the duration of each letter (and blank screen between letters) depended on the number of letters being presented. During the blank presentation at the end of the trial, participants responded by pressing the space bar if an X was detected in the RSVP display. If no X was detected, then they reported the orientation of the Gabor patch that appeared to be of higher contrast.
envelopes had a standard deviation of 0.3º. The Gabor patches were also coloured –
varying in luminance around one of two possible colours (blue and yellow). The blue
patch was drawn using only the green and blue channels, in equal proportion, and the
yellow patch was drawn using only the red and green channels, in equal proportion.
Due to the fact that blue and red channels contribute different amounts to brightness,
the absolute perceived contrast of the blue and yellow Gabors may not have been
equivalent. However, because neither the Test nor the Standard Gabor was
preferentially associated with either colour, this difference should not bias the results.
Gabor patches varied in proportion of maximum contrast through one of nine values:
0.13, 0.20, 0.25, 0.29, 0.32, 0.35, 0.40, 0.50, and 0.76. These contrast steps match
those of Liu, Abrams and Carrasco (2009), who demonstrated a shift in contrast
perception with voluntary spatial attention.

Procedure.

As with our stimuli, the procedure for this set of experiments was intended to
closely mirror that of the Liu et al. (2009) study, which demonstrated an effect of
voluntary spatial attention on perceived contrast. Participants completed 810 trials,
arranged in 9 blocks of 90 trials. Each trial began with a fixation display for 1,000 ms;
next, in the cue display, a coloured square was presented for 400 ms. A blue or yellow
cue indicated the colour of the target letter X, if present in the RSVP stream, with 100%
validity. In addition, no other letters in the RSVP stream could possess the cue colour,
providing considerable incentive to attend only to stimuli of the cued colour. In the case
of a white cue, which served as a non-informative neutral cue (no information regarding
target letter colour), the target letter X could be any of the five other letter colours (i.e.,
not blue or yellow). Cue colour for a given trial was random, with each colour cue comprising 33% of all trials, and therefore independent of the response required for the perceptual judgment task.

Following the cue display, the RSVP display was presented. The RSVP display consisted of a rapid simultaneous presentation of coloured letters. The RSVP contained a variable number of coloured letters, initially five, presented in quick succession for 1,200 ms. To avoid ceiling effects, the number of letters in the RSVP display was continuously adjusted to achieve an accuracy of 85% using a QUEST staircase procedure that continually estimated the psychometric function describing likelihood of correctly detecting an X based on the number of letters in the RSVP stream (Watson & Pelli, 1983).

Immediately following the last letter in the RSVP stream, the perceptual judgment display (Gabor patches) was briefly presented (50 ms). Unbeknownst to participants, one of the two Gabor patches on every trial was fixed at a medium contrast level (0.32), the Standard Gabor, and the other was free to vary along a range of possible contrast levels, referred to as the Test Gabor.

Participants were instructed to ignore the Gabor patches if an X had appeared in the RSVP stream (20% of trials), and to press the space bar after the Gabors had disappeared. If an X did not appear in the RSVP stream (80% of trials), participants were told to perform a perceptual judgment task on the Gabor patches. In the perceptual judgment task, participants were required to report the orientation (tilted left or right from vertical) of the Gabor patch that appeared to be higher in contrast. Participants’ decisions were reported by pressing the ‘Z’ or ‘X’ key to indicate a leftwards
or rightwards tilt, respectively, of the leftmost Gabor, or by pressing the ‘N’ or ‘M’ key to indicate a leftwards or rightwards tilt, respectively, of the rightmost Gabor. The rationale for requiring participants to report the orientation of the Gabor chosen as higher in contrast is adopted from the paradigm implemented by Liu, Abrams and Carrasco (2009). The intention of this instruction is to de-emphasize the subjective contrast judgment to participants, in order to reduce any biases. While our procedure retained this additional task component, removing it and requiring only a contrast judgment has been shown to provide similar results (Schneider & Komlos, 2008).

Using this procedure, we were able to characterize the perceived contrast of Gabor patches for the three experimental conditions: (1) attended feature condition – when the Test Gabor patch was the same colour as the cue (both blue or both yellow); (2) unattended feature condition – when the Test Gabor patch was a different colour than the cue (cue blue and Gabor yellow, or vice versa), (3) neutral condition – when the cue was white and the Test Gabor patch is either blue or yellow. If feature-based attention results in an increase in perceived contrast, then a Gabor patch ought to be chosen as higher contrast more frequently when its colour matches the cued colour (i.e., when it is being attended).

After the Gabor display, a final fixation display was presented. At this display, participants were instructed to provide a response to either the RSVP stream, or the Gabors, as described above. After a response was provided, or after 2,000 ms had elapsed, the display terminated and the next trial immediately began.
Experiment 1b

Methods.

It was possible that the results of Experiment 1a would produce evidence of an increase in the apparent contrast of attended Gabors. However, strong conclusions could not be drawn based on such a result because the cue’s effect on attentional allocation is confounded with a cue response bias. Because participants were to report the Gabor that appeared higher in contrast, an increase in responses at the cued location may be due to a true increase in the perceived contrast of Gabors or simply a response bias such that there was an increase in the tendency to respond to stimuli at the cued location. To distinguish between these possibilities, a control experiment, Experiment 1b, was conducted that was identical to Experiment 1a with only one change in the instructions. Rather than reporting the tilt of the Gabor that appeared higher in contrast (Experiment 1a), participants were instructed to report the tilt of the Gabor that appeared lower in contrast. Results of Experiment 1b can be used to determine whether effects in Experiment 1a are due to a change in appearance or a response bias. If attention actually increases contrast, a Gabor should be reported less often when attended in Experiment 1b (report Gabor lower in contrast). But if a response bias underlies the results from Experiment 1a, then attended Gabors will be responded to more in both Experiments 1a and 1b despite the change in instructions.

Results

Before assessing the effect of feature-based attention on contrast judgments, it was necessary to determine whether providing feature-cues led to better target detection in the RSVP task. If participants were indeed orienting their attention to
the cued colour in a trial, target detection should be better in trials where the cue provides advance information about the target’s colour. For each participant in Experiments 1a and 1b, his or her detection ability with attention (colour-cue trials) was compared to his or her detection ability without attention (trials with a non-informative neutral cue). \(d'\) scores (Green & Swets, 1966) were used to measure target detection performance, as they provide an estimate of detection ability that is free from the confound of response bias. The scores were calculated using the equation \(d' = z(H) - z(FA)\), where \(H\) is hit rate, and \(FA\) is the false alarm rate. When calculating \(d'\), if a participant did not produce at least one miss or false alarm, 0.5 was subtracted from their total number of hits or correct rejections (respectively) and 0.5 was added to the miss or false alarm count to enable the calculation of a \(d'\) score (Macmillan & Kaplan, 1985). This correction was used eight times out of the total 32 \(d'\) scores calculated, indicating that in eight cases, participants were at ceiling for either Hit Rate or False Alarm Rate. The \(d'\) of each participant for both cue conditions is displayed in Figure 2. A paired samples t-test indicated target detection on colour-cue trials (\(M = 4.03, SD = 1.03\)) was significantly better than target detection on neutral trials (\(M = 3.25, SD = 0.98\)), \(t(15) = 4.97, p < .001\). This suggests that participants did in fact deploy feature-based attention to the cued colour during a trial. The \(d'\) values we obtained were quite high, indicating that participants found the RSVP task easy. While this may have reduced the need to rely on feature-based attention to improve performance, it was necessarily high due to the fact that every incorrectly classified trial is one that is excluded from the analysis of contrast judgments. It is worth noting that the improvement in performance we found was in fact of a greater magnitude than that
reported by Liu, Abrams and Carrasco (2009), although a proper statistical comparison of these effect sizes is not possible.

Next, to test whether attention to a colour (feature-based attention) caused a shift in the perceived contrast of a Gabor stimulus that matched the attended colour, I conducted two analyses. The first analysis examined whether the predicted points of subject equality (PSEs) varied across attentional conditions. A second, non-parametric analysis examined the effect of physical Test Gabor contrast and attention on contrast judgments. There were three attentional conditions, which we refer to as Test Cue,

![Figure 2. RSVP detection performance in Experiment 1. Colour-cue trials were trials where a blue or yellow cue, indicating the possible colour of the RSVP target, was presented, and Neutral Cue trials were trials where no advance target colour information was given (a white cue was displayed).](image)
Neutral Cue, and Standard Cue. Test Cue refers to all trials where the colour cue matched the colour of the Test Gabor – for example, a blue colour cue (indicating that participants should actively search for blue stimuli) and a blue Test Gabor. Neutral Cue refers to all trials where the colour cue was white, hence no attentional manipulation. Lastly, Standard Cue refers to trials with a colour cue that matched the colour of the Standard Gabor, so that feature-based attention was directed away from the Test Gabor.

