LATERAL BIASES IN ATTENTION AND WORKING MEMORY SYSTEMS

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ABSTRACT

Neurologically healthy individuals misbisect their visual space by erring towards the left. This misreprentation has been attributed to the right hemisphere dominance in processing of spatial information. Lateral biases are thought to emerge as behavioural outcomes of cognitive processing, mainly attention. Recently, attention mechanisms have been reported to be closely inter-related to memory systems, where attention directs what will be remembered and memory impacts where attention is directed. Although spatial biases attributed to attention have been widely accepted, the claim that memory exhibits similar biases has been more controversial. Recent research shows that recall of representations is biased towards the left side of space, indicating that lateral asymmetries may not necessarily be limited to perceptual and attentional mechanisms, but may extend to memory mechanisms as well.

The purpose of this work is to understand better the relationship between lateral biases within working memory and attention interactions. Two approaches were considered. First, working memory, as defined by the representations and operations related to manipulate the representations, used time delay and visual load. Second, backward masking was used to control the relative formation of the working memory trace, which strengthens with recurrence of the visual stimuli and is through to progress from attention to working memory. To explore these two theoretical avenues, a novel task was constructed. Two circular arrays were presented at the top and bottom of the computer screen. These arrays were composed of six individual discs of varying shade. Hence, the overall array represented a greyscale gradient, where discs on one lateral side were darker compared to the middle discs and the other lateral side. For example, if two darkest discs were presented on the left side, the lightest discs were presented on the right side. Such array was presented with its left/right mirror reversed image. In this example, the second array was with the lightest discs on the left side and growing progressively darker, with darkest discs on the right side. Such presentation requires the participants to integrate the array of individual discs into an overall representation to perform a brightness judgment and select the array seemingly darker.

A total of six behavioural studies addressed the two theoretical approaches. The first approach, to determine the impact of inter-stimulus time interval and visual load on lateral asymmetries, was addressed in four experiments. The findings indicated that participants were able to integrate the discrete disks into an overall array. Participants exhibited an overall leftward bias similar to that obtained in attention tasks, where they selected an array to be overall darker when the darkest disks were presented on the left side of the array. Furthermore, these biases increased the most when the stimuli were presented in the lower half of the computer screen, consistent with the lower visual field. Conversely, stimuli presented to the upper half of the screen elicited a rightward bias, which is consistent with the upper visual field. Stronger biases were observed when the stimulus noise, in the form of black, white and grey pixels, was relatively low and weaker biases were attained with a relatively high noise levels. In the second study, the findings showed that the magnitude of upper and lower visual field biases shows dependence on the vertical and lateral stimulus manipulation within these fields. Upper-left, lower-right interactions indicate that biases may not simply rely on the horizontal and vertical dimensions, as previously thought, but also on the relative spatial distribution of stimuli within these dimensions. The third study, which used the standard rectangular greyscale stimuli, revealed that visual load does not impact the lateral biases, but shows to impact the upper and lower visual field processing. Further, time interval between stimulus presentation and response, extended past 1 second eliminated lateral and vertical biases.

The remaining two studies investigated lateral asymmetries within working memory by selectively manipulating the formation of working memory trace using backward masks. The presence of a mask, following a stimulus, inhibits the memory trace formation for that stimulus. Conversely, if no mask is presented following the stimuli, the memory trace is permitted to form within working memory. Again, using the circular array task, participants were required to select the overall darker array while retaining either a shade of position information from the array within their working memory. Findings showed increased rightward biases when memory trace was permitted to form with longer inter-stimulus (3 sec) time interval, as compared to shorter (0 to 1 sec) time interval. In the last study, the participants were required to make brightness judgment while maintaining either a position or shade information within working memory to determine whether previously acquired information, which does not serve as a cue, impact the brightness judgment task. Rightward biases were evident when participants were required to maintain either a position or shade information relating to the array, but did not provide any cue-type of information, which could facilitate performance. Rightward biases were stronger while retaining position information and completing the brightness task, hence indicating a spatial nature of the bias. As well, stronger rightward biases were obtained when the to-be-remembered position information was allowed to create a memory trace. Furthermore, recall accuracy of the position information was increased when the memory trace was permitted to form, indicating involvement of working memory processes. Overall, the data attained in this set of experiments can be interpreted using the activation-orientation model presented by Reuter-Lorenz (1990) indicating that this model may also be valuable when integrating working memory in addition to attentional processes.

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What a journey. I still remember how I felt holding my acceptance letter to the U of S graduate program. I remember the overwhelming feeling of what is to come, the excitement, anticipation, and thrill of this privilege. I thought I was so lucky. I could not wait to make the 3000 km trip in my 2003 Pontiac Sunfire from Windsor to Saskatoon. It was a short while between receiving that letter and my big trip. With the blessings from my undergraduate supervisor and my family, I packed my car as much as could with all my belongings and prepared for the trip of a lifetime. What I did not anticipate was that I was not only making a trip to attend a graduate program, but I was beginning a journey that would redefine me as a person: A journey that would challenge me intellectually, professionally, and personally.

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LIST OF ABBREVIATIONS

Abbreviation	
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ERP	Event related potential
fMRI	Functional magnetic resonance imaging
LGN	Lateral geniculate nucleus
LVF	Lower visual field
M	Mean
SE	Standard error of the mean
TPJ	Temporo-parietal junction
UVF	Upper visual field
V1	Primary Visual cortex

CHAPTER ONE

GENERAL INTRODUCTION

It is difficult to image not being able to respond to, orient, or even acknowledge one side of our external space. Yet, patients with hemispatial neglect consistently fail to eat from the left side of their plate, dress the left part of their body, or orient any of their attention to the left side of space. To them the left side does not exist. These patients have suffered neural damage typically to their right hemisphere and as behavioural outcome express hemispatial neglect (Heilman, Velenstein, & Watson, 2000). As the sensory and motor processes remain intact, the disorder represents a failure in perceptual and attentional processing of visuospatial information (Bartolomeo, de Schotten, & Chica, 2012). The critical neuronal regions involved in neglect include the parietal and frontal cortices as well as several subcortical structures, such as the pulvinar nucleus of the thalamus and the superior colliculus (Bartolomeo & Chokron 2001; 2002; Bartolomeo, de Schotten, & Doricchi, 2007; Bisiach & Vallar, 1988; Heilman, Watson, & Valenstein, 1993; Mesulam, 1985; 1981; Parton, Malhotra, & Husain, 2004; Vallar, 2001). This variance of implicated neuronal regions suggests that attentional spatial processes that may be disrupted emerge from an interaction of several large-scale networks (Bartolomeo et al., 2007; Mesulam, 1981; Heilman et al., 1993).

Variations in magnitude and, at times, direction of hemispatial neglect occur under various contexts and the full spectrum of the involved neurocognitive processes remains controversial. Deficits resulting in hemispatial inattention could occur in three separate frames of reference: environment, body (*i.e.*, retinal, head, and trunk), and object-centered (Bisiach, Perani, Vallar, & Berti, 1986; Halligan & Marshall, 1993). These various frames of reference interact with the underlying left/ right visual hemifield dissociation. Additionally, neglect can also be described along the vertical (upper/ lower space) plane where patients will neglect the stimuli presented in the lower as compared to the upper visual hemifield; however, this has been shown to be task specific. The processing of the information in the left/ right and upper/ lower visual space has shown to be independent where early visual mechanisms process input based on the upper/lower differentiation. The left/right asymmetries, as observed in greyscale tasks, have been attributed to later stages of processing visuospatial attention information in the right hemisphere (Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004).

In addition to attentional and perceptual tasks, hemispatial neglect has been shown in imagery tasks where previously acquired images were recalled from long-term memory without any visual input (Bisiach & Luzzatti, 1978). Using a cathedral square of Milan that was familiar to the participants, Bisiach and Luzzatti required neglect patients to list objects on their left and right sides as the participants imagined themselves to be facing towards or away from the cathedral. These patients were unable to list objects to their left side irrespective of the view point. Presumably, these patients were forming a mental image of the cathedral square as viewed from a particular location and were attempting to read off the features that they could "see" in that mental image. The knowledge these patients had of the related objects was acquired prior to their condition and stored in memory but they were unable to access this information. In a replication of this study, Bisiach, Capitani, Luzzatti, and Perani (1981), included a control group, which consisted of patients with no known neurological damage, to perform the same task. Unlike patients with neglect, this neurologically healthy group showed a slight leftward representational bias.

The findings by Bisiach et al. (1981) are not the first evidence of leftward bias in the neurologically intact population. One year prior, Bowers and Heilman (1980), in a line bisection task requiring participants to bisect a horizontal line, showed that participants erred towards the left of center. As the phenomenon seemed to resemble the effects of patients with neglect in line bisection tasks, the authors termed it "pseudoneglect." Subsequent studies using neurologically healthy population revealed spatial lateral biases in a plethora of tasks and conditions including manual and computerized line bisection (Jewell & McCourt, 2000; McCourt & Jewell, 1999), landmark tasks (Dufour, Touzalin, & Candas, 2007), cancellation (Vingiano, 1991), greyscale (Nicholls, Bradshaw, & Mattingley, 1999), and gratingscale (Niemeier, Singh, Keough, & Akbar, 2008; Niemeier, Stojanoski, & Greco, 2007; Niemeier, Stojanoski, Singh, & Chu, 2008) tasks. Lateral biases have also been observed in judgments of numerosity, size (Nicholls et al., 1999), distance (Krupp, Robinson, & Elias, 2005), and while overlaying a background to an image (Dickinson & Intraub, 1998). Finally, biases have been observed in numerous 'real-world' scenarios including passing through a doorway (Nicholls, Loftus, Mayer, & Mattingley, 2007; Nicholls, Loftus, Orr, & Barre, 2008), completing multiple-choice questionnaire (Nicholls, Orr, Okubo, & Loftus, 2006), kicking soccer ball into a net (Nicholls, Loetscher, & Rademacher, 2010) and putting golf balls into the putting holes (Roberts & Turnbull, 2010). Therefore, the prevalence of biases in such a variety of behaviours indicates underlying asymmetries in processing of information that still remain elusive.

It is generally agreed that lateral biases are attributed to the hemispheric specialization in information processing. As the left hemisphere specializes in language, the right hemisphere is attributed to visuospatial information (Bjoertomt, Cowey, & Walsh, 2002; Çiçek, Deouell, & Knight, 2009; Corbetta, Schulman, Miezin, & Petersen, 1995; Fink, Driver, Rorden, Baldeweg,

& Dolan, 2000; Fink, Marshall, Weiss, & Zilles, 2001; Foxe, McCourt, & Javitt, 2003; Posner & Petersen, 1990; Posner & Rothbart, 2007). Therefore, the increased activation within the right hemisphere is related to the contralateral, visuospatial bias. The effects of this hemispheric asymmetry are evident when presenting two mirror reversed stimuli, such as the greyscales. One rectangular stimulus is darker on the left side and gradually becomes brighter toward the right. This stimulus is presented with its mirror image, which is brighter on the left and gradually becomes darker towards the right. The participants reliably indicate that the stimuli with the darkest shade on the left are darker overall, despite that the two images are equiluminant. It is hypothesized that the visuospatial attention mechanism provides a type of a magnification effect where the sought after features of stimuli, such as brightness, appear emphasized in the left visual space (Carrasco, Loula, & Ho, 2006; Carrasco, Williams, & Yeshurun, 2002).

The selection of perceptual information varies depending on the amount of visual information presented concurrently and the cognitive demands associated with its processing (Lavie, Hirst, de Fockertm & Viding, 2004; Lavie, 1995; Lavie & Tsal, 1994). A bottleneck is created when filtering this attentional information, which prevents cognitive resources from being overloaded, yet, maintains a maximum intake for further processing. This attentional load is determined by the amount and type of information entering the processing system. The impact of such information processing has been shown to take place even in the earliest stages of visual processing, including the primary visual cortex (V1) (Rauss, Pourtois, Vuilleumier, & Schwartz, 2009). In this experiment, participants performed a lowly or a highly demanding visual task at fixation while recording EEG response. The results revealed that attentional load modulated earliest component of the visual evoked potential (C1 amplitude) regardless of the visual distracters, even though this region has been typically shown to be invariable to different levels of attention and the obtained effects differed as a function of the visual field tested.