Trials where a target appeared in the RSVP stream were excluded from analyses (20% of all trials), as well as trials where participants did not provide a response, or provided an incorrect response (indicating the wrong tilt for the chosen Gabor). On average, the number of excluded trials due to participant error comprised 11.5% of all trials. Cumulative Gaussian distributions were fit to the resulting data, given by

\[ y = (\gamma - \delta) \cdot \left(1 + \int \frac{x-\mu}{\sigma \sqrt{2}} \right) + \delta, \]

where \( \mu \) is the central tendency of the distribution, \( \sigma \) is the standard deviation, or spread, of the distribution, and \( \gamma \) and \( \delta \) are the upper and lower asymptotes of the distribution, respectively. These fits summarized the relationship between Test Gabor contrast and contrast judgments. Average fit \( R^2 \) values, across participants, for each attentional condition were .96, .92, and .93 for the Test Cue, Neutral Cue, and Standard Cue conditions, respectively. Psychometric function fitting was also done with 4-parameter Weibull cumulative distribution functions for this and all further curve-fitting, but no improvement in the quality of fits was observed, and so we report only the Gaussian distribution fits and analyses. All psychometric fits were estimated with Matlab code that utilized the lsqcurvefit function which employs the Least Squares fitting method. Overall contrast judgments (the probability that the Test Gabor
was chosen as being higher contrast) averaged across participants for each contrast level and attentional condition, are presented in Figure 3.

We first tested for the presence of a shift in contrast perception due to feature-based attention in two ways: (1) comparing the points of subjective equality (PSEs) as calculated from the psychometric functions for each attentional condition, and (2) comparing the mean number of trials on which the Test Gabor was chosen for each attentional condition. The first analysis involved using planned, conditional paired

**Figure 3. For Experiment 1a, participants were instructed to report the Gabor with higher contrast. The graph depicts the proportion of trials where the Test Gabor was chosen for each Test Gabor contrast level, and for each attentional condition. The dashed line indicates the contrast of the Standard Gabor patch. Error bars represent 1 SE.**
samples t-tests. The procedure was to first test whether there was a significant difference between Test Cue and Standard Cue condition. If this test indicated that the two conditions were significantly different, only then would the effect of each attentional condition be compared to the Neutral Cue, or baseline, condition with two additional paired samples t-tests. This analysis procedure was intended to be a fairly conservative approach to testing the hypothesis that attention altered contrast judgments, as it tests for a global effect of attention before using further tests to determine the directionality.

The second, non-parametric, analysis consisted of one 3X5 repeated measures ANOVA, with attention and Test Gabor contrast as factors. In this analysis, if a main effect of Test Gabor contrast was found, its directionality was assessed with a linear contrast, which would determine whether increasing the contrast of the Test Gabor produced an increase in the probability that the Test Gabor was chosen. Only the middle five contrast levels were included in the analysis, as this area of the psychometric function is expected to show the attentional modulation. Follow-up analyses for a main effect of attention mirrored the approach of the parametric analysis, such that both the Test Cue and Standard Cue conditions were compared to the Neutral Cue condition.

A plot of the PSEs in the Test Cue and Standard cue conditions for each participant is shown in Figure 4. While the majority of participants showed a decrease in the PSE with attention, it was not true of all participants. The mean PSEs for the Test Cue condition ($M = 0.30$, $SD = 0.03$) and the Standard Cue condition ($M = 0.34$, $SD = 0.05$) did not significantly differ, $t(7) = 1.27$, $p = .24$. This indicated that attention to a colour did not shift apparent contrast for a Gabor of the same colour. If there was an
effect of feature attention on perceived contrast, then there should have been a significant leftwards shift in the psychometric function (i.e., a decrease in the amount of contrast needed for the Test Gabor to perceptually match the Standard Gabor).

I then conducted a non-parametric test, comparing differences in the mean probability of choosing the test Gabor as higher in contrast instead of differences in fitted parameters. This involved running a 3X5 repeated-measures ANOVA, with attentional condition (Test Cue, Neutral Cue, Standard Cue) and Test Gabor Contrast (five middle-most contrast increments: 0.25, 0.29, 0.32, 0.35, 0.40) as factors on overall contrast judgments. Probability of reporting the Test Gabor was, as expected, significantly differed as a function of actual Test Gabor Contrast, $F(4, 28) = 79.67, p < .001$. A significant linear contrast indicated that increasing Test Gabor contrast increased the likelihood of reporting the Test Gabor, as expected, $F(1, 7) = 150.60, p < .001$. As for the effect of attention, we found no significant main effect of attentional condition, $F(2,14) = 1.63, p = .23$. There was no evidence for an interaction between attention and physical contrast, $F(18, 56) = 0.47, p = .87$. This analysis and the previous

![Figure 4](image-url)

*Figure 4. Plots of the PSEs for the Test Cue and Standard Cue conditions relative to the Neutral conditions for each participant in Experiment 1. Markers are expected to fall on the dotted line if no change in contrast occurs relative to the Neutral condition.*
analysis then converge on the same conclusion that feature-based attention does not produce a significant change in the apparent contrast of stimuli.

I conducted the same analyses for Experiment 1b. Contrast judgments, still defined as the probability of selecting the Test Gabor, for each Test Gabor level and attentional condition are depicted in Figure 5. Average fit $R^2$ values for each attentional condition were .87, .92, and .90 for the Test Cue, Neutral Cue, and Standard Cue conditions, respectively. A comparison of the mean PSE for the Test Cue psychometric function ($M = 0.36, SD = 0.08$) was not significantly different from the mean PSE for the

![Figure 5](image-url)

*Figure 5. For Experiment 1b, participants were instructed to report the Gabor with lower contrast. The graph depicts the proportion of trials where the Test Gabor was chosen for each Test Gabor contrast level, and for each attentional condition. The dashed line indicates the contrast of the Standard Gabor patch. Error bars represent 1 SE.*
Standard Cue function ($M = 0.29, SD = 0.04$), $t(7) = 1.54, p = .17$. This finding corroborates the conclusion from Experiment 1a that feature attention does not produce a change in apparent contrast.

Running the same 3x5 repeated-measures ANOVA as used in Experiment 1a, I again found a significant main effect of physical Test Gabor Contrast on contrast judgments $F(4,28) = 25.32, p < .001$, with a significant linear contrast showing that as physical contrast of the Test Gabor increased, reporting of the Test Gabor decreased, $F(1,7) = 36.09, p = .001$. This finding also shows that the instructional manipulation used in Experiment 1b (report lower contrast Gabor) was successful as this effect was opposite to that observed in Experiment 1a (report higher contrast Gabor). Interestingly, a significant main effect of attentional condition did exist, $F(2,14) = 4.864, p = .025$.

Comparing the Test Cue and Standard Cue conditions to the Neutral condition with paired samples t-tests yielded a significant difference for the Standard Cue vs. Neutral Cue condition, $t(7) = 2.64, p = .03$, but not for the Test Cue vs. Neutral Cue condition, $t(7) = 1.09, p = .31$. It is critical to note that the direction of the effect is opposite to that expected by an attention increases apparent contrast account. Participants in Experiment 1b were instructed to report the Gabor that appeared lower in contrast, so if feature attention increases apparent contrast then participants should have been less likely to report the Test Gabor in the Test Cue condition than in the Standard Cue condition. However, we found the opposite trend -- the probability of reporting the Test Gabor was lower for the Standard Cue condition than the Neutral Cue condition. This finding then supports the conclusion that the effect of feature attention on apparent contrast reflects a response bias such that participants are more likely to report the
object containing the attended feature, regardless of the contrast instruction. Lastly, there was no evidence of an interaction between attention and physical contrast, $F(8, 56) = 0.575, p = .79$.

Finally, a correlation was performed to assess whether the extent to which an observer benefitted from using feature-based attention might correlate with the shift in appearance he or she exhibited. To do this, a $d'$ change score was calculated, subtracting the $d'$ when the target letter’s colour was known from the $d'$ when it was not, and this was correlated with a PSE change score, which was calculated by subtracting the Test Cue PSE from the Standard Cue PSE. For Experiments 1a and 1b, there were no significant correlation between the feature-based attentional benefit and the change in appearance, $rs = -.38, .63; ps > .05$. We therefore could not present evidence that there was a relationship between the amount of benefit gained from employing feature-based attention in the RSVP task and the degree to which perceived contrast was reported to change.

In sum, there were inconsistent findings from Experiments 1a and 1b with the results of Experiment 1a suggesting that feature attention did not change perceived contrast, and the results of Experiment 1b suggesting that feature attention decreases perceived contrast. Regardless, neither of these experiments supported the hypothesis that feature attention increases perceived contrast. Rather, these results seem to be more consistent with the response bias account such that participants are biased to report the Gabor that matches the attended colour regardless of instructions.

Discussion

The ability of participants to detect the target letter in the RSVP stream of a trial
improved when the target’s colour was provided at the beginning of a trial, which indicates that participants were able to attend preferentially to stimuli of the cued colour. Attending to a colour, though, did not seem to increase the apparent contrast of Gabor patches presented after the RSVP stream. In Experiment 1a, we found no impact of feature-based attention on the reported contrast of a Gabor, and in Experiment 1b, the attended Gabor was more likely to be reported even though the instruction was to report the Gabor that was lower in contrast. This contradicts the hypothesis that feature-based attention acts like spatial attention, and increases the perceived contrast of stimuli. Instead, our results are more consistent with a response bias account in which participants have a simple bias to report the attended Gabor.

The results from Experiment 1b suggest that attention to a specific colour altered participants’ tendency to report the congruently coloured Gabor patch, despite the fact that they appeared at peripheral locations. This is an important finding, as it shows that although targets only appeared centrally, participants did not merely attend a particularly coloured stimulus at the center. Rather, feature-based attention appeared to have operated in a spatially non-specific manner. This is in line with a number of studies that demonstrate a global effect of feature-based attention. That is, feature-based attention need not be restricted to locations – when attending to a particular colour, stimuli that match the attended colour but appear in irrelevant spatial locations show attentional modulations (Saenz, Buracas, & Boynton, 2002; Saenz, Buracas, & Boynton, 2003; Zhang & Luck, 2009, Painter, Travis, Dux, & Mattingley, 2011; Liu & Mance, 2011, Serences et al., 2005).

Although spatial attention has been found to increase the perceived contrast of a
stimulus (Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco 2009; Liu, Abrams, & Carrasco, 2009; Störmer, McDonald, & Hillyard, 2009), our results suggest that top-down, feature-based attention does not produce an increase in perceived stimulus contrast. Instead, it appears that feature-based attention only produces a response bias—increasing the tendency of observers to report a stimulus that matched the attended colour. The finding that no change in perceived contrast accompanies attention to a stimulus feature may help to explain the inability of Turatto et. al (2008) to find an effect of holding a colour in working memory on the perceived speed of a moving Gabor. Possible interpretations of this finding will be considered in the General Discussion.

Our next goal was to examine whether holding a location in visual working memory would mirror voluntary spatial attention by producing an increase in perceived contrast for stimuli in memory-congruent locations.

**Chapter 4: Experiment 2**

The second goal of this thesis is to determine whether holding a location in working memory alters the appearance of stimuli. Awh, Jonides, & Reuter-Lorenz (1998) have shown that attention is biased to locations compatible with those held in working memory, and so requiring participants to remember a location is a promising test of whether working memory alters perceptual experience. In their study, participants were required to remember either the location or identity of a single letter. While remembering the target letter’s location or identity, a visual discrimination task was performed at a Memory Congruent or Memory Incongruent location. When the target letter’s location was to be remembered, response times for the visual discrimination task were consistently faster when the discrimination stimulus appeared in the same location.
as the memory stimulus (Memory Congruent), compared to when the discrimination had to be made at a non-remembered location (Memory Incongruent). Importantly, this was only the case when the location of the stimulus was to be remembered – no congruency effect was observed when simply remembering the identity of the stimulus. This finding indicates that remembering the location of an item biases attention towards that location while the memory is being maintained. This, in conjunction with the finding that sustained, voluntary spatial attention produces a shift in appearance (Liu, Abrams, & Carrasco, 2009) motivated Experiment 2, as holding a location in working memory is presumed to be the mechanism by which voluntary spatial attention occurs (Desimone & Duncan, 1995).

To measure the effect of holding a location in memory on perceived contrast, I will embed the same two-alternative forced choice perceptual judgment task used in Experiment 1 into a working memory task. Participants will first remember the location of a dot appearing in one of three locations: a location that is congruent with the Test Gabor (the Gabor whose contrast varies), a location that is incongruent with the Test Gabor (and therefore congruent with the Standard Gabor), or a location in which the Gabors never appear, providing a neutral baseline. Given the findings of Liu et al. (2009), this manipulation will test a prediction of the working memory account of attentional deployment – that if working memory truly orients spatial attention to the remembered location, stimuli at that location should appear higher in contrast.
Experiment 2a

Methods.

Participants.

We recruited 30 participants, enrolled in the Psychology program as undergraduate or graduate students at Queen’s University, for Experiments 2a (13 participants) and 2b (17 participants). Participants were required to have normal, or corrected-to-normal, vision. The data of five participants in Experiment 2a, and nine participants in Experiment 2b, were excluded from analysis, for reasons discussed in the results section.

Stimuli.

Stimuli for these experiments are depicted in Figure 6, consisting of five stimulus presentations: A fixation display, memory sample display, perceptual judgment display, blank display, and memory probe display. The fixation display was identical to the fixation display in the feature-based attention experiment, consisting of a 1º X 1º white fixation cross on a uniform, grey background. The memory sample display consisted of a small, white dot (0.5º) appearing either on the left (3º from fixation), right (3º from fixation), or bottom (3º from fixation) of the screen. All memory sample dots were free to vary either 0.6º left or 0.6º right of these three positions. This allowed remembered locations for left and right dots to roughly correspond to the location of one of the subsequently presented Gabor spots. Although the presentation of only one stimulus to be remembered might be considered a low memory load task, such an approach has successfully shown a memory-driven shift of attention to the remembered location (Awh & Jonides, 2001).
For memory probe displays, the probe dot appeared in the same general location as the sample dot. That is, if the sample dot was left of fixation, then the probe dot would also be left of fixation. However, the probe dot was always slightly offset such that it appeared ~1.3º left or right of the location of the sample dot. A QUEST procedure was

Figure 6. A sample trial from Experiment 2. Participants had to hold the location of a memory sample (small dot) in working memory, and indicate whether the memory probe (at the end of the trial) was in the same location or a different location as the memory sample. While holding the sample location in memory, participants had to perform a perceptual judgment task, indicating the orientation of the Gabor patch which appeared to be higher in contrast.
implemented to attempt to produce a probe to sample distance offset that would challenge the participants by maintaining an 85% correct performance level. Unfortunately, an error caused the QUEST procedure to produce invalid distance offsets during the experiment. To patch this issue, memory probe distances were set to the last valid offset produced by the QUEST procedure before it began to provide invalid offsets. As a result, the probe offsets varied between 1.26° and 1.36°. The blank display consisted solely of a uniform grey background. Finally, the perceptual judgment display was identical to that used in the feature-based attention experiments.

**Procedure.**

Participants completed 540 trials, separated into 6 blocks of 90. All trials began with a 400 ms fixation display. Following this display, participants were presented the memory sample dot, appearing to the left, right, or below the fixation cross for 400 ms, each with an equal probability of occurring. Participants were instructed to remember the location of this dot for a later memory test. A second fixation display followed the presentation of the memory sample dot, persisting for 3000 ms. Following this interval, the perceptual judgment display was presented for 50 ms, immediately followed by a blank display, which lasted until a response was given, or until 2000 ms elapsed. As with Experiment 1a, participants were required to report the orientation of the Gabor that appeared to be higher in contrast. This response was given by using either the Z or X key, to indicate that the left Gabor appeared higher in contrast (and was tilted left or right, respectively) or the N or M key, to indicate that the right Gabor appeared higher in contrast (and was tilted left or right, respectively). Finally, after the blank display, the memory probe display appeared, at which time participants were required to report
whether the probe dot appeared to the left or right of the memory sample dot, using the C and B keys, respectively.