Attention has also been shown to have impact on later stages of processing such as memory (Makovski, Sussman, & Jiang, 2008; Awh, Vogel, & Oh, 2006; Awh & Jonides, 2001; Dell' Acqua, Sessa, Toffanin, Luria, & Jolicoeur, 2010; Downing, 2000). Working memory maintains and stores information for a short period of time even if the information is no longer visually accessible and it is assumed to underline human thought process (Baddeley, 2003). This system is comprised of the central executive, phonological loop, and visuospatial sketchpad. The central executive is considered to be the least understood. It is thought to be a general pool of processing capacity assigned directly or relating to the two sub-systems. The phonological loop consists of a phonological store that holds memory traces for a few seconds before fading. Memory traces can be refreshed by being continuously retrieved and articulated (Baddeley, 2003). Similarly, the visuospatial sketchpad permits manipulation and retention of information pertaining to one's surroundings and navigation in space (Baddeley, 2003) and is the area of focus in this work.

This close, reciprocal relationship between attention and working memory is indicated by an overlap in information processing goals. Both mechanisms enable goal driven processing by increasing the accessibility of relevant information from the background of distracters (Awh & Jonides, 2001; Awh et al., 2006). Awh and Jonides (2001) indicate that processing of spatial information can direct the earliest stages of visual analysis. The attentional mechanisms direct the information that will be encoded in memory. Reversely, memory processes direct the information which will be attended to. Such transfer is facilitated by the use of cues, which increase the detection sensitivity especially when stimuli are backwardly masked and the processing of the cued target is prematurely disrupted (Posner, 1980). If, however, the stimuli are unmasked, recall accuracy for cued and miscued stimuli does not differ, indicating completion of information processing to working memory (Smith, Ellis, Sewell, & Wolfgang, 2010). These findings indicate a possible relative control of information processing at the early attentional and later working memory stages. With the implementation of a mask, the working memory trace formation is inhibited possibly restricting the processing of information to mainly attentional stage. However, if rehearsal of the information is permitted, then the memory trace is permitted to form and processing may be continued to the working memory stage (Smith et al., 2010).

Taken together, visuospatial information processing in perceptual and attention mechanisms is susceptible to hemispheric asymmetries yielding lateral behavioral response biases. Yet, spatial information processing does not stop at these stages; it continues to be processed creating long- and short-term memories which may impact the direction of attention under similar circumstances in the future (Nobre, Griffin, & Rao, 2007; Summerfield & Lepsien, 2006). Therefore, the question that arises here is how these asymmetries in early processes impact the formation of working memory. Reversely, how does the information maintained in working memory impact lateral asymmetries that are expressed behaviourally?

Recent evidence does indicate common neuronal areas in orienting attention to locations in perceptual and mental representations (Nobre, Coull, Maquet, Frith, Vandenberghe, & Mesulam, 2004) as well as the presence of asymmetries in later stages of processing visuospatial information including, working memory. Della Sala, Logie, Beschin, and Denis (2004), showed that patients with representational neglect were impaired in manipulating information on the neglected side of their representation which would involve working memory. The participants were required to specify the name of each object presented on the left and right side corners of the display. The participants were required to recall the seen images either from their view-point, or imagining the layout of the images from across their seat. The patients with neglect syndrome were able to mentally rotate their representation of the picture array and the limited available information from the left of the representation showed to be available when imagined on the right. This response indicates the involvement of the visuospatial working memory as the system responsible for holding the mental representation is impaired on the neglected side, but the process which allows the manipulation of information shows no further loss of information from that representation. Therefore, as indicated by Della Sala et al. (2004), the patients showed no substantial difficulty in directing their attention to the neglected side of the mental representation for mental transformation of that representation, but the lateralized damage to the mental representation held in visuospatial working memory was the source of the deficit.

The evidence indicating presence of lateral biases in later stages of processing visuospatial information have also been shown in the neurologically normal population. McGeorge, Beschin, Colnaghi, Rusconi, and Della Sala (2007), revisited the Bisiach and Luzzatti (1978) study and investigated representational bias in the normal population. Using an identical experimental paradigm as Bisiach and Luzzatti (1978) where participants were asked to imagine themselves in a familiar cathedral square and list the objects they could recall to their left and right sides of the cathedral while imagining themselves facing towards or away from the cathedral. McGeorge et al. (2007) indicated that participants recalled more objects, and did so more accurately, when the objects were presented on their left side as compared to the right side independent of whether the participants' imagined themselves facing towards or away from the cathedral. Therefore, McGeorge et al. concluded that this was one of the first examples of leftward *representational bias* in an imagery task, indicating that perceptual and attentional processes are not the sole contributor to lateral biases, but that memory might also play a role.

Further evidence of the presence of representational biases has been emerging recently under various experimental conditions. Dickinson and Intraub (2009) demonstrated a bias in the boundary extension paradigm. Participants were asked to adjust the background of a presented image. The results showed a bias in how these images were adjusted where participants overestimated the right side of the image. As well, the participants showed increased recall accuracy for images on the left side of the screen. Additionally, Della Sala, Darling, and Logie, (2010) showed a leftward bias in feature binding task where participants were asked to match colour, shape, location, and identity of the stimuli presented on either the left or right side of the computer screen. Furthermore, leftward biases have been reported in tactile (Brooks, Logie, McIntosh, & Della Sala, 2011) and visual (Darling, Logie, & Della Sala, 2012) bisection of stimuli from memory.

All of the above mentioned evidence clearly indicates that lateral biases are evident in early and later stages of processing visuospatial information. Moreover, there is indication that memory processes themselves may also contribute to these biases. Although promising, this research is still in its infancy and further questions need to be answered. Generally, it remains unknown whether these asymmetries in early visual processes impact the formation of working memory. Also, it is unknown how different types of information will impact these biases. Furthermore, it remains unknown how working memory impacts asymmetries.

Rationale, Research Questions and Approach

The research discussed in the previous section, indicates the presence of lateral biases in later stages of processing, referred to as *representational bias*. Questions arise from a review of this literature, such as, how different information will impact lateral biases. Also, it is unknown how information already maintained in working memory, which does not serve as a cue, will impact lateral biases. Although it may not be feasible to eliminate perceptual and attentional factors which impact lateral biases, the goal here is to relatively emphasize either early or later stages of visual processing. The work in this dissertation can be divided into two areas of focus.

The first area is led by Baddeley's definition of working memory which indicates that visual load and timing are important for working memory to process and manipulate the information. Hence, the first three chapters (four experiments) of this dissertation focus on this area. An important factor of working memory is the ability to integrate information into an overall representation; a specific task was designed to address this factor. I designed a novel brightness judgment task which used a circular array comprised of six individual disks with an overall greyscale gradient as a stimulus. One side of the array was darker and increased in brightness along the horizontal plane. This array was presented with its mirror image where the brightness gradient was in the opposite direction. The participants were required to select the array which seemed overall darker to them. This paradigm was derived from the greyscale task which is highly sensitive in detecting perceptual asymmetries in clinical population (Mattingley, Berberovic, Corben, Slavin, Nicholls, & Bradshaw, 2004; Tant, Kuks, Kooijman, Cornelissen, & Brouwer, 2002) and in neurologically healthy participants (Nicholls, Bradshaw, & Mattingley, 2001).

The second area (chapters four and five) focuses on facilitation and inhibition of memory trace formation through the use of backward masking, where a noise mask is presented immediately following the stimulus to inhibit memory trace formation, and its impact on brightness judgment tasks. In the current work, the paradigm for memory trace formation was used to selectively manipulate the attention and working memory processes. Again the circular array stimuli were used for participants to determine which array was overall darker. In addition, the participants were also required to recall selected properties of the array, or the array itself, to determine the relationship between biases and the retained information.

In this dissertation, there were two questions which were investigated:

1) What impact do visual load and stimulus-response time intervals have on perceptual asymmetries?

2) How does the stimulus information maintained in working memory impact perceptual asymmetries?

The relationship between spatial attention and working memory mechanisms has been widely investigated with the results indicating an intricate and reciprocal relationship between these two mechanisms. Spatial asymmetries, where people select preferentially their left side of space as compared to the right have also been widely accepted. However, it is less known whether these spatial asymmetries translate to working memory mechanisms, hence the purpose of this work.

CHAPTER TWO

UPPER AND LOWER VISUAL FIELD PERCEPTUAL ASYMMETRIES IN A CIRCULAR ARRAY TASK

Introduction

Neurologically normal individuals will bias their responses to the left when making visuospatial judgments, such as a line in line bisection, presented across their left and right visual field. This phenomenon is known as pseudoneglect (Bowers & Heilman, 1980). Handedness, gender, age, and stimulus type have been shown to modulate the magnitude of this bias (Jewell & McCourt, 2000 for review). Despite these modulators, pseudoneglect shows to be a robust effect attributed to the right parietal region processing spatial information (Bultitude & Aimola Davies, 2006; Corbetta, Mezein, Shulman, & Petersen, 1993; Corbetta & Shulman, 2002; Fink et al., 2000; Malhorta, Coulthard, & Husain, 2008; Singh-Curry & Husain, 2008). Damage to this region results in neglect of the left hemifield (Bisiach & Luzzatti, 1978). These patients will experience a strong preferential bias to the right visual field and fail to report, respond or orient to stimuli presented to their left side of space (Brain, 1941; Gainotti, Messerli, & Tissot, 1972). Consequently, pseudoneglect and hemispatial neglect are thought to be twin manifestations of one attentional mechanism (Jewell & McCourt, 2000).

In neurologically healthy participants, left/ right perceptual asymmetries have been observed when making judgments of luminosity, size, numerosity (Nicholls, Bradshaw, & Mattingley, 1999), and distance (Krupp, Robinson, & Elias, 2010). Numerous explanations have been put forth to account for these leftward biases including scanning and reading habits (Chokron, Bartolomeo, Perenin, Helft, & Imbert, 1998; Manning, Halligan, & Marshall, 1990) as well as motor/ intentional biases (Brodie & Pettigrew, 1996; Heilman & Valenstein, 1979).

However, these explanations cannot entirely account for the reported asymmetries as Nicholls and Roberts (2002) showed that leftward biases are present in right-to-left readers and in bimanual responding.

The most widely adopted and supported explanation is that of hemispheric specialization for processing visuospatial attention. Attention is spontaneously biased to the left visual space, as a result of the posterior parietal areas in the right hemisphere processing spatial attention (Bultitude & Aimola Davies, 2006; Corbetta & Shulman, 2002; Corbetta, Shulman, Miezin, & Petersen, 1995; Posner & Rothbart, 2007; Posner & Petersen, 1990; Kinsbourne, 1970). This mechanism seems to alter perception, for example, it increases the apparent luminance contrast (Carrasco, Ling, & Read, 2004). Thus, when making a luminosity judgment on two mirror-reversed stimuli, the sought after feature will appear more emphasized on the left, despite that the two stimuli are equiluminant (e.g. Nicholls et al., 1999). This preferential leftward direction of attention is supported by neuroimaging data showing increased activation in visuospatial attention networks when viewing information in the left visual field (Siman-Tov et al., 2007). Furthermore, increased activation in the right hemisphere has also been found in line bisection and landmark tasks (Bjoertomt, Cowey, & Walsh, 2002; Çiçek, Deouell, & Knight, 2009; Fink et al., 2000; Fink et al., 2001; Foxe, McCourt, & Javitt, 2003), which are widely used to study this phenomenon and robustly show leftward biases (for review see Jewel & McCourt, 2000). Therefore, left/ right perceptual asymmetries seem to be attributed to the functional differences between the left and right hemispheres (Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004).

In addition, attentional orienting might also take place along the upper/ lower vertical dimension which have been associated with the parvo- and magnocellular systems in the early visual processing (Chen, Yao, & Liu, 2004; Christman & Niebauer, 1997; Niebauer & Christman, 1998; Previc, 1990) when presenting and processing visuospatial stimuli. Various cancellation and reading tasks reveal more omissions of stimuli in the lower than in the upper visual field (Halligan & Marshall, 1989; Nichelli, Venneri, Pentore, & Cubelli, 1993; Pitzalis, Spinelli, & Zoccolotti, 1997, experiment I). These differences are also evident when presenting visual stimuli on a computer screen as investigated in advertising. Participants view websites presented to them without any eye or head restriction, the response to the content presented in the upper and lower halves of the computer screen have shown to stimulate response consistent with the upper and lower visual field distribution (Goodrich, 2010).