Once again, this procedure provided three memory conditions that were used to assess the effect of memory on apparent contrast: Memory Congruent, Memory Neutral, and Memory Incongruent. Memory Congruent trials were those in which the memory sample dot appeared in the same location as the Test Gabor. Memory Neutral trials included the trials whose memory sample dot appeared at the location of neither the test nor the Standard Gabor (i.e., below the fixation cross). Finally, Memory Incongruent trials occurred when the memory sample dot appeared at the location of the Standard Gabor.

**Experiment 2b**

**Methods.**

As with Experiment 1, we ran an additional control experiment, Experiment 2b, in which participants were instructed to report the Gabor that appeared lower in contrast. This control experiment allowed for the determination of whether a response bias could account for the results of Experiment 2a. Other than the change in instructions, Experiment 2b was identical to Experiment 2a.

**Results**

Data analysis for Experiment 2 included the data 16 of the 30 participants whose data were collected. The criteria for inclusion in data analysis was as follows: (1) a participant needed to provide a correct response to the memory probe on at least 75% of all trials, thus insuring at least 15 observations per condition, and (2) the contrast judgments of a participant needed to be significantly correlated with the physical
contrast of the Test Gabor. Ten participants were excluded for having poor memory
accuracy, < 75%, and five were excluded for non-significant Spearman correlations
between Test Gabor Contrast and probability of choosing the Test Gabor, indicating that
the participant could not, or did not, reliably perceive differences in the contrast of
Gabor. It is evident that participants found the combination of a memory task and
perceptual task challenging, and a number of participants lacked the motivation or
ability to complete both with sufficient accuracy.

For those participants included in the data analysis of Experiments 2a and 2b,
average accuracy on the memory task was $M = 88.77\%, \ SD = 7.65\%$ and $M = 88.52\%,$
$SD = 7.06\%$ respectively. Memory accuracy was highest in the Neutral condition (when
the memory sample appeared below the fixation cross, and where no Gabor ever
appeared), $M = 97.31\%, \ SD = 4.66\%$, compared to the Memory Congruent and Memory
Incongruent conditions where the memory sample appeared at a possible Gabor
location, $M = 89.94\%, \ SD = 6.72\%$. A paired samples t-test revealed that this difference
was significant, $t(15) = 4.44, p < .001$. This result might seem peculiar until you consider
that the memory probe task was to detect a right or left displacement of the initial
memory sample. Neutral memory probes always appeared below the fixation cross, and
so the fixation cross probably provided a reference for the horizontal position of the
memory probe. The same strategy could not be used for probes that appeared at the
Memory Congruent and Memory Incongruent locations as these locations were
horizontally displaced from fixation. The critical point is that, overall, participants were
very successful in accurately reporting changes in the location of a remembered item.

To determine whether stimuli presented in a remembered location appeared
higher in contrast, contrast judgments were compared in three conditions, in a similar fashion to Experiment 1. The three conditions will be referred to as Memory Congruent, Neutral, and Memory Incongruent. Trials were Memory Congruent when the remembered stimulus appeared at the same location as the Test Gabor. Neutral trials were those in which the memory stimulus appeared at a location in which neither Gabor patch appeared (i.e., below fixation), and Memory Incongruent trials were those in which the memory stimulus was located in the position of the Standard Gabor, on the opposite side from the Test Gabor. Individual trials were excluded from analysis if an incorrect response was provided to the Gabor display (no response, or reporting the tilt of the chosen Gabor incorrectly), or if an incorrect response was given to the memory probe, indicating a failure to maintain a veridical representation of the memory stimulus. Once again, cumulative normal distributions were fit for each memory condition, summarizing the relationship between physical Test Gabor contrast, and perceived Test Gabor contrast. Overall goodness of fit, measured with $R^2$ for the Memory Congruent, Neutral, and Incongruent conditions were .79, .79, and .80, respectively. The variation in fit quality was quite high, with average $R^2$'s across the three conditions varying from .56 to .95 between participants. Figure 7 depicts the PSEs in the Test Cue and Standard cue conditions for each participant. No consistent effect of attention appears to be present across observers. Although we performed an analysis of the shift in PSEs for the three memory conditions, due to the relatively poor quality of some fits, the validity of this analysis is questionable. Therefore, while the parametric analysis will be included for completeness, our conclusions will be largely based on the non-parametric analyses. For the parametric analysis, no significant change in the PSE was found between the
Memory Congruent ($M = 0.30, SD = 0.10$) and Memory Incongruent ($M = 0.28, SD = 0.04$) conditions, $t(7) = 0.19, p = .85$. A plot of the mean contrast judgments for each memory condition is provided in Figure 8.

Our non-parametric analyses also failed to find evidence of a change in perceived contrast due to the contents of working memory. We conducted a 3 (Memory Condition) X 5 (Test Gabor Contrast) repeated measures ANOVA to investigate whether increasing contrast, or manipulating memory, altered the probability of reporting the Test Gabor as higher in contrast. The results showed a main effect of Test Contrast, $F(4,28) = 4.59, p = .006$. A significant linear contrast confirmed our expectation that increasing physical Test Gabor Contrast increased the likelihood of the Test Gabor being reported as higher in contrast, $F(1,7) = 9.75, p = .017$. We found no main effect of the memory condition, $F(2,14) = 1.16, p = .34$, and thus have no evidence that a Gabor appearing at a location held in working memory can increase perceived contrast. No significant interaction between memory and Test contrast was observed, $F(8, 56) = 0.71, p = .68$.

Figure 7. Plots of the PSEs for the Test Cue and Standard Cue conditions relative to the Neutral conditions for each participant in Experiment 2. Markers are expected to fall on the dotted line if no change in contrast occurs relative to the Neutral condition.
The results of our control experiment (Experiment 2b) paralleled the findings of Experiment 2a. Overall, we obtained much better fits in each Memory Condition, the mean Memory Congruent, Neutral, and Incongruent $R^2$ being .91, .87, and .87, respectively. Mean contrast judgments for each memory condition can be seen in Figure 9. No difference was found between the PSEs for the Memory Congruent condition ($M = 0.32$, $SD = 0.03$) and the Memory Incongruent condition ($M = 0.35$, $SD = 0.03$), $t(7) = 1.72$, $p = .13$. A 3 x 5 repeated measures ANOVA confirmed this finding, indicating no significant main effect of memory condition on the probability of reporting the Test Gabor.

![Figure 8](image_url)

**Figure 8.** For Experiment 2a, participants were instructed to report the Gabor with higher contrast. The graph depicts the proportion of trials where the Test Gabor was chosen for each Test Gabor contrast level, and for each memory condition. The dashed line indicates the contrast of the Standard Gabor patch. Error bars represent 1 SE.
as being lower in contrast, $F(2, 14) = 1.09, p = .363$. We did find the expected main effect of Test Gabor contrast, $F(4, 28) = 33.22, p < .001$, with a significant linear contrast indicating that as the Test Gabor increased in contrast, the probability of choosing it decreased, $F(1, 7) = 93.24, p < .001$. Again, memory and physical contrast did not interact significantly, $F(8, 56) = 0.95, p = .49$. Overall, these results corroborate our findings from Experiment 2a, further supporting the conclusion that holding a location in working memory has no impact on perceived contrast of a stimulus at that location.

As a final test of whether memory-driven attentional shifts might produce change

**Experiment 2b: Report Lower Contrast**

![Graph showing the proportion of trials where the Test Gabor was chosen for each Test Gabor contrast level, and for each memory condition. The dashed line indicates the contrast of the Standard Gabor patch. Error bars represent 1 SE.]

*Figure 9. For Experiment 2b, participants were instructed to report the Gabor with lower contrast. The graph depicts the proportion of trials where the Test Gabor was chosen for each Test Gabor contrast level, and for each memory condition. The dashed line indicates the contrast of the Standard Gabor patch. Error bars represent 1 SE.*
in perceived contrast, an index of the size of memory-driven shifts was correlated with the size of each observer’s shift in perceived contrast. The size of memory-driven shifts was operationalized by the increase in memory accuracy that occurred when the orientation of the Gabor that appeared on the remembered side was reported instead of the non-remembered side. As in Experiment 1, the size of the shift in perceived contrast was calculated by subtracting the PSE in the Standard Cue condition from the PSE in the Test Cue condition. In both Experiments 2a and 2b, there was no significant correlation between the memory benefit that accompanied an orientation discrimination at the remembered location and the change in appearance, \( r_s = -.39, .46; p_s > .05, \) respectively. This compliments the findings of our previous analyses, showing no consistent effect of memory location on perceived contrast across observers.