The asymmetries along the horizontal meridian can be observed along the early visual system including the retina and the lateral geniculate nucleus (LGN) (Curcio, Sloan, Packer, Hendrickson & Kalina, 1987). Within the retina, the cone density is highest along the horizontal meridian, which might correlate to the upper and lower anisotropy (Curcio & Allen, 1990). As well there are more cones in the superior than in the inferior portions of the retina, which processes the lower and upper visual fields respectively. Such division is also present in the distribution of ganglion cells in the retina, which has a greater asymmetry as compared to the distribution of cone cells themselves (Curcio & Allen, 1990).

The cell layers within the LGN have been examined to reveal that the layers 1 and 2 contain larger neurons than layers 3, 4, 5, and 6. The magnocellular ganglion cells project to layers 1 and 2, whereas, parvocellular cells project to layers 3, 4, 5, and 6 (Abrams, Nizam, & Carrasco, 2012). The parallel processing within the distinct information channels which begin in the retina shows to be maintained through the LGN. However, it should be noted that within the

LGN layers there is much interconnection leading to cross communication between the two channels, making the distinction more relative than absolute.

Line bisection (Mennemier, Vezey, Chatterjee, Rapcsak, & Heilman, 1997; Reuter-Lorenz & Posner, 1990), greyscales (Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994; Nicholls, Bradshaw, & Mattingley, 1999), and gratingscales (Niemeier, Stojanoski, Singh, & Chu, 2008; Niemeier, Singh, Keugh, & Akbar, 2008; Niemeier, Stojanoski, & Greco, 2007) tasks have shown to be invaluable in understanding intricate mechanisms of visuospatial perceptual biases. In the case of gratingscales and greyscales, two comparison images are presented on a computer screen showing a gradually changing gradient from left to right. These images are equiluminant and one is mirror reversed. For example, when judging brightness in a greyscale task, one image is darker on the left, growing progressively lighter to the right and the second image is mirror reversed. In such judgments of brightness, numerosity, or size in greyscale tasks, the desired variable is perceived as more pronounced when located on the left side (Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994; Nicholls, Bradshaw, & Mattingley, 1999). Similarly, gratingscale tasks also rely on a horizontally changing gradient, however, the grating is from low to high spatial frequencies (or *vice versa*). The participants reliably choose the gratingscale with higher frequencies on the left as the one with more thinner stripes overall (Niemeier, Stojanoski, Singh, & Chu, 2008; Niemeier, Singh, Keugh, & Akbar, 2008; Niemeier, Stojanoski, & Greco, 2007).

Although clearly distinguished by the variability of questions either can answer, these tasks can be viewed as a continuous and linear type of stimuli where information is carried mainly along the horizontal dimension and contains limited requirement for stimulus integration. However, it remains unknown whether attentional biases are evident when integrating distinct stimuli into a non-linear array where information is carried along the horizontal and vertical dimensions simultaneously. Furthermore, it is also unknown how biases along the horizontal and vertical dimensions interact with one another. Rectangular greyscales and gratingscales are presented either horizontally, vertically, or diagonally on the computer screen with its left/ right mirror reversed image and participants determine which greyscale seems overall darker to them. However, with this approach it is difficult to determine whether preservation of such gradient is necessary to obtain lateral behavioural biases. Furthermore, these greyscales are not easily malleable further restricting insight into the interaction between the vertical and horizontal spatial dimensions.

Using a novel task, the participants were asked to view a set of six individual disks presented in a circular array. Two disks were presented on either lateral side of the top and bottom disk. Within each disk there was a random distribution of black, white, and grey pixels at a preset distortion ratio. Globally, the arrays showed a greyscale where either the leftward- or rightward- most disks were the darkest and grew progressively brighter to the other side. The arrays were presented one on the top and one on the bottom of a computer screen. The participants were required to determine which array seemed overall darker to them. These stimuli are unique as they require the participants to integrate the shades presented in the individual disks while making a brightness judgment of the overall array. Furthermore, with the unique configuration of the stimuli providing an easier malleability of the arrays, it is feasible to obtain further insight into how the horizontal and vertical biases may interact with one another.

This is the first time such approach has been done to the author's knowledge and presents a new dimension in understanding perceptual asymmetries. Generally, the first experiment investigates whether lateral biases will be observed using such stimuli and whether varying noise within stimuli has any further effect on these biases. The second experiment presented in this chapter investigates whether the greyscale gradient must be preserved to obtain lateral biases.

Experiment One

Introduction

A number of event related potentials (ERP) and behavioural studies show support for asymmetries occurring at early perceptual stage. For example, Qu, Song and Ding (2006) using ERP investigated the electrophysiological and attentional asymmetries between the upper and lower visual field (parvo- and magno- cellular pathways respectively) in a target detection paradigm. The differences in the activation of the cortical areas showed that the function of the upper and lower visual field areas differ in terms of both, early visual information processing and attentional modulation. Furthermore, Thomas and Elias (2011) showed variance in visual field bias modulated by stimulus presentation time when using greyscale tasks. Participants were presented with two greyscales (either free viewing or 150 msec presentation) in the upper and lower visual fields and were required to choose the seemingly darker greyscale. The results showed that participants examined the left and lower visual fields most often during the prolonged presentations, which was consistent with a subsequent leftward response in lower visual field. Thomas and Elias concluded that the obtained visual field differences were a result of magno- and parvo-cellular dissociations in the early visual processing. Such upper and lower visual field differences were also reported by Barrett, Crosson, Crucian, and Heilman, (2000) in free viewing manual line bisection paradigm, further supporting asymmetries in early visual processing.

In early processing of visual stimuli, the subcortical magnocellular pathway is related to the lower visual field (LVF) and carries all transient motion related information and low contrast black-and-white information. The information is usually processed much faster, as the fibers of this type A cell are thicker than in the parvocellular pathway. On a cortical level, the magnocellular pathway is related to the dorsal stream which is responsible for low spatial resolution (Carrasco, Willimas, & Yesherun, 2002; Rezec & Dobkins, 2004), contrast sensitivity at low and moderate spatial frequencies (Cameron, Tai & Carrasco, 2002; Lundh, Lennerstard, & Derefeldt, 1983), motion perception (from Thomas and Elias, 2011), as well as coordination and orientation within the peripersonal space (Previc, 1990). The subcortical parvocellular pathway is relatively linked with the upper visual field (UVF) and carries colour and high contrast black-and-white information. The information is processed more slowly because the fibers in these B cells are thinner than in the magnocellular pathway. On the cortical level, the parvocellular pathway is relatively linked with the ventral stream responsible for processing colour and form (Livingstone & Hubel, 1988) as well as coordination and orientation within the extrapersonal space (Previc, 1990).

Niemeier, Singh, Keugh, and Akbar, (2008) investigated whether biases due to attentional involvement in stimulus noise removal occur in early visual processes. Niemeier et al. reasoned that if noisy stimuli favoured the magnocellular system due to luminance differences detection, causing the bias to rise, then the isoluminant noise and isoluminant stimuli should favour the parvocellular system which favours hue detection, resulting in no increase of bias. A gratingscale task was used with horizontally incrementing spatial frequency pattern. Varying degrees of pixel noise was used to determine the impact of spontaneous leftward bias in noise reduction and the perceptual stage at which this noise removal occurs. The results showed a strong leftward non-monotonic bias dependent on the noise ratio. Niemeier et al. suggested that attention reduces the influence of distracters (including noise) within the focus of attention.

Thus, as the noise level increases, the bias will also increase, but only if additional resources are necessary to reduce the within-stimulus noise. However, as they did not obtain an effect based on the differentiation based on the parvocellular and magnocellular system, Niemeier et al. concluded that the attentional influence relevant for the attention bias is conveyed through mechanisms downstream from early visual areas, where the separation between the magno- and parvocellular system is lost.

It is possible that Niemeier, Singh et al., (2008) did not obtain significant dissociations in the early visual processing due to the method used in the study. The differences between parvo- and magno- cellular pathways may be distinguished by the visual field to which the image is presented - either the UVF or LVF, respectively (Abrams, Nezam, & Carrasco, 2012; Goodrich, 2010). Although Niemeier, Singh et al. presented the images to the top and bottom of the screen, they did not report this dissociation. Their results for the upper and lower visual field stimuli presentation were collapsed, possibly eliminating any early visual processing asymmetries based on the magno- and parvo- cellular systems.

The disks within the array contained predetermined noise in the form of random patterns of pixels that gave the image a grainy appearance. The ratio of this noise was constant for all the disks within the array and varied between the arrays. There were three asked questions. First, can a leftward bias be observed when integrating information from a circular presentation of individual stimuli which carry information along the horizontal and vertical dimension? Consistent with previous findings using greyscales and gratingscales, it is expected that the overall array will be viewed as darker when the darkest disks are presented on the left. Second, does the leftward bias change in magnitude or direction when presenting noisy stimuli in an array task? Third, is there an upper and lower visual field difference in leftward bias when presenting integrated horizontal and vertical information simultaneously? Unlike Niemeier, Singh et al., differences between the UVF and LVF will be investigated by presenting the stimuli to the upper and lower halves of the computer screen, which representatively coincide with the upper and lower visual fields respectively. The stimuli presented in the lower half of the screen will be favoured overall and modulated by noise within the stimuli as predicted by lower visual field processing. This is the first study, which incorporates the horizontal and vertical gradient information simultaneously to investigate perceptual asymmetries. Furthermore, it builds on previous findings that biases are not equally distributed across the visual field by directly investigating the interaction between the upper and lower visual field asymmetries.

Method

Participants

In total, 85 undergraduate Psychology students at the University of Saskatchewan were recruited from the participant pool. Forty one (20 male and 21 female) participants took part in the first part of the experiment and 44 (12 male and 31 female) participants took part in the second part of the experiment. In exchange for their participation, the students received one course credit. All participants had normal or corrected to normal vision, as based on self-report. Both right (n = 78) and left (n = 7) handed participants, as per self-report, took part in the experiment. The mean age of all the participants was 19. All participants used their writing hand to respond. This experiment was conducted with the ethical approval of the Behavioural Research Ethics Board at the University of Saskatchewan.

Images

Circular array

The circular array comprised of six individual disks that gradually varied in shading from darker to lighter depending on the left or right horizontal direction (Figure 1). There were three comparative noise conditions with relatively low (5%, 15%, and 25%), moderate (25%, 50%, and 75%) and high (75%, 85%, and 95%) within-array noise that were presented in the form of random patterns of pixels, giving the image a grainy appearance. Therefore, the overall shade of each disk was preserved but the arrangement of black, white, and grey pixels was varied. Noise level was identical in all disks within the array, but varied between the arrays. Each equiluminant pair of arrays was presented centered on the computer screen on top and bottom of the fixation point. Arrays were counterbalanced by their orientation and position on the screen.

A pair of greyscale images was presented among the circular arrays as control trials in both parts of the experiment. The greyscale task has been widely used and shows a robust leftward bias (for an example, refer to Nicholls, Bradshaw & Mattingley, 1999; Nicholls & Roberts, 2002). Each greyscale changed in luminance from left to right or vice versa by linearly adjusting the ratio of the white to black pixels. The images were mirror reversals of one another and were overall equiluminant. As with the circular arrays, the presentation of the greyscales was counterbalanced for the top/bottom screen presentation and left/ right orientation. The circular arrays were presented on a white background and greyscales on a grey background.

The images were presented on a Sceptre CRT DragonEye standard 17 inch monitor with a 28 cm height and 36 cm in length screen size. The screen resolution was 1280 x 960 pixels. Each participant was sitting between 60 to 80 cm away from the monitor. The top circular stimuli were presented approximately 200 pixels from the fixation point towards the top of the screen and extended for approximately 280 pixels. Similarly, the bottom circular stimuli were presented 200 pixels below the fixation point and extended towards the bottom of the screen. As well, the greyscales were presented at similar distances as the circular arrays from the fixation point.

Design and Procedure

Other than the noise level, the general design and procedure was identical in both parts of the experiment. Each trial (refer to Figure 2.1) began with a fixation point presented in the center of the screen for 1 second. Following, the stimuli would appear consecutively or simultaneously on the top and bottom of the fixation point. Each stimulus was presented for 1 second. Once the display disappeared, a response prompting screen appeared and stayed on until the participant made a response. All trials were administered randomly using a desktop computer running E-prime software (Psychology Software Tools Inc., Pittsburgh, PA; www.pstnet.com/eprime).

The task for each trial was for the participants to determine which one of the two presented images seemed darker overall and press the corresponding key on the computer keyboard. The "t" key was pressed if the top image seemed darker and the "b" key if bottom image seemed darker. The key press method was used to minimize the motor effects and possible motor bias in this task (refer to Nicholls, Bradshaw & Mattingley, 1999; Nicholls & Roberts, 2002). This was a forced choice task; hence, the trials did not advance if the participant did not make a response.

The trial administration format was identical in the training and test trials (Figure 2.1 and described above). In total, each participant received eight training trials which represented the combinations of disk noise and rectangular greyscale, counterbalanced for the orientation along the horizontal and vertical axes of the screen. The purpose of these trials was to ensure that the participant was familiarized and comfortable with the general procedure of the experiment. Test trials were administered immediately after training. In total, there were 16 test trials where each trial was repeated eight times for a total of 128 trials. All trials were presented randomly and counterbalanced for left/ right orientation and top/ bottom position on the screen.

Upon completion of the experiment, the participants were thanked and debriefed.

Data Analysis

The responses and the response times were recorded by the software. For each trial there were two greyscales presented on the computer screen, which were mirror images of one another. For example, greyscales presented on the top of the screen was darker on the left, the greyscale on the bottom would be darker on the right side. These images were counterbalanced between trials, so that there were an equal number of presentations of greyscales with the darkest sides on the left on the top and bottom of the screen. The same was true for greyscales presented with darkest side on the right. Therefore, a bias was obtained from the imbalance of responses the participants made by selecting the greyscale which seemed darker to them. In other words, if the participants, in general, perceived the greyscales as overall darker with the darkest side was presented on the left, then there should be a higher proportion of responses indicating as such. These responses should be independent of whether the greyscale was presented on the top or on the bottom of the computer screen.

The participants pressed either the "top" or the "bottom" key to indicate which image seemed darker. Such responding limits motor and response biases. A 'right response' was counted when participants chose the stimuli as darker overall when the darkest disks were presented on the right side. Whereas, a 'left response' was counted when array with darkest disks the left side was judged as darker. For each individual a laterality score was calculated, based on their responses, using the following formula:

[(# of right responses) – (# of left responses)] / [(# of left responses) + (# of right responses)]

A negative score yields a leftward bias and a positive score rightward bias. The bias is strongest at al laterality score of 1 and weakest at 0. The mean bias was calculated for each individual in each condition and averaged to determine the mean bias for each condition.

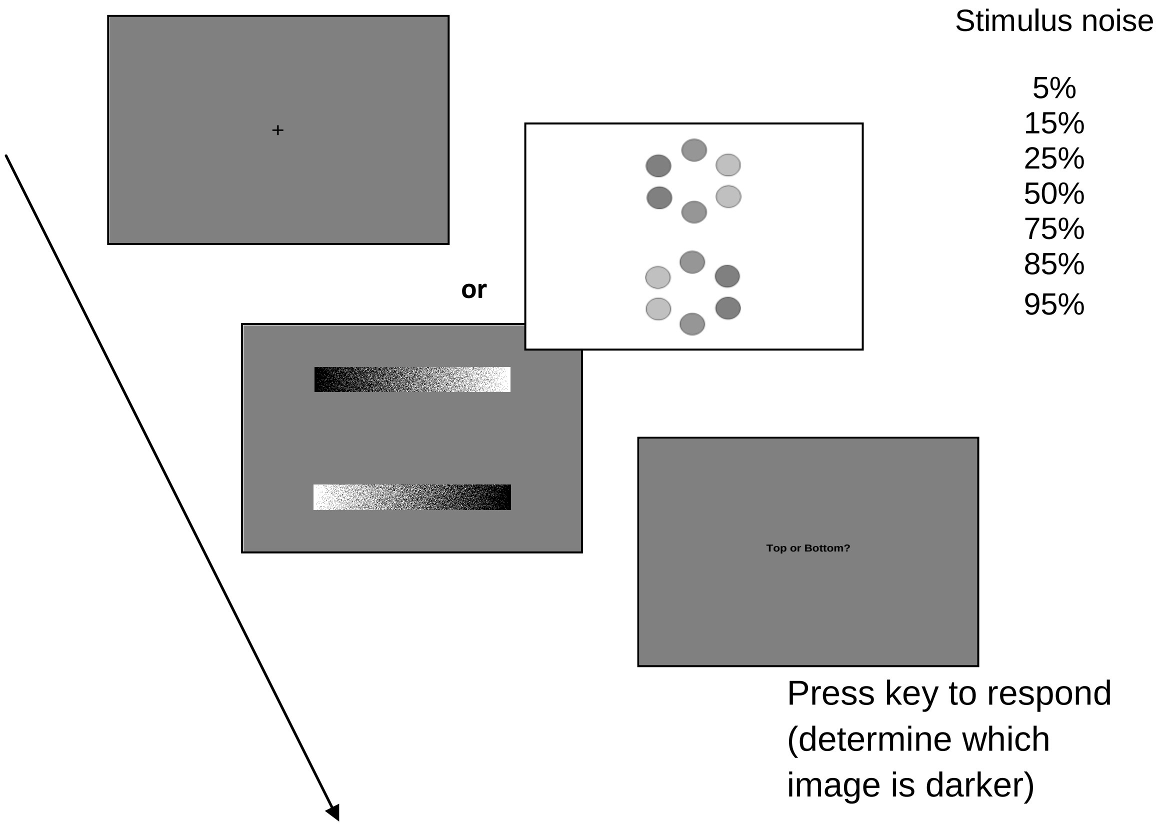

Figure 2.1. Schematic representation of trial progression. Training and test trials followed an identical progression. Fixation point and stimuli were presented for 1 s each. The response prompting screen remained on until a response was made. The stimulus noise percentages represent the amount of white, grey and black pixels introduced to the disks of the arrays.

Results

The individual laterality indexes were calculated using the above-mentioned formula and used as the dependent variable in the analyses. The average for each stimulus type and visual position on the screen was calculated and determined if it is significantly different from zero (no bias) using a one sample two-tailed t-test (refer to Figure 2.2 to determine which condition yielded a significant bias). The data showed significant leftward biases for circular arrays presented to the lower half of the screen. In other words, participants judged an array as darker overall when the darkest disks were presented to the left in the lower half of the screen as compared to its mirror image presented in the upper half of the screen.

An overall mixed-factors analysis of variance (ANOVA) was calculated with the comparative noise group (5-25%, 25-75%, 75-95%) set as a between-subjects variable. Within each comparative group, there were four corresponding conditions: three for each relative noise and one greyscale. These corresponding conditions and the screen position (top and bottom) were set as within-subjects variables. There was no significant difference between low, moderate, and high comparative noise groups, $F(2, 126) = 0.540$, $p = .58$. When considering the within-subject factor of the three relative noise conditions and the greyscale, the sphericity assumption was violated, $X^2(5) = 77.311$ $p < .001$, $\varepsilon = .689$ and the Greenhouse-Geisser correction was used. The results show no significant main effect of noise condition, $F(2.068, 260.625) = 2.288$, $p = .10$, $\eta^2 = .018$, indicating that the overall bias was similar along the three conditions. There was a significant main effect of screen position, $F(1,126) = 52.798$, $p < .001$, $\eta^2 = .295$. As seen in Figure 2, there is a pronounced leftward bias when the stimuli presented to the lower half of the screen extending through all the noise conditions. The bias for stimuli presented in the upper half of the screen indicates an overall small trend towards the right in the low (5-25%) and high (75-95%) comparative noise groups. In the moderate (25-75%) noise group there is a trend of leftward bias for stimuli presented in the upper half of the screen.

No significant interaction between comparative noise groups (low, moderate, high) and noise condition, $F(4.137, 260.625) = 0.953$, $p = .436$, $\eta^2 = .015$ was obtained. A significant interaction between the screen presentation (upper, lower) and comparative noise group (low, moderate, high) was obtained, $F(2, 126) = 6.437$, $p = .002$, $\eta^2 = .093$ where the biases for stimuli presented in the upper half of the screen were towards the left in the 25-75% noise group and trending towards the right in the 5-25% and 75-95% noise groups. When calculating the screen position x noise interaction, the sphericity assumption was violated, $X^2(5) = 13.806$ $p = .017$, $\varepsilon = .965$ and the Greenhouse-Geisser correction used. The results show a significant interaction, $F(2.779, 350.216) = 25.207$, $p < 0.001$, $\eta^2 = .167$. Furthermore, a significant three way interaction between visual field, comparative noise group, and absolute noise condition was also obtained, $F(5.559, 350.216) = 6.758$, $p < .001$, $\eta^2 = .097$.

To consider the data more thoroughly, a separate 2 (visual screen position) x 4 (noise condition) repeated-measures ANOVAs were conducted for each comparative noise group (5-25%, 25-75%, 75-95%). In the low noise group the upper and lower screen positions were set as first factor and the noise condition (5%, 15%, 25%, and greyscales) were set as the second factor. As expected, there was a significant difference of visual screen position, $F(1, 43) = 24.985$, $p < 0.001$, $\eta^2 = .368$, indicating strong leftward biases in the lower screen position. Rightward biases were observed when the circular arrays were presented to the upper half of the screen. The sphericity assumption for noise condition was violated, $X^2(5) = 51.470$, $p < .001$, $\varepsilon = .550$ and the Greenhouse-Geisser correction was used. The results show a non-significant main effect of noise condition, $F(1.649, 70.903) = 1.510$, $p = .23$, $\eta^2 = .034$. The sphericity assumption was also violated when calculating the noise condition and screen position interaction, $X^2(5) = 18.785$, $p = .002$, $\varepsilon = .803$ and the Greenhouse-Geisser correction was also used. The results indicate a significant interaction, $F(2.275, 97.830) = 12.160$, $p < .001$, $\eta^2 = .220$. When presenting the circular array, rightward biases were obtained when the stimuli were presented to the upper half of the computer screen. However, these biases reversed to leftward in the control condition, when presenting greyscales.

A second repeated-measures ANOVA was calculated for the moderate noise group (25-75%) with the within-subjects factors of screen position (upper and lower) and noise (25%, 50%, 75%, and greyscale).When considering the proportion of noise, the sphericity assumption was violated, $X^2(5) = 26.274$, $p < .001$, $\varepsilon = .684$, thus the degrees of freedom in the analysis were corrected using the Greenhouse-Geisser method. There was no significant main effect, $F(2.051, 82.055) = 1.781$, $p = .174$, $\eta^2 = .043$ indicating that the arrays do not differ from one another or the greyscales. There was a significant main effect for the upper and lower screen presentation, $F(1, 40) = 4.900$, $p = .03$, $\eta^2 = .109$. Post hoc paired samples t-test indicated a stronger leftward bias towards stimuli presented in the lower half of the screen, $t(40) = 2.194$, $p = .03$. The interaction between visual field and noise factors was also significant, $F(3, 120) = 13.006$, $p <.001$, $\eta^2 = .245$. Post hoc paired samples t-tests show a significant difference in bias between the upper and lower half of the screen presentation in the 25% condition, $t(40) = 4.980$, $p < .05$. In this condition the bias to the left was stronger in the LVF and the bias in the UVF was directed to the right and not statistically significant, $t(40) = 0.783$, $p = .438$. There were no significant differences between the visual fields in the 50% ($p = .37$), 75% ($p = .506$), and the greyscales ($p = .875$).