**Discussion**

The results of Experiments 2a and 2b provided no evidence that holding a location in memory produced a shift in apparent contrast. This null finding was unexpected because previous research has shown that the allocation of attention (both involuntary and voluntary) to a spatial location produces an increase in apparent contrast (Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco 2009; Liu, Abrams, & Carrasco, 2009; Störmer, McDonald, & Hillyard, 2009). While this suggests a dissociation between the contents of working memory and the allocation of spatial attention, we cannot, based on these experiments, be entirely confident that spatial attention was in fact oriented towards the location held in memory. Previous research has shown that spatial attention is drawn to a remembered location by demonstrating speeded processing of stimuli appearing at the remembered location (e.g., Downing,
Therefore, to ensure that spatial working memory actually was influencing spatial attention in our experiments, we conducted a third experiment. This experiment was intended to measure whether spatial attention was deployed to remembered locations by replacing the contrast judgment with a simple tilt discrimination judgment. If spatial attention is indeed oriented to remembered locations, tilt judgments should be made faster and more accurately when they are made on stimuli appearing in a remembered location.

**Chapter 5: Experiment 3**

In Experiment 3, participants completed trials that were as similar as possible to Experiment 2, in order to test whether spatial attention was allocated to the remembered location, as has been previously shown to occur (Awh & Jonides, 2001). The memory task was left identical, but instead of completing a comparative contrast judgment on two Gabors, participants simply reported the orientation of a single Gabor, which could appear in one of two locations. If attention indeed was allocated to the remembered location, orientation discriminations should improve at that location, either in accuracy or in speed. Memory accuracy should also suffer if discriminations are made in non-remembered locations, which presumably requires a shift in attention away from the remembered location.

**Methods**

**Participants.**

Twelve individuals, enrolled in the Psychology program as undergraduate or graduate students at Queen’s University, participated in Experiment 3. Participants were again required to have normal, or corrected-to-normal, vision. The data of four
participants was excluded from analyses, as discussed in the results section.

**Stimuli.**

The stimuli for Experiment 3 were identical to those used in Experiment 2, except for one alteration. Instead of being presented two Gabors in the perceptual judgment display, only one Gabor was presented, 3° to the left or right of fixation, and a solid coloured patch was presented on the opposite side of fixation, identical in size to the Gabor. The Gabor was identical to the Test Gabor from Experiment 2 – the solid coloured patch was the Standard Gabor drawn with zero contrast. The Gabor could therefore vary in colour (blue, yellow), tilt (-5° or 5°), and contrast, in the same intervals as all previous experiments, whereas the Standard patch could vary only in colour (blue, yellow). Compared to the previous experiments, the tilts were reduced to increase the challenge of the visual discrimination task.

**Procedure.**

The procedure of Experiment 3 closely followed that of Experiments 2a and 2b. Participants were again instructed to remember the location of the memory sample dot. The only change occurred during the retention interval. Instead of reporting the orientation of the higher contrast Gabor that was presented, participants simply had to report the location (left or right) and tilt (left or right) of a single Gabor patch. Responses were given using the same keys as in previous experiments: Z or X, indicating a leftward or rightward tilt of a Gabor appearing on the left, and N or M, indicating a leftward or rightward tilt of a Gabor appearing on the right. Figure 10 depicts a sample trial from this experiment. Response times and accuracy of tilt discriminations were recorded.
Results

Analyses were performed on eight of the 12 participants’ data. Four participants were excluded from analyses; two that did not provide responses on the memory task, and two that performed at chance on the tilt discrimination. In both cases, this likely indicates poor motivation, given the high accuracy rates that other participants were able to attain.

Figure 10. A sample trial from Experiment 3. Participants were instructed to remember the location of the memory sample (small dot) for a memory test at the end of the trial, and to report the location and tilt of the Gabor in the Perceptual Judgment display.
To determine whether holding a location in memory involved a shift in attention to that location, performance was examined under three conditions: Memory Congruent, Memory Neutral, and Memory Incongruent. The three conditions summarized the relationship between the location of the memory stimulus on a trial, and the location of the Gabor patch that had to be reported on during the retention interval. We then examined whether memory congruency had an effect on three performance indices: accuracy of tilt discrimination for the single Gabor that was presented, response latencies for the tilt discrimination, and memory accuracy (whether the memory probe was correctly classified as being shifted left or right).

A summary of the tilt discrimination performance (both accuracy and response time) and memory performance in the three memory-congruency conditions is provided in Table 1. Memory congruency had no effect on participants’ ability to correctly report the tilt of a Gabor patch or the response latency with which they made their reports, as revealed by two repeated measures ANOVAs, $F(2,14) = 0.191, p = .83$ and $F(2,14) = 2.49, p = .12$, respectively. We did find a significant main effect of memory congruency

---

**Mean Tilt Discrimination Accuracy and Response Time and Memory Accuracy as a Function of Memory Congruency**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Accuracy (%)</th>
<th>Response Time (ms)</th>
<th>Memory Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Congruent</td>
<td>88.6 (8.5)</td>
<td>925 (121)</td>
<td>81.7 (16.1)</td>
</tr>
<tr>
<td>Memory Neutral</td>
<td>90.1 (7.7)</td>
<td>930 (102)</td>
<td>96.1 (3.8)</td>
</tr>
<tr>
<td>Memory Incongruent</td>
<td>89.6 (7.7)</td>
<td>897 (87)</td>
<td>82.3 (14.9)</td>
</tr>
</tbody>
</table>

*Table 1. Mean Accuracy, Response Time, and Memory Accuracy for each Memory Condition. Standard deviations are listed in parentheses.*
on the subsequent accuracy of memory reports, $F(2,14) = 6.97$, $p = .03$, but a paired-samples $t$-test revealed that this effect was due to memory accuracy being significantly higher for the Neutral condition than for the Memory Congruent and Memory Incongruent conditions, $t_s(7) = 3.27, 3.46; ps = 0.01$. Furthermore, the memory accuracy of the Memory Congruent and Incongruent conditions was not significantly different, $t(7) = 0.41, p = .70$. Whether the tilt discrimination occurred on the remembered side or not, then, did not appear to interfere with the memory’s fidelity, which might have occurred were attention involved in preserving the memory trace. For the same reason described in Experiment 2, the greater accuracy for the Neutral condition was likely due to the fact that the memory test involved determining whether a memory probe stimulus appeared left or right of a sample stimulus, and in the Neutral condition, the memory probe appeared below the fixation cross, which would allow the fixation cross to serve as a reference for the horizontal displacement of the probe relative to the sample stimulus. This benefit was not available in the other two memory conditions.

Overall, the analyses of Experiment 3 suggest that spatial working memory has no impact on perceptual tilt judgment discrimination. Therefore, there is no evidence from this experiment that spatial working memory influences the allocation of spatial attention.

**Discussion**

Our data do not show any evidence of an influence of spatial working memory on spatial attention, nor do they provide evidence of an influence of spatial attention on spatial working memory. Remembering a location did not improve visual discrimination
performance in that location, and reporting a stimulus that appeared in a non-
remembered location did not interfere with spatial memory, trends that would be
expected if remembering a location required one to attend to that location. These results
contradict earlier findings showing that attention and spatial working memory do seem
to be related (Awh, Jonides, & Reuter-Lorenz, , 1998; Awh, et al., 1999). We have
considered that our null effects could be due to a limitation in our procedure. By using a
memory sample to memory probe offset distance of ~1° visual angle in our memory
task, we inadvertently presented probes at locations in which memory samples were
never presented. All Memory Congruent and Incongruent memory samples were
presented at the locations of subsequent Gabor patches, which themselves only
subtended 1° of visual angle. This means that the memory task manipulation might
have failed in that participants could complete the memory probe task without holding
the location of the memory sample in working memory; participants only needed to
employ a strategy of comparing the location of a memory probe to the Gabor that
preceded it, and the offset of the memory probe relative to the Gabor would provide
sufficient information for an accurate response.