A third repeated-measures ANOVA was set for the high noise group (75-95%) with the screen position (upper and lower) and the noise condition (75%, 85%, 95%, and greyscales) set as factors. Again, the results show a significant main effect of visual field, $F(1, 43) = 24.844$, $p < .001$, $\eta^2 = .366$, where stronger leftward biases were present when the array was presented to the lower half of the screen. There was a trend of rightward biases when the array was presented to the upper half of the screen, but the results show no statistically significant rightward bias ($p = .334$, 0.434, 0.211, 0.081; 75%, 85%, 95% greyscale noise conditions, respectively). The sphericity assumption was violated for the noise condition, X^2 (5) = 14.399 $p = .013$, $\varepsilon = .853$ and the Greehnouse-Geisser correction was used. There was a non-significant main effect of noise, $F(2.406, 103.475) = 0.892$, $p = .43$, $\eta^2 = .020$, indicating a similarity across these conditions. The sphericity assumption for visual screen position x noise interaction was also violated, X^2 (5) = 18.340 $p = .003$, $\varepsilon = .844$ and the Greenhouse-Geisser correction was also used. Results indicated a significant screen position x noise interaction, $F(2.382, 102.446) = 14.148$, $p < .001$, $\eta^2 = .248$ where a leftward bias was observed for the greyscale stimuli presented to the upper half of the screen.

Thus, these findings show that a leftward bias, in the lower half of the screen presentation especially, is observable when integrating a series of discrete stimuli into one global circular array. Also, as per Niemeier, Singh, et al., (2008) the biases do not increase proportionally with noise, *i.e*. little stimulus noise did not result in smaller bias and large stimulus noise did not yield a large bias (Figure 2.2). However, unlike the findings in Niemeier, Singh, et al. (2008), the results showed a significant difference between the upper and lower screen presentation relating to the noise level (Figure 2.2).

Previous findings indicate correlations in biases dependent on spatial frequencies (Singh et al., 2011). The following analysis was conducted to investigate the correlation in the upper and lower screen presentation of stimuli for the four relative noise conditions (low, medium, high, greyscale). The overall analysis between the upper and lower half of the screen position showed a significant positive correlation, $r = .465$, $p < .001$. I also correlated the visual fields within each of the four relative noise conditions. In all four conditions, significant positive correlations were obtained: low noise: $r = 0.467$, $p < .001$; medium: $r = 0.374$, $p < .001$; high: $r = 0.375$, $p < .001$; rectangles: $r = 0.707$, $p < .001$. These findings indicate that the processes specific to upper and lower half of the screen presentations yield respective biases which do not work independently.

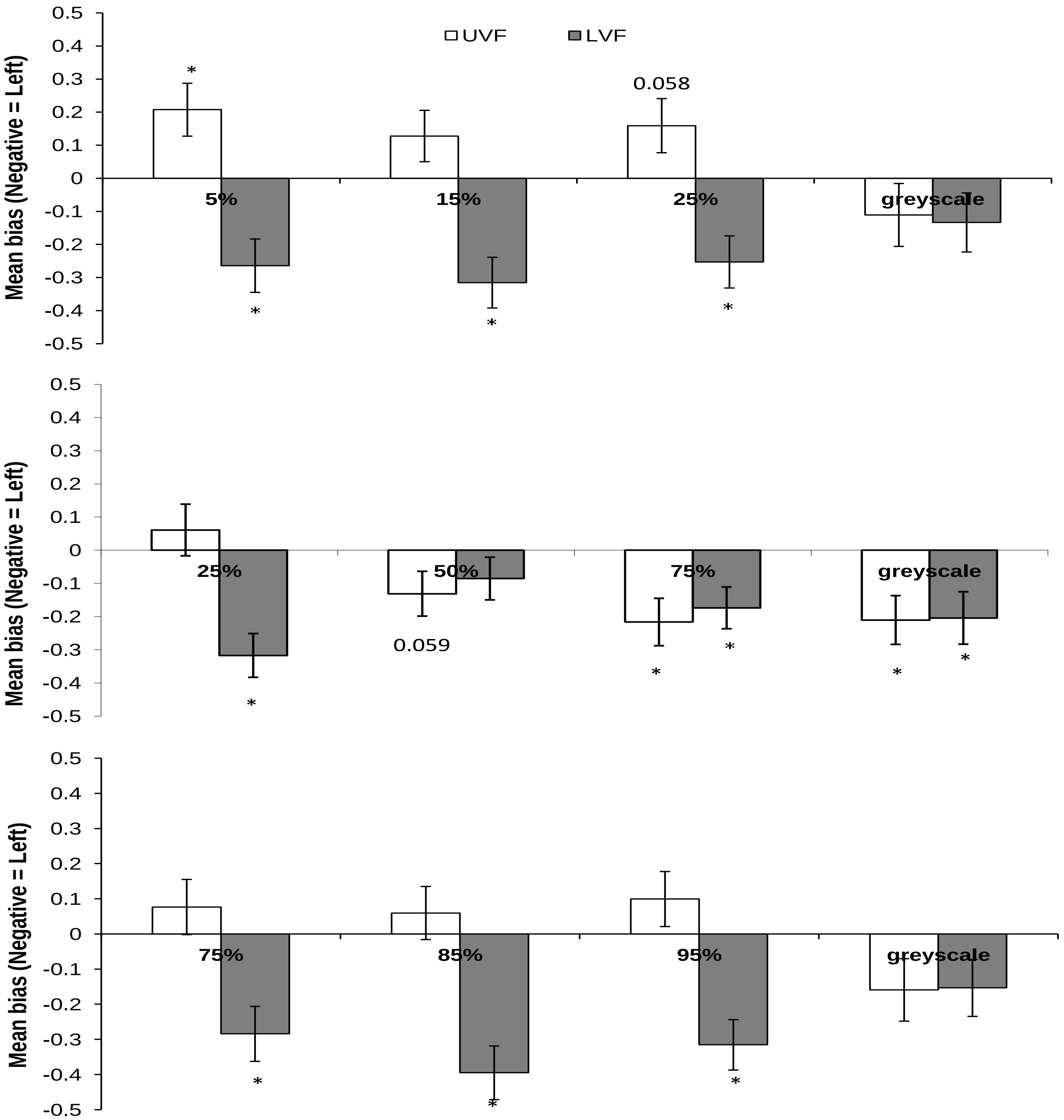

Figure 2.2. Mean biases for upper and lower screen position (UVF and LVF, respectively) in each noise condition. Top histogram represents absolute low noise condition. Middle histogram represents absolute moderate noise condition. Bottom histogram represents absolute high noise condition. Error bars represent standard error of the mean. Asterisks represent mean bias significantly different from 0 at α < .05. The values 0.058 and 0.059 represent almost significant biases and represent the value of *p*. 95% confidence intervals for the two conditions which almost reached significance are as follows: UVF 25% [-0.9, 0.2], UVF 50% [-0.3, 0.01].

An independent samples t-test was conducted to determine the difference between the moderate and high comparative noise group in the upper half screen presentation at the 75% noise level. There was a strong leftward bias in the moderate noise group condition, $t(83) = 2.749$, $p = .007$. Although these findings seem to indicate a cross-over effect in the upper visual field, it would be incorrect to infer such an effect. Robust leftward biases in the lower half of the screen presentation were observed. However, no significant rightward biases were attained where stimuli were presented to the upper half of the screen, other than in the 5% noise condition. The biases obtained when stimuli were presented in the upper half of the screen show to be only overall trends and not significantly different from zero. In contrast, biases obtained when stimuli were presented in the lower half of the screen show robustness across the noise groups and conditions, indicating a possible involvement of the right hemisphere. Additionally, the leftward biases show to be slightly, however, not significantly, stronger when the overall noise level is high.

Discussion

In this experiment, perceptual asymmetries using stimuli that simultaneously present information along both axes were investigated, which has not been previously done in detail. Furthermore, it was also investigated whether the magnitude of the bias was dependent upon on the noise level within the stimuli. Finally, to expand on previous findings showing an unequal distribution of biases along the vertical hemifields, this study investigated possible interaction in relation to the upper and lower screen presentation which may allude to the upper and lower visual field processing. In a novel brightness judgment task, a circular array comprised of six disks was presented with its mirror image to the upper and lower portion of the computer screen, respectively. Participants were asked to determine which one of the presented arrays was darker overall. The results showed that the array was judged as overall darker when the darkest disks appeared on the left side of the array. Thus, leftward bias was observed when judging brightness of an overall circular configuration composed of several individual stimuli. This bias did not linearly increase with increasing stimulus noise. Finally, the bias showed to be modulated by horizontal elevation of stimuli and was shown to interact where stronger leftward biases were related to smaller rightward biases and vice versa. These findings, to my knowledge, have not been previously reported using a similar type of stimuli and extend on the limited work indicating that the biases may not be equally distributed across the visual fields.

In this experiment, although an overall leftward bias was obtained, there is a discrepancy in direction and magnitude of biases which is dependent on the presentation of the array in relation to the fixation point. Arrays presented below the fixation point, or on the lower half of the screen, showed a strong leftward bias whereas stimuli presented above the fixation point, or to the upper half of the screen, showed a rightward trend. As the participants were required to keep their gaze on the fixation point throughout the experiment, it can be assumed that this differentiation can possibly be attributed to the upper and lower visual field processing of stimuli. The arrays presented on the upper half of the screen could be directed to the upper visual field whereas the arrays presented on the lower half of the screen could be directed to the lower visual field. The stronger leftward bias obtained when arrays were presented in the lower portion of the screen supports this rationale as the stimuli contain attributes preferential to lower visual field processing.

The differential processing of information in the upper and lower visual fields has been shown as a result of an overall lower visual field advantage in threshold and reaction times under specific conditions (Cameron, Tai & Carrasco, 2002; He, Cavanagh & Intrilligator, 1996; Levine

& McAnany, 2005; McAnany & Levine, 2007; 2006; 2004; Previc, 1990). Other research indicates that the upper and lower visual field asymmetries are dependent on a multitude of other factors including attention, task difficulty and presentation time (Thomas & Elias, 2011). For example, in Thomas and Elias (2011), participants viewed greyscales in the upper and lower visual field at different presentation lengths. The presentation time and visual field interacted such that prolonged presentation times, stronger biases occurred in the lower visual field. Stronger leftward bias was attained in the upper visual field during brief presentation of stimuli. These findings indicate a relationship between lower and left visual fields as well as upper and right visual fields, which up to then, has not been directly shown using within-participants design (Thomas & Elias, 2011). This variability in magnitude and direction of biases based on task and condition specificity indicates that various mechanisms might play a role, therefore supporting earlier presented research that horizontal and vertical biases might be a result of different mechanisms.

Although no clear consensus has been reached regarding the mechanisms that mediate these upper and lower visual field asymmetries (McAnany & Levine, 2007), the physiological and functional differences in the magnocellular and parvocellular system of the early visual processing emerges as a strong contender which, in addition to other factors, may lead to such asymmetries. The lower visual field has been linked with the magnocellular subcortical pathway (Previc, 1990), connecting with the cortical dorsal visual stream (Livingstone & Hubel, 1988; Goodale & Westwood, 2004). The upper visual field has been linked with the parvocellular pathway (Previc, 1990) that passes on the information to the ventral visual stream (Livingstone & Hubel, 1988). Physiologically, neurons of the magnocellular system have been shown to have larger receptive field centers, making them more responsive to low contrast information

(Livingstone & Hubel, 1988). The magnocellular system, however, is not capable of sustained scrutiny of information from images. The information obtained only by the magno- system disappears after a few seconds of voluntary fixation (Livingstone & Hubel, 1988). Therefore, the parvocellular system is thought to have evolved to complement the magnocellular system, as it seems to be important for analyzing a scene in much greater detail, as shown by experiments with fading, low contrast images (Livingstone & Hubel, 1987, 1988). Additionally, this system is able to scrutinize in more detail the shape, color, and surface properties of objects and thus, possibly assigning multiple attributes to the visual stimulus (Livingstone & Hubel, 1988). Therefore, the strong leftward bias obtained in this experiment in the lower visual field could be attributed to the preferential processing of information by the magnocellular system. The array comprised of individual disks presented on the lower half of the screen biased the processing to the magnocellular system, which is specialized in the processing of global information (Christman, 1993). This would explain why a stronger leftward bias was obtained in the lower visual field. Interestingly, no consistent rightward bias was obtained when the array was presented to the upper half of the screen and, by relation, possibly to the parvocellular system. Possibly, in this case, the parvocellular system served as the mediator (Livingstone & Hubel, 1988). This account is supported by the correlation in bias between the upper and lower visual fields obtained in this experiment.