We investigated the possibility that subjects learned this strategy. If it was a
learned strategy, then participants may not have employed it during early trials, but in
later trials may have employed it so that in these later trials they did not hold the
memory samples in working memory. Figure 11 depicts the mean difference in
response times between congruent and incongruent memory trials throughout the
experiment, bordered by a 95% confidence interval. Each trial’s response time
difference was calculated using a moving-window procedure, averaging response times
from 10 trials before and 10 trials after the labeled trial. This provides an index of whether remembering a location facilitated tilt judgments at that location compared to when an opposite location was to be remembered. If participants learned that they could complete the task without remembering the memory sample’s location at all, we would expect to see an early response time benefit that decays quickly. From an examination of the data, there appears to be no evidence for an early attentional benefit that then disappears in later trials; basically, a zero-magnitude attentional benefit is consistently found within the confidence intervals of the estimated response time difference,

**Tilt Discrimination Benefit Due To Memory**

![Graph showing Tilt Discrimination Benefit Due To Memory](image)

*Figure 11. Estimated difference in response times for Memory Congruent trials and Memory Incongruent trials, with 95% confidence intervals. Estimates were obtained by averaging response times for 21 trials; 10 before and 10 after the indicated trial, providing approximately 7 observations for each RT estimate. A positive response time indicates that when a memory sample appeared in the same location as a subsequent visual discrimination, the discrimination was made faster.*
indicating that the benefit is never reliably different from zero.

In sum, our data do not provide support for the notion that spatial working memory can influence spatial attention in the experimental paradigm we used. Therefore, to test the effect of working memory on appearance, clearly a revised working memory task must be implemented. To this end, we have begun to collect data using a match-to-sample paradigm, where all memory probes are selected from the same pool as memory samples, ensuring that subjects must actively store the location of the memory sample to achieve successful performance.

Chapter 6: General Discussion

In the present study, we examined whether feature-based (Experiment 1) and memory-driven attention (Experiment 2) altered the perceived contrast of visual stimuli. Spatial attention, both involuntary and voluntary, has consistently been shown to increase the perceived contrast of an attended Gabor patch (Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco 2009; Liu, Abrams, & Carrasco, 2009; Störmer, McDonald, & Hillyard, 2009). In Experiment 1, we measured the perceived contrast of Gabors while manipulating feature-based attention to a colour. Our results were inconsistent with the hypothesis that attention to a Gabor’s colour produces an increase in its perceived contrast. Instead, results from Experiment 1 were more consistent with a response bias account such that attending a colour simply increases one’s tendency to report the Gabor that was the same colour.

Experiment 2 addressed whether holding a location in working memory would produce an increase in perceived contrast for a Gabor presented at that same location. This question was motivated by previous research showing that spatial attention is
involved in the maintenance of a location in memory (Awh, Jonides, & Reuter-Lorenz, 1998; Awh, et al., 1999). The results of Experiment 2 indicated neither an increase nor a decrease in perceived contrast due to the remembered location, thus providing no evidence for the hypothesis that spatial working memory can influence perceived contrast.

**Voluntary Feature-Based Attention**

In Experiment 1, we showed that feature-based attention to a colour does not influence the perceived contrast of a Gabor stimulus. This conflicted with previous research on spatial attention that showed that attending the location of a stimulus causes it to be reported as having more contrast than when it is not attended (Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco 2009; Liu, Abrams, & Carrasco, 2009; Störmer, McDonald, & Hillyard, 2009). Our results therefore suggest that attending to a colour and attending to a location may have different consequences for our perception of the visual world.

The perceptual change due to spatial attention is believed to reflect modulations in the activity of neurons in the visual cortex (Treue, 2004). When a location is attended, neurons in extrastriate area V4 whose receptive fields fall within that location show increased firing to stimuli presented in their receptive fields (Reynolds, Pasternak, & Desimone, 2000). The dynamics of this modulation in activity do not appear to be the result of an amplification of a neuron’s response (response gain); instead the authors suggest that attention operates by a *contrast gain* mechanism. Such a mechanism operates in a way that mimics increasing physical contrast: a neuron will respond more vigorously with attention, and its firing rate will also saturate at a lower stimulus contrast.
The result of this mechanism is a shift in a neuron’s contrast-response function leftwards, allowing it to respond to a given stimulus as though it had more contrast (Reynolds, Pasternak, & Desimone, 2000). Therefore, when attention is directed to the location constituting a neuron’s receptive field, less contrast is required to produce a criterion response. Changes in the appearance of an attended stimulus may therefore be a sort of epiphenomenon, not serving a functional role at the level of awareness, but rather resulting from mechanisms used to enhance stimulus salience in visual cortex due to a contrast gain mechanism of attention.

Since the seminal work on attention and appearance however, neurophysiological studies of spatial attention have produced results that are better accounted for by response gain mechanisms, which produce changes in a neuron’s response that do not mimic the changes produced by incrementing physical contrast (Williford & Maunsell, 2006). Recently, two models have proposed that the mechanism of attention is a general reduction in the normalization factor that is applied to a visual neuron’s response. Normalization here is the degree to which a neuron's response is attenuated by the overall activity of the neural population; a mechanism that allows neurons to code relative changes and be less drastically affected by differences in overall stimulation. These models demonstrate that both contrast gain and response gain can result from attention modulating the degree of normalization applied to a neuron. While these recent interpretations complicate the issue of how to relate the reported psychophysical data to the neural dynamics of attention in visual cortex, the following discussion will consider our findings assuming that changes in perceived contrast reflect attention’s affect on perceptual representations in visual cortex.
Alternative interpretations are discussed afterwards.

The results of our study showed that attending to a feature of a stimulus, in this case, colour, did not alter the appearance of the visual stimulus. Instead, feature-based attention may have produced a response bias – increasing the tendency to select a stimulus for a response if it is attended, regardless of the task instructions. Such a response bias has been ruled out in studies of spatial attention (e.g., Carrasco, Ling, & Read, 2004; Gobell & Carrasco, 2005; Liu, Abrams, & Carrasco, 2009), and so our results suggest that feature-based attention may operate by a different mechanism than spatial attention. Being a behavioural study, our results can only provide coarse distinctions between the mechanisms of spatial and feature-based attention.

Our results suggest that feature-based attention does not operate by boosting the contrast of early visual cortex representations for attended stimuli, as is proposed for spatial attention (Reynolds, Pasternak, & Desimone, 2000). This is an unexpected finding because previous research has shown that feature-based attention does increase the responses of visual neurons that match the attended feature, suggesting a gain mechanism (Treue & Martinez-Trujillo, 1999; Martinez-Trujillo & Treue, 2002). Based on such findings, one would expect feature-based attention to have boosted the perceived contrast of attended stimuli in the current study. Treue and Martinez-Trujillo's Feature Similarity Gain model posits that attention operates by increasing or decreasing the response of neurons that code an attended feature, to the degree that they match (or do not match) the attended feature-value. It is critical to note that although we directed participants' attention to stimuli based on their colour, our dependent measure was the perceived brightness contrast of those stimuli, and so our results do not
necessarily contradict the Feature Similarity Gain model. Rather, they demonstrate that
feature-based attention and spatial attention have different effects on the apparent
brightness contrast of stimuli.

While it was surprising that attention failed to increase perceived contrast, there
may be stimulus attributes other than contrast whose appearance could be modulated
by feature-based attention. In particular, feature-based attention may produce feature-
specific perceptual changes. This would differ from the observed effects of spatial
attention, which appears to influence numerous stimulus attributes: contrast (Carrasco,
Ling, & Read, 2004; Liu, Abrams, & Carrasco, 2009), spatial frequency, spatial
resolution (Gobell & Carrasco, 2005), motion coherence, flicker rate (Liu, Fuller, &
Carrasco, 2006), colour saturation (Fuller & Carrasco, 2006), speed (Turatto, Vescovi, &
Valsecchi, 2007), and size (Anton-Erxleben, Henrich, & Treue, 2007). In contrast, the
effect of feature-based attention might be more specific such that attention to a
particular feature only modulates the appearance of that feature. For example, attention
to colour may only alter the perceived colour contrast or colour saturation of stimuli.

This difference in the scope of the effects spatial attention when compared to
feature-based attention can be understood in terms of the Feature-Similarity Gain model
introduced earlier (Treue & Martinez-Trujillo, 1999). This model proposes that attention
increases the gain of neurons that code an attended feature. Because visual neurons
have spatially restricted receptive fields, location can be seen as a feature that is coded
throughout the visual cortex. This means that when attending to a location, the
responses of a wide variety of neurons (e.g., those that code orientation, colour, motion,
and so forth) will be amplified because they code those features for a given location.
Neurons that code features such as colour are not as ubiquitous (i.e., restricted to sub-regions of V1, V2, and V4; Heywood, Gadotti, & Cowey, 1992) and so the effect of attention to colour ought to be restricted to altering the appearance of attributes coded by colour-selective neurons.