In studies investigating leftward biases, the stimuli used are often horizontal lines, as in line bisection, or horizontal bars with grey gradient, as in greyscales. Although judging the stimuli yield leftward bias, pointing out the involvement of the right hemisphere, the involvement in global and local processing can be limited. The current experiment shows that the leftward bias is evident when integrating an array of discrete stimuli into one representation while making a brightness judgment. This global processing of information results in preferential and faster selection of information at a global level. Conversely, patients with lesions to the right temporo-parietal junction (TPJ) preferentially bias to local information (Bultitude & Woods, 2010). Thus, the circular array task can be implemented to further investigate the differences in biases when processing local and global information.

The current study showed that lateral biases are obtained when participants are required to integrate several distinct stimuli into one, while making a judgment of brightness of the overall array. Furthermore, these biases are consistent with those obtained using a greyscale task, used to investigate attentional and perceptual biases. However, it has not been previously investigated whether the greyscale gradient is required to be preserved for these biases to occur. Hence, this is investigated in experiment 2.

Experiment Two

Introduction

As seen in experiment 1, lateral biases were obtained when participants are required to integrate a series of stimuli into one representation and compare the overall brightness. Furthermore, these biases showed to differ depending on the noise within the stimuli highlighting the function of attentional processes in noise reduction. Clearly, there has been an observed left/right asymmetry observed with stronger left biases, which was consistent with previous findings. Furthermore, there was an observed dissociation between the stimuli presented in the upper and lower halves of the computer screen, coinciding with the upper and lower visual field differentiation.

There is evidence that the left/ right and upper/ lower biases are more complex than previously thought and they may not be equally distributed across the visual field as indicated by Thomas and Elias (2012, 2011). The circular array task is able to investigate these biases more thoroughly as the stimuli presented contain both, horizontal and vertical information presented simultaneously.

Unlike left/ right asymmetries, the upper and lower visual field biases are attributed to differential processing of visual information within the subcortical magnocellular and parvocellular pathways. The information presented to the lower visual field is primarily propagated through the magnocellular pathway into the dorsal stream. The information of motion and low contrast is quickly processed as the fibers are much thicker than those in the parvocellular pathway. Conversely, the information presented to the upper visual field is processed by the parvocellular pathway and subsequently delivered to the ventral stream (Goodale & Westwood, 2004; Livingstone & Hubel, 1988). The information containing colour and high contrast is processed slower as the fibers are thinner than in the magnocellular pathway. Even though the differential information in the subcortical visual pathways is kept separate; the magnocellular and parvocellular pathways are only partially segregated and join in the lateral geniculate nucleus (LGN) (Nieuwenhuis, Jepma, La Fors, & Olivers, 2008). As these visual streams have shown to conjoin and interact (Goodale & Westwood, 2004), the processing differences indicate a relative advantage.

The upper and lower visual field differences are found depending on the task at hand. The lower visual field superiority has been shown in searching for a target amongst distracters (Rezec & Dobkins, 2004), spatial resolution (Carrasco, Williams, & Yeshurun, 2002; Rezec & Dobkins, 2004), contrast sensitivity at low and moderate spatial frequencies (Cameron, Tai, & Carrasco, 2002; Lundh, Lennerstrand, & Derefeldt, 1983) as well as coordination and orientation within the peripersonal space (Previc, 1990). Lower visual field advantage was also shown in motion processing, for example, in direction discrimination (Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Edwards & Baddock, 1993), segmentation of moving targets (Lakha & Humphreys, 2005) and motion in depth (Regan, Erkelens, & Collewijn, 1986). Upper visual field superiority was observed in processing colour, form (Livingstone & Hubel, 1988), and coordination and orientation with the extrapersonal space (Previc, 1990).

To add to this complexity, there is evidence that the left/ right and upper/ lower dimensions interact resulting in an additive effect. In patients with parietal damage resulting in hemispatial neglect, the most severe neglect is observed in the lower-left visual quadrant and the least severe neglect is found in the upper-right visual quadrant (Rubens, 1985). For example, in Ladavas, Carletti, and Gori, (1994) more errors were made in the lower-left visual field when performing externally and internally controlled covert orienting task. Conversely, neurologically normal participants show an advantage in the lower-left quadrants for global processing and coordinate spatial judgments requiring visuomotor coordination. An upper-right quadrant advantage is observed in tasks including local processing and categorical judgments such as object identification (for review see Christman & Niebauer, 1997). Taken together, the findings reveal not only our viewing space to be divided between the left/ right hemispace and upper/ lower visual fields, but also an interaction between these fields which results in differing processing capacity in patients with neglect and in normal population.

This experiment was set out to investigate whether the progression of the greyscale from dark to light, or vice versa, must be undisrupted for the lateral biases to be observed. As well, this study investigated the interaction between the horizontal and vertical biases and their modulation of the lateral biases.

The ability to integrate the individual discs into an overall representation of the gradient should preferentially engage the right hemisphere which has been shown to specialize in global processing (Christman, 1993; Kosslyn, 1987; Niebauer & Christman, 1998), thus emitting overall leftward behavioural bias. Distortion of the array would also engage the right hemisphere by further increasing global processing yielding stronger leftward bias. Furthermore, if the upper and lower visual field differences were overcome by hemispheric specialization, then stronger leftward biases in the upper and lower visual fields as the global processing in the right hemisphere would overpower any processing differences resulting from the upper and lower visual field presentation. On the other hand, if the upper and lower visual field processing differs with stimulus presentation and consequently yields different subsequent hemispheric processing, rightward biases should be observed for stimuli presented to the upper visual field and leftward biases for stimuli presented to the lower visual field. In the control condition, with no distortion of the greyscale gradient strong leftward biases in the lower visual field and right biases in the upper visual field should be attained.

Methods

Participants

Forty-nine (38 female and 11 male) undergraduate students at the University of Saskatchewan took part in this experiment. All students were recruited from the Participant Pool and had normal or corrected to normal vision, as per self-report. In exchange for their participation, the students received one course credit. The experiment was performed on the first 49 participants who signed up for the study, resulting in 48 right handed and 1 left handed participants, as per self-report. Participant age ranged from 17 to 30 years old with a mean age of 20. All participants made their responses with their writing hand. This experiment was conducted with the ethical approval of the Behavioural Research Ethics Board at the University of Saskatchewan.

Stimuli

As in experiment 1, the stimuli used in this experiment comprised of six individual disks arranged in a circular array which transmitted gradient information along the vertical and horizontal dimensions simultaneously. Overall, the circular array was approximately 10 cm in diameter from the outermost disk circumference and each disk was approximately 3 cm in diameter (Figure 2.3). The disks consisted of three shades of grey: dark, medium, and light. An even distribution of shade was implemented so that the darkest shade was twice as dark as the lightest and medium shade was half as dark as the darkest shade. Each shade within the dark, medium and light categories was of the same overall luminosity. However, black, white and grey pixels within each disk were randomized at a rate of 75% giving the image an overall grainy appearance (Figure 2.3, panel A). Despite this pixilation effect, it was easily deducible which disk was dark, medium, or light. The arrays were configured so that one disk was presented on top and one on the bottom and two disks were presented on each lateral side. Therefore, for reference only and not known to the participants, the positions can be labeled (clockwise) as *top, top-right, bottom-right, bottom, bottom-left,* and *top-left*. These positions remained constant throughout the experiment to preserve the circular configuration. Only the shades varied depending on each experimental condition.

As control, the circular array greyscale gradient was undisrupted. Both darkest disks were on the same lateral side and the lightest on the opposite side of the array (Figure 2.3, bottom of panel B). For example, such array would have a medium shaded disk presented on the *top* and *bottom*, both darkest shades presented in *top-left* and *bottom-left* positions, and the two lightest shades presented in the *bottom-right* and *top-right* positions. Such array was presented with its left/ right reversed mirror image where the lightest disks were presented in the *top-left* and *bottom-left* positions and darkest disks in the *top-right* and *bottom-right* positions. Therefore, there was an overall greyscale gradient expanding across the array where one lateral side was darker than the other.

To determine whether it is necessary that the stimulus must maintain an incremental change in greyscale, the shades in two positions were varied thus disrupting the overall greyscale (as shown in Figure 2.3, panel B). Note that no cue information was presented to the participants indicating which disks have been manipulated. In total there were 11 combinations including the control array (Figure 2.3, panel B). Array combinations that, when mirror reversed, looked identical were excluded as stimuli. Also, combinations with the same shade switched were considered as redundant and were not presented. All arrays were presented with their left/right reversed mirror images.

Design and Procedure

The stimuli were administered using E-prime software (Psychology Software Tools, Inc., Pittsburgh, PA; www.pstnet.com/eprime) on an IBM clone computer (PIV 2.4 GHz) interfaced with a 17” (28 cm width and 36 cm length) Sceptre DragonEye CRT monitor running at 1280 x 960 resolution. Black fixation point was presented in the center of the screen on a grey background for 1 second. Following, two arrays (approximately 250 pixels in diameter) were presented for 1 second on a white background. One array was presented centered on the top half and one on the bottom half of the computer screen (approximately 120 pixels above and below the fixation point). Each presented pair of the arrays represented one combination. For example, an array, where *bottom* and *bottom left* disks were switched, was presented with its left/ right mirror reversed image. Two arrays with different disk combinations were never presented at the same time.

Once a pair of the arrays was presented, a grey screen appeared prompting the participants to respond. The goal for the participants was to determine which one of the two arrays appeared overall darker. If it was the top array, they selected the "t" key on the computer keyboard; if it was the bottom array, they selected "b" key. This method was used to minimize the motor effects and possible motor bias in this task (Nicholls, Bradshaw, & Mattingley, 1999; Nicholls & Roberts, 2002). As this was a forced choice task, the trials did not advance until a response was made.

Prior to commencement of the experiment, participants were seated comfortably in front of the computer screen and elevated such that their gaze was horizontal with the fixation point. All participants were required to keep their gaze on the fixation point even when not illuminated during the array presentation. On average, the distance of the participants' eyes was approximately 50 to 70 cm from the computer screen.

The training and test trial format was identical. In total, there were 12 training trials administered prior to testing. The training trials were given to ensure the participants were aware of the methodology and comfortable with the general procedure. In total, each participant was given 264 test trials, which began immediately following training. Each trial was repeated six times and each array was repeated 24 times. The trials were counterbalanced for left/ right orientation and top/ bottom position on the screen. All trials were presented randomly to each participant within the training or test blocks.

Upon the completion of the experiment, the participants were thanked and debriefed.

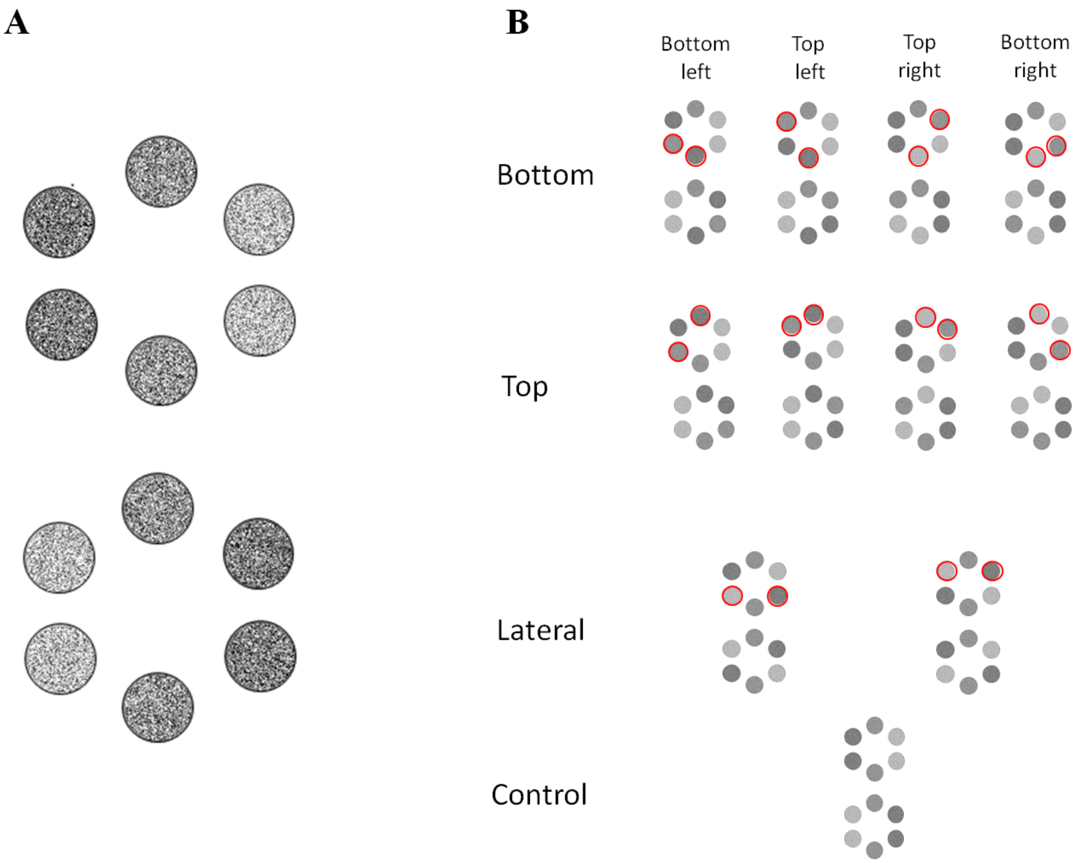

Figure 2.3. (A) Representation of the circular array random pixilation at 75% to provide images with random black, white and grey pixels. Participants were asked to determine which array seemed overall darker to them. (B) Representation of the disk manipulation within the array presented with its mirror image. The circles on two of the six disks in the top arrays are representative of the manipulation and were absent in the experiment. In total there were 11 manipulations including the control trials. Combinations with same grey gradient value switched and arrays when mirror reversed looked identical were considered as redundant and not presented in the experiment.

Data Scoring

The data were scored as in Experiment 1. The responses and response times were recorded by the software. Bias was determined by calculating the total number of left and right responses by each participant for each condition and then calculating the laterality index using the following formula:

[(# right responses) – (# left responses)] / [(# right responses) + (# left responses)]

A negative score yields a leftward bias and positive score rightward bias. The biases are strongest in magnitude the closer they are to 1. Although there always was one stimulus on top and one on the bottom of the screen, a bias was obtained when participants favoured one orientation of the array. For example, a strong leftward bias, irrespective of the upper and lower visual field, is observed when participants select the array with darkest disks on the left side over the array with the lightest disks on the left side. The array configurations were such that there was one side of the array appearing overall slightly darker or lighter than the other. Therefore, the task was designed such that if participants selected at random, or there would be no bias, we would expect to obtain value of 0 as the laterality index.

Results

Mean bias calculated for each individual in each condition was used in the analysis. On average participants showed either a leftward or rightward bias on 9 out of 11 conditions, ranging from 7 to 11 conditions. One participant (right-handed female) showed a bias in only 4 conditions, 3.8 standard deviations below the mean, indicating an outlier. Therefore, the data for this participant were not included in the analysis as I was unable to determine definitively the reason of this deviation.

To determine whether the obtained biases for each condition and visual field were different from chance, one sample t-tests were conducted with 0 set as the test value. Nearly all conditions obtained significant biases and are represented by an asterisk in Figure 2.4. As well, Figure 2.4 shows a division where leftward biases are observed in the lower visual field and rightward biases in the upper visual field. Furthermore, there is an indication that the bias magnitude varied depending on the horizontal and lateral positions of the switched disks. Therefore a 2 (upper visual field, lower visual field) x 2 (*top* or *bottom* position of the switched disk) x 4 (lateral position of the second switched disk) repeated-measures ANOVA was conducted to investigate whether these biases were statistically significant. In this analysis only the conditions in which the *top* and *bottom* disks were swapped with their lateral counterparts were considered. The conditions where two of the swapped disks were placed laterally and with no manipulation (marked as "Lateral" and "Control" in Figure 2.4, respectively) were not included.

There was a significant main effect of visual field, $F(1, 47) = 85.161$, $p < .001$, $\eta^2 = .64$, where arrays presented to the upper visual field showed a strong rightward biases ($M = 0.198$, $SE \pm .04$) and arrays presented to the lower visual field showed strong leftward biases ($M = -0.293$, $SE \pm .04$). There was also a significant main effect of the *top* and *bottom* position, $F(1, 47) = 6.084$, $p = .017$, $\eta^2 = .12$, showing leftward biases which were slightly stronger when one of the manipulated disks was in the *top* position ($M = -0.07$, $SE \pm .03$) as compared to the *bottom* position, ($M = -0.025$, $SE \pm .03$). The sphericity assumption was violated for the main effect of the lateral disk manipulation, χ^2 (5) = 18.020, p = .003, $\varepsilon = .82$ and Greenhouse-Geisser correction was used to adjust the degrees of freedom. There was no significant main effect of lateral position disk manipulation, $F(2.333, 109.653) = 0.851$, $p = .45$, $\eta^2 = .02$.

The interaction of visual field and horizontal disk manipulation was significant, *F*(1, 47) = 10.504, *p* = .002, η^2 = .18, due to the crossover in bias from right to left when the *top* and right positions were manipulated (Figure 2.4). Further *post hoc* t-tests were conducted to investigate the visual field and horizontal (*top* and *bottom*) disk manipulation interactions more closely using the Bonferroni correction for multiple comparisons. There was no significant difference between the horizontal disk manipulations in the lower visual field, *t(*47) = 1.615, *p* = .11, but there was a significant effect for the horizontal disk manipulations in the upper visual field, *t(*47) = 3.220, *p* = .002. Furthermore, there were significant differences when comparing the visual fields for the *top* and *bottom* positions; *t*(47) = 12.740, *p* < .001 for the upper and lower visual field and *bottom* position and *t(*47) = 6.456, *p* < .001, for the *top* position and upper and lower visual field.

As well, the visual field and lateral position interaction was also significant, *F*(3, 141) = 11.846, *p* < .001, η^2 = .20. Additional *post hoc* t-tests were conducted using the Bonferroni correction for multiple comparisons to further investigate the significant interaction of visual field and lateral position of the second disk manipulation. Within the lower visual field presentation, when compared the *bottom left* and *top left* positions, there was a significant effect, *t*(47) = 3.607, *p* < .001, where the bias was stronger for the *bottom left* position (*M* = -0.39, *SE* ± .05) as compared to the *top left* position (*M* = -0.25, *SE* ± .05). Similarly, there was a significant difference between the *bottom right* and *top right* positions within the same (lower) visual field, *t*(47) = 5.234, *p* < .001. The bias was stronger when the disk in the *top right* position was manipulated, (*M* = -0.37, *SE* ± .04), as compared to the *bottom right* position, (*M* = -0.17, *SE* ± .05). In the upper visual field presentation, there was a significant difference when comparing the bottom and top position in the right lateral side, *t*(47) = 3.068, *p* = .003, where stronger rightward biases were obtained in the *top right* position (*M* = 0.24, *SE* ± .05), as compared to *bottom right* position, (*M* = 0.11, *SE* ± .05). There was no significant difference when comparing the *top left* and *bottom left* lateral sides within the upper visual field, *t*(47) = 1.272, *p* = .21.

The horizontal position and lateral manipulation of the second disk interaction was not statistically significant, *F*(3, 141) = 1.023, *p* = .384, η^2 = .02. The sphericity assumption was violated for the three-way interaction of visual field, horizontal disk position and lateral disk position, χ^2 (5) = 65.944, p < .001, ε = .52, and degrees of freedom were adjusted using the Greenhouse-Geisser method. The interaction was statistically significant, *F*(1.559, 73.246) = 24.597, *p* = .001, η^2 = .34. Lateral biases show to differ within the upper and lower visual fields depending on the left/ right manipulation of the greyscale within the array. Four paired-samples t-tests with Bonferroni corrections for multiple comparisons were conducted to investigate this three-way interaction further. For each visual field and top/bottom position manipulation, the differences between left and right lateral positions were considered. As evident in Figure 2.4, the biases show to differ depending on the manipulation of the greyscale values within each visual field. Manipulating leftward disks with the *bottom* disk results in weakened biases in, both, the upper and lower visual field presentations (*M* = -.18, *SE* ± .047) as compared to the right disk manipulation (*M* = -.47, *SE* ± .038). This was statistically significant, *t*(47) = 5.059, p < .001, for the lower visual field presentation and *t*(47) = 4.074, p < .001, for the presentation in the upper visual field (left *M* = .14, *SE* ± .055; right *M* = .41, *SE* ± .043). Conversely, biases were stronger when manipulating the top with the leftward disks as compared to the top and rightward disks, in both, the lower visual field (left, *M* = -.45, *SE* ± .045; right *M* = -.07, *SE* ± .048), *t*(47) = 7.465, p < .001, and the upper visual field (left *M* = .29, *SE* ± .045; right (*M* = -.06, *SE* ± .049)), *t*(47) = 5.806, p < .001. As indicated, biases do not appear to be uniform within each visual field, but vary depending on the lateral and vertical manipulation of stimuli within the upper and lower visual fields.

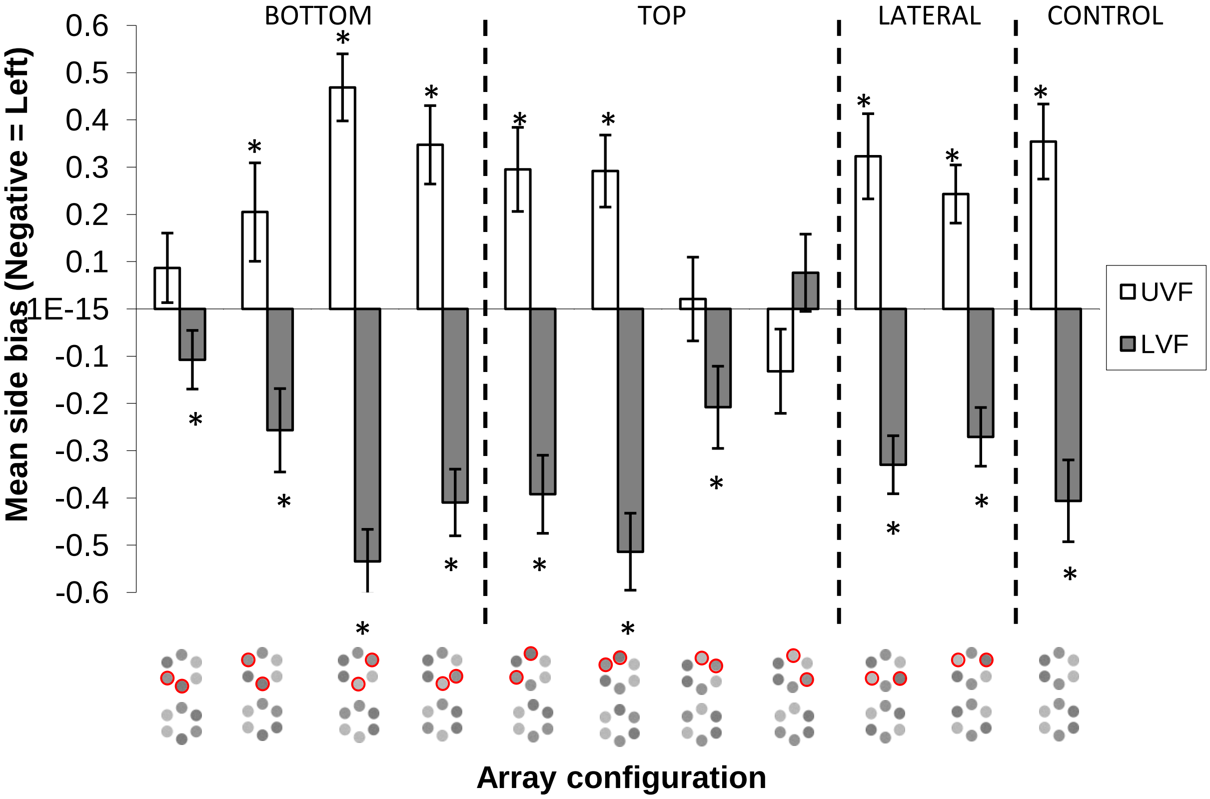

Figure 2.4. Mean bias for the upper and lower visual field and each configuration possibility. UVF represents upper visual field and LVF represents lower visual field. Subtitles represent disk manipulation category; "lateral" indicates that the two grey values on the left and right were switched. In control, no disruptions of the grey values were implemented. Error bars represent standard error of the mean. Asterisks represent biases statistically different from 0 (no bias).