Neuroimaging studies have shown that attention to a particular feature will modulate processing in cortical regions that are specialized for processing that feature. For example, attention to a particular direction of motion will modulate processing in areas MT and V3 (Büchel et al., 1998), and attention to faces selectively increases activity in the fusiform face area (Wojciulik, Kanwisher, & Driver, 1998). Therefore, it should be emphasized that this study does not conclusively rule out a role of feature-based attention on stimulus appearance, but does speak to the limits of any such modulation. Further investigations should address whether feature-specific stimulus attributes are altered with attention to these features (e.g., altered speed perception when attending to motion).

The differential effect of feature-based and spatial attention on contrast perception indicates that these two modes of attention modulate perceptual processing in unique ways. We take this as evidence that the two modes of attention are at least partially independent, neural mechanisms. Additional evidence that spatial attention and feature-based attention are distinct mechanisms, rather than simply modes of operating within a single mechanism, comes from research linking shifts of spatial attention to eye movements (Crawford & Muller, 1992; Doyle & Walker, 2001; Moore & Fallah, 2001; Müller, Philiasiades, & Newsome, 2005). Feature-based attention, on the other hand, does not involve orienting to locations, but to stimulus attributes, ruling out the
possibility that systems controlling saccades could also orient feature-based attention. The extent to which feature-based and spatial attention mechanisms differ is not yet understood, but our data suggest that in addition to involving separate or partially independent control systems, feature-based attention may modulate different aspects of visual processing.

The results of Experiment 1 also correspond well to the finding that working memory does not alter perceived motion, reported by Turatto et al. (2008). In these experiments, participants judged the contrast of coloured Gabors while holding an object feature (colour or orientation) in memory. The authors found no effect of the memory manipulation on participants’ contrast judgments. We have suggested that feature-based attention may selectively alter appearance only within the attended dimension (e.g., if attending red, perceived saturation and hue may be modulated, but not perceived brightness contrast). If our interpretation of our findings is correct, Turatto et al.’s results are not surprising. The authors’ previous work showed that spatial attention altered the perceived motion of stimuli (Turatto, Vescovi, & Valsecchi, 2007). Therefore, holding an object feature in working memory should not be expected to prompt a spatial deployment of attention, rather it should engage feature-based attention.

Spatial Working Memory

In Experiment 2, we expected that holding a location in working memory would cause an increase in the perceived contrast of a stimulus presented at that location. We expected this result because holding a location in working memory is associated with similar neural and behavioural outcomes to those seen when voluntarily attending to
that location (Awh et al., 1999; Awh & Jonides, 2001) and because spatial attention, both voluntary (Liu, Abrams, & Carrasco, 2009) and involuntary (Carrasco, Ling, & Read, 2004), lead to an increase in perceived stimulus contrast. The results of Experiment 2 indicated that no change in perceived contrast occurred at locations being held in working memory. This is most likely due to a procedural limitation in our study that allowed participants to complete the working memory task without actively storing the memory sample during the period in which the Gabor stimuli appeared. In order to resolve whether maintenance of a location in working memory alters the appearance of stimuli in the same way that voluntary spatial attention does, a future experiment is needed with a revised memory task that will ensure the engagement of working memory.

Our study is not the first to have failed to demonstrate attention-like change in performance by manipulating working memory. A number of studies have failed to find evidence for an influence of working memory on attention (Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Woodman & Luck, 2007). It seems that small variations in task parameters are able to nullify or change the relationship between the contents of working memory and attention. The way that an item is represented in working memory can then dictate whether or not it influences attentional capture. It is not clear whether the reason our study also failed to find an attentional effect is that participants were not storing the memory sample in working memory, or whether some other methodological element caused memory and attention to operate independently. Olivers (2009) has shown that when the target in a search task varies from trial to trial, presence of a memory-matching item in the search display has no impact on search performance. The
author suggests that this is due to prioritization of the search target's representation in working memory over the memory target's representation. In contrast, when the search target is constant, it does not exert as high a load on working memory. In our experiment, the perceptual task's target was always defined the same way (e.g., report the orientation of the higher contrast Gabor). Given this constant target definition, we were surprised that working memory contents did not impact attentional processing in our experiments.

Even though our memory task could have been successfully completed without necessarily storing a representation of the memory sample, this non-memory strategy would not be immediately evident and would need to be learned through experience with the trials. If such a non-memory strategy was learned, then early trials prior to learning might show the expected effect of spatial working memory on discrimination performance (Experiment 3). However, our analyses showed no evidence that spatial working memory impacted discrimination performance at any stage of the experiment. It should be noted that our analysis is insensitive to rapid learning (i.e., less than 10 trials). In any case, we can conclude that in Experiment 2, no memory-based shifts of attention occurred, which may explain the lack of an effect on perceived contrast. In sum, based on the limitations in our study, we can not rule out the possibility that holding a location in working memory could increase the perceived contrast of stimuli that appear in that location.

**Response Biases**

One additional surprising finding was an indication of a response bias in Experiment 1. Thus far, no studies using Carrasco's paradigm (Carrasco, Ling, Read,
2004) have shown an overall increase in reporting a stimulus due to attention – control experiments have always supported the conclusion that attention shifts perceived contrast, and have ruled out the conclusion that response biases influence the results. It has, though, been reported that effect sizes tend to be smaller in control conditions (discussed in Anton-Erxleben, Henrich, & Treue, 2007). Our finding of a response bias suggests a possible reason for the difference in effect sizes. That we found a response bias in our study can be seen as evidence that the two-alternative forced choice paradigm used in this and previous studies simultaneously measures response biases and perceptual changes. If this interpretation is correct, then that would explain the reduction in observed effect sizes in control experiments requiring participants to report the stimulus with less of a given attribute. In general, when reporting more of a given attribute, the effect of attention on perceived contrast and the bias to respond with the attended stimulus will add together producing an inflated estimate of perceived contrast. On the other hand, when reporting less of a given attribute, the response bias will work against the effect of attention on perceived contrast producing an underestimate of perceived contrast. In addition, our results show that multiple, competing effects of attention may be present when using the two-alternative forced choice method employed in recent studies of attention and appearance.

**Decision Biases**

Although the psychophysical results showing that attention alters appearance have been interpreted as linking neurophysiological findings with perceptual consequences (Treue, 2004), there has been marked skepticism towards this interpretation. Earlier investigations of attention’s affect on appearance, using different
paradigms, produced entirely different conclusions: Tsal et al. (1994) reported that spatial attention reduces the perceived contrast of a stimulus with the background, while Prinzmetal et al. (1997) reported no change in appearance with attention, only reduced variance in perceptual matching responses. These previous studies presented single stimuli, attended or unattended, and required participants to match the appearance of stimuli to a reference scale either in memory, or presented with the stimuli. Carrasco and colleagues have criticized these approaches on the grounds that participants may be, in one case, relying on possibly unreliable memory traces for stimulus comparison, and in the other case, be shifting covert or overt attention during the process of comparing a stimulus to the matching sample (Carrasco, Ling, & Read, 2004). Carrasco’s paradigm does not escape criticism either, as participants must be attending both Gabor stimuli in order to even make a comparison (Schneider, 2006).

Alternative accounts of the behavioural data gathered using the Carrasco paradigm have been proposed that do not involve any change in stimulus appearance. Schneider and Komlos (2008) have suggested that the heightened tendency to report an attended stimulus as having more of a given attribute (contrast, spatial frequency, size, et al.) is not due to any change in the perceptual representation of a stimulus, but is due to a bias at the decision level. Attention increases the salience of a stimulus, which biases observers to alter their decision about its appearance. It is not perfectly clear how the increase in salience leads participants to consistently report a stimulus as having higher contrast. The authors have proposed that observers decide which Gabor patch has higher contrast by default, and invert their responses if necessary (i.e., in a control condition when told to report the lower contrast Gabor). The key aspect of this
theory is that it states that no change in the appearance of stimuli occurs due to attention, but that attention operates at a post-perceptual, decisional stage that occurs before response selection. This hypothesis has received support from psychophysical studies requiring participants to report whether two stimuli are the same or different (Schneider & Komlos, 2008; Valsecchi, Vescovi, & Turatto, 2010), although this task has been criticized as being less sensitive to the subtle perceptual changes caused by attention (Anton-Erxleben, Abrams, & Carrasco, 2010).