Discussion

To investigate the interaction of biases along the horizontal and vertical dimensions, a pair of circular arrays with disrupted left/ right grey scale gradient was presented to the upper and lower visual fields. In concordance with previous findings, strong leftward bias for arrays presented to the lower visual field were obtained in this study, where an array was judged as overall darker when the darkest disks were presented to the left side. Strong rightward biases were observed when the arrays were presented to the upper visual field. The arrays were judged as darker when the darkest disks were presented to the right side. These findings support the importance and involvement of upper and lower visual field differences in processing visuospatial information. More importantly, these findings point out that biases are evoked not only as a result of the horizontal and vertical dimension (visual field presentation), but also within the visual field's horizontal and vertical meridian manipulation. Manipulating the uppermost center disk with either upper or lower disk on the left side yields a stronger bias than when manipulating upper or lower disks on the right side. Conversely, when manipulating the bottom center disk with upper or lower disks on the right side yields stronger biases.

The results showing visual field asymmetries are in line with prior research indicating stronger rightward bias in the upper visual field and leftward bias in the lower visual field. Rightward biases in the upper visual field have been observed in visual search, local processing, and categorical judgments such as object identification. On the other hand, leftward and lower visual field advantage has been observed in global processing, coordinate spatial judgments requiring visuomotor coordination, and global motion (Efron, Yund, & Nichols, 1987; 1990; Previc & Blume, 1993). In an ecological explanation of upper and lower visual field differences, Previc (1990) indicates that most reaching and grasping occurs in the lower visual field and visual search where object recognition occurs in the upper visual field. Consequently, the lower and upper visual fields became specialized for these functions. Objects in the peripersonal (near) space are more likely to be grasped or picked up therefore making more visuomotor judgments similar to coordinate computations (Niebauer & Christman, 1998). On the other hand, objects in the extrapersonal (far) space are primarily processed in the upper visual field. The upper visual field became specialized for processes such as object recognition and visual search, as these functions are more likely to occur in the far space (Christman & Niebauer, 1997). These findings indicate a functional linkage between the lower and left visual field and the upper and right visual fields (Christman & Niebauer, 1997).

The magnocellular and parvocellular pathways can trigger attentional capture (Ries & Hopfinger, 2011). This activation of attentional mechanism will bias visual processing at multiple levels including early and late sensory processing and later higher order processing (Ries & Hopfinger, 2011). This finding supports Nicholls, Mattingley, Berberovic, Smith, and Bradshaw, (2004) point that the horizontal and vertical biases result from different cognitive/ neural processes. In this set of experiments, a pair of greyscales was presented horizontally, vertically and diagonally. Leftward and upward biases were observed in the horizontal and vertical conditions. When the greyscales were presented diagonally, the leftward and upward biases combined to produce a strong shift of attention towards the upper left. As there was a lack of correlation between the vertical and horizontal biases, the authors concluded that different cognitive/ neuronal mechanisms were involved at different stages of processing. Therefore, differential processing in the upper and lower visual fields and ventral and dorsal streams respectively (Miles & Walman, 1990; Niebauer & Christman, 1998) might bring out biases along the vertical dimension. Horizontal biases are brought out as a result of relative hemispheric differentiation in information processing (Nicholls et al., 2004) possibly in later stages of processing.

Neuroimaging studies also point to separate mechanisms working together to obtain the horizontal and vertical biases. Liu, Heeger, and Carrasco (2006) showed that neural asymmetries relating to the above and below fixation along the vertical meridian arise at the earliest stages of cortical visual processing in an fMRI study. They presented Gabor stimuli of different spatial frequencies on the horizontal and vertical meridians. The data were analyzed in sub-regions of early visual cortex (V1/ V2) that corresponded retinotopically to the stimulus locations. The results showed that the spatial extent and amplitude of the fMRI measurements correlated with the behavioural results pointing out the horizontal asymmetries in early stages of cortical processing. Furthermore, Weiss et al. (2000) showed differential neural activation in dorsal and ventral streams dependent on the upper or lower stimulus presentation. Thus, obtaining bias differences in the upper and lower visual field in this experiment is not surprising and it coincides with my hypotheses.

The unique finding in the current study is that horizontal and vertical meridian biases seem to be present at different levels within the upper or lower visual field. Previous findings indicate that the viewing space is divided into four quadrants: upper left, lower left, lower right, and upper right (e.g. Nicholls et al., 2004; Thomas & Elias, 2012; 2011; 2010; Niebauer & Christman, 1998). Considering these data within the upper or lower visual field, I also obtained upper and lower stimulus manipulation differences which, although alter the magnitude of the bias, do not change the direction relating to the upper or lower field presentation. Varnava, McCarthy and Beaumont (2002), suggests that each cerebral hemisphere has a unique spatial coordinate system that maps out the contralateral hemispace. For each hemisphere there is a distinction between mechanisms dealing with stimuli at different distances within the map system. As the distance increases, the bias will gradually switch from left to right. Therefore, it seems that each hemisphere specializes to monitor along multiple spatial dimensions and shift attention accordingly. Possibly such coordinate system is also formed for the circular arrays leading to the gradual fluctuations of the biases. A larger coordinate system would be formed for each hemispace and a smaller one for the spatial configuration of the arrays.

In this report, the results are considered based on the manipulation of stimuli relative to the circular array with an undisrupted greyscale. For example, the *top* and the *top left* disks are switched as would be accurate considering an undisrupted left/ right or right/ left gradient. However, it is important to note that these circular arrays were presented with their left/right reversed mirror image which would create the opposite manipulation (*top* and *top right* switch – as per the example). As eye-tracking method was not used in this experiment, it is impossible to determine which changes in the arrays the participants were attending to. Previous studies indicate that spatial attention is spontaneously deployed to the left visual field (Niemeier, Singh, Keough, & Akbar, 2008; Niemeier, Stojanoski, & Greco, 2007; Niemeier, Stojanoski, Singh, & Chu, 2008) indicating that any changes within the left field would be noticed more.

The current experiment investigated whether the incremental gradient in greyscales is necessary to attain perceptual asymmetries and whether these biases alter depending on the horizontal and vertical manipulation of such gradient. Current findings indicate that perceptual asymmetries are observed when two greyscale values are disrupted within a circular array comprised of six individual disks. More importantly, these findings also indicate that the additive effect of the biases may not simply rely on the horizontal (left/ right) and vertical (upper/ lower) dimensions dichotomy but also on the relative spatial horizontal and vertical distribution within these dimensions. This view is supported by the lack of sudden jump in magnitude of bias as a result of array manipulation supporting coordinate spatial systems presented by Varnava et al., 2002. Therefore, such distribution should be closely considered when attempting to understand the interaction of horizontal and vertical visuospatial biases in neurologically healthy participants as well as patients with hemispatial neglect. Patients complete line bisection tasks which rely heavily on either the horizontal or vertical dimension dichotomy as an index in determining the severity of neglect. The findings in the current experiment suggest that the magnitude of the error in the performance of these tasks should be used with caution and with consideration of different spatial domains.

Experiment 1 and 2 Conclusion

Hemispheric asymmetries have been widely studied using tasks that provide visuospatial information along either the horizontal or the vertical dimensions. The two experiments showed that lateral biases are observed when the overall greyscale gradient is disrupted and an integration of the stimulus information is required to create an overall representation. Furthermore, these biases also show to be modulated based on the horizontal and vertical distribution of the individual disks and modulated non-linearly with stimulus noise. Finally, these studies showed modulation of the bias direction and magnitude based on the vertical and horizontal axes spatial dissociation.

There are several explanations as to why leftward biases are observed, including visual scanning, reading direction, and motor responses. The asymmetry related to visual scanning and reading habits (Chokron, Bartolomeo, Perenin, Helft, & Imbert, 1998; Manning, Halligan, & Marshall, 1990) was more pronounced in left-to-right readers. However, this explanation does not fully account for biases, as right-to-left readers, also show leftward biases, although smaller in magnitude (Nicholls & Roberts, 2002). Motor bias (Brodie & Pettigrew, 1996; Heilman & Valenstein, 1979) resulting from the engagement of lateralized motor processes, also falls short of fully explaining biases, as previous findings indicate that bimanual responding led to leftward biases as well (Nicholls & Roberts, 2002). Therefore, visual scanning, reading habits, and motor biases fail to provide a complete account of perceptual biases, highlighting the need for a more comprehensive explanation.

The explanation with the most support states that leftward bias could be a result of the asymmetrical distribution of attention between the right and left hemispheres (Niemeier, Sigh et al., 2008). Attention is spontaneously biased to the left side of space due to the dominance of the right hemisphere in spatial and attentional functions (Corbetta & Shulman, 2002; Coull, Nobre, & Firth, 2001; Fink, Marshall, Weiss, & Zilles, 2001; Fink, Marshall, Weiss, Toni, & Zilles, 2002; Foxe, McCourt, & Javitt, 2003). This mechanism seems to alter perception. For example, it increases the apparent luminance contrast (Carrasco, Ling, & Read, 2004). Thus, in this experiment, when viewing the circular array, attention would be spontaneously deployed to the left visual field; the array with the dark disks on the left would seem darker overall when compared to the array's mirrored representation with the dark disks on the right. The current study shows that this bias is evident when judging stimuli that present information along both horizontal and vertical dimensions simultaneously and when the individual stimuli are integrated together into a global representation.

There is a strong relationship between the horizontal elevation and the leftward bias when processing spatial information (Christman & Niebauer, 1997; Chen, Yao, & Liu, 2004; Niebauer & Christman, 1998). This asymmetry is not limited to visual perception or attention, but has also been shown in spatial memory (Genzano, Di Nocera, & Ferlazzo, 2001). Both, the magnocellular and parvocellular pathways of the early visual processing can trigger attentional mechanisms (Reis & Hopfinger, 2011). This activation of attentional mechanism can bias visual processing at multiple levels including early and late sensory processing (Ries & Hopfinger, 2011). This supports the research indicating that the horizontal and vertical biases result from different cognitive/ neural processes at different stages of processing (Nicholls, Matingley, Berberovic, Smith, & Bradshaw, 2004). Differential processing in the upper and lower visual fields and the ventral and dorsal streams respectively (Miles & Walman, 1990; Niebauer & Christman, 1998) might bring out biases along the vertical dimension. Horizontal biases are brought out as a result of relative hemispheric differentiation in information processing (Nicholls & Roberts, 2002), possibly in later stages of processing.

Neuroimaging studies further support the notion that separate mechanisms work together to obtain the horizontal and vertical biases. Liu, Heeger, and Carrasco (2006) showed that neural asymmetries relating to fixation above and below the vertical meridian arise at the earliest stages of cortical visual processing in an fMRI study. They presented Gabor stimuli (e.g. stimuli with light intensity alternates between its darkest and lightest values according to a sine function) of different spatial frequencies on the horizontal and vertical meridians. The data were analyzed in sub-regions of the early visual cortex (V1/ V2) that corresponded retinotopically to the stimulus locations. The results showed that the spatial extent and amplitude of the fMRI measurements correlated with the behavioural results indicating the horizontal asymmetries in early stages of cortical processing. Furthermore, Weiss et al. (2000) showed differential neural activation in dorsal and ventral streams which were dependent on the upper or lower stimulus presentation, indicating a possible emergence of substantial differences in biases.

Taken together, experiments 1 and 2 showed an interesting insight into the prevalence of lateral biases based on the vertical and horizontal distribution of the stimuli information. These studies indicate that integration of visuo-spatial information results in lateral biases which are modulated similarly to those as found in attentional studies. As well, such integration alludes to the involvement of working memory processes.

CHAPTER THREE

VISUAL LOAD AND STIMULUS-RESPONSE TIME INTERVAL IMPACT ON UPPER AND LOWER VISUAL FIELD BIASES

Introduction

We attend to our visual space in an asymmetrical manner where targets located on the left side of our perceived space appear to have accentuated sought after features including brightness, numerosity, size (Nicholls, Bradshaw, & Mattingley, 1999) and distance (Krupp, Robinson, & Elias, 2010). Perceptual processing is considered to proceed automatically and continues until the mechanism runs out of capacity. Therefore, selection becomes a necessary natural consequence of allocating attention (Lavie, 1995). Attention modulates the processing of visual stimuli