An additional hypothesis proposed by Prinzmetal (2008) contends that the apparent increase in contrast in psychophysical studies of attention is due to a reduction in the detection criterion for cued stimuli. If the Gabor stimuli used are not sufficiently above threshold, participants may be likely to report a cued Gabor as having higher contrast because the cue has led them to believe that there is more of a signal at the cued location (i.e., more contrast). Requiring participants to report the stimulus with less contrast does not control for this possibility, as a stimulus with more contrast constitutes a more detectable stimulus, and so stimuli appearing at a cued location will still be thought to be higher in contrast. The authors have shown that when detecting the presence of Gabors in a paradigm similar to Carrasco’s, attention does not improve perceptual sensitivity, but instead promotes a more liberal detection criterion (Prinzmetal, Long, & Leonhardt, 2008). Furthermore, Prinzmetal et al. found that attentional cues led participants to erroneously report stimuli with no contrast at all as having higher contrast than uncued Gabors, a result which cannot be due to contrast enhancement, as no contrast existed to be enhanced.

Because there are still multiple accounts for the effect of attention on
appearance, new paradigms and stimuli will need to be developed that will allow for
differential predictions from these competing accounts. Differentiating between the post-
perceptual and perceptual accounts is not straightforward, as the two types of
hypotheses make many of the same predictions. For example, Prinzmetal's (2008)
hypothesis predicts that as stimuli are brought into the supra-threshold range, the effect
of attention should disappear. A perceptual account that is informed by
neurophysiological evidence will make the same predictions: as stimuli become higher
contrast, the response of visual neurons begins to saturate, and the effect of attention
goes away.

One approach that we have adopted to resolve the debate is to use stimuli that
change in appearance qualitatively when contrast is manipulated. In this approach, we
are not examining how attention might quantitatively shift the appearance of a stimulus,
rather we are examining whether attention can produce a categorical change in the
perception of the stimulus. A candidate for such stimuli are gender-ambiguous faces,
which have been shown to shift their apparent gender when contrast is manipulated
(Russell, 2009). We have preliminary data that shows that increasing the contrast of a
face leads to an increase in the apparent maleness regardless of response instructions
(i.e., report the male face or report the female face), but spatial attention's effect
reverses depending on instructions (Rajsic & Wilson, 2011). If participants are instructed
to report the male face, attention increases the chances of a face being chosen as
male, but if participants must report the female face, attended faces are reported as
more female. This finding suggests that the effect of attention is not in fact perceptual,
but that it causes a post-perceptual bias to select a face as having more of what is
being searched for. This conclusion does not fit well with physiological data, which demonstrate real changes in the supposed anatomical correlates of perception (Martinez-Trujillo & Treue, 2002; Reynolds & Chelazzi, 2004; Reynolds, Pasternak, & Desimone, 2000).

It should be stressed that the perceptual and decision bias accounts do not need to be seen as mutually exclusive. It is possible that each account may contribute to our understanding of attentional effects. We suggest that the key to teasing these accounts apart is by using a more diverse range of methods to measure changes in appearance with attention; branching off from simply using two-alternative forced choice procedures. In addition, we must note that whether the effect of attention is perceptual or not ought not to affect the validity of our test of the overlap of working memory and attentional processing. If working memory is the means by which voluntary attention is guided, then any behavioural change that occurs with voluntary attention ought to be brought about by the appropriate working memory manipulation as well, whether the behavioural change results from a perceptual effect or a decisional effect.

Conclusion

In the present study, we sought to uncover whether there are perceptual consequences to attended non-spatial features of stimuli (colour), or to holding a location in memory. Previous work has shown that shifting spatial attention to a stimulus increases its apparent brightness contrast (Carrasco, Ling, & Read, 2004; Liu, Abrams, & Carrasco, 2009). Our work demonstrates that attending the colour of a stimulus does not alter its perceived brightness contrast, which implies that feature-based attention and spatial attention alter early visual processing in distinct ways. In addition, we
investigated the impact of holding a location in working memory on contrast perception. We found no evidence that spatial working memory produced a shift in appearance, but Experiment 3 indicated that the memory task we used did not produce a shift in attention at all. Additional experiments are necessary to fully resolve the issue of why in our study holding a location in memory did not shift attention. It will be critical to employ a task that does not allow participants to accurately classify memory probes without actively storing the memory sample. This can be accomplished by ensuring that memory sample stimuli and memory probe stimuli are always selected from the same pool of locations. Although our study does not resolve the question of whether visual working memory can produce an attention-like shift in appearance, we show that the link between working memory and attention may not be as strong as theories of attention assume (Desimone & Duncan, 1995; Knudsen, 2007; Postle, 2006).


Appendix A: General Research Ethics Board Approval

February 4, 2011

Mr. Jason Rajacic
Department of Psychology
Queen’s University
c/o 49 Main St.
Kingston, ON K7K 3Y5

Dear Mr. Rajacic:

GREB Ref #: GPSYC-517-11
Title: "The Effects of Visual Working Memory on Appearance"

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "The Effects of Visual Working Memory on Appearance" for ethical compliance with the Tri-Council Guidelines (TCPS) and Queen’s ethics policies. In accordance with the Tri-Council Guidelines (article D.1.6) and Senate Terms of Reference (article G), your project has been cleared for one year. At the end of each year, the GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, if applicable, of any adverse event(s) that occur during this one year period (details available on webpage http://www.queensu.ca/ors/researchethics/GeneralREB/forms.html – Adverse Event Report Form). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example you must report changes in study procedures or implementations of new aspects into the study procedures on the Ethics Change Form that can be found at http://www.queensu.ca/ors/researchethics/GeneralREB/forms.html - Research Ethics Change Form. These changes must be sent to the Ethics Coordinator, Gail Irving, at the Office of Research Services or irvingg@queensu.ca prior to implementation. Mrs. Irving will forward your request for protocol changes to the appropriate GREB reviewers and / or the GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Joan Stevenson, PhD
Professor and Chair
General Research Ethics Board

c.c.: Dr. Daryl Wilson, Faculty Supervisor
Dr. Leandre Fabrigar, Chair, Unit REB
Marie Tooley, Dept. Admin.

JS/gi
Appendix B: Research Ethics Change Form

Research Ethics Change Form
Submitted to the General Research Ethics Board

To make changes or additions to an approved ethics application, please complete and return this form and revised documents to the Research Ethics Office in 302C Fleming Hall-Jemmott Wing. It is also acceptable to email these materials and additional revised items to Gail Irving at irvingg@queensu.ca

TITLE OF RESEARCH PROJECT:
The Effects of Visual Working Memory on Appearance

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<tbody>
<tr>
<td>Principal Investigator</td>
<td>NAME</td>
<td>DEPT./ADDRESS</td>
<td>PHONE</td>
</tr>
<tr>
<td>Jason Rajsic</td>
<td>Psychology Dept. 62 Arch St.</td>
<td>613-531-1007</td>
<td><a href="mailto:jason.rajsic@queensu.ca">jason.rajsic@queensu.ca</a></td>
</tr>
<tr>
<td>Supervisor</td>
<td>Daryl Wilson</td>
<td>Psychology Dept. 62 Arch St.</td>
<td>613-533-2611</td>
</tr>
<tr>
<td>Co-investigator</td>
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1. Please describe all changes you wish to make to your approved ethics application and attach any revised or new documentation to support the changes.

I would like to expand my participant recruitment procedure to include undergraduates recruited via e-mail (using the same recruitment message as before) or via the Psychology Subject Pool, where a profile for my study will be created, containing the same information as the e-mail message.
I will also require only one 1-hour session to be completed per participant, at $10/session, instead of requiring each participant to complete 2 sessions.

2. Will these changes result in a different test or test instrument (questionnaire, etc.)?
   Yes [ ]  No [X] If yes, please submit.

3. Will these changes result in a revised Letter of Information and Consent Form?
   Yes [X]  No [ ] If yes, please re-submit and highlight the changed sections.

4. How will these changes affect the potential benefits to the participants?
   Completing only one session will be increase the convenience of participation.

5. How will these changes affect the potential risks of the study and what safeguards are in place?
   The potential risks of the study will not be changed.

6. How will these changes affect the privacy and confidentiality originally offered to the participants?
   The privacy and confidentiality offered will not be changed.

7. Do these changes alter any deception involved in the study? If so, please explain modified procedures.
   No changes will occur to deception involved in the study.

Principal Investigator's Signature

Supervisor or Co-Investigator's Signature

Date: 03/25/2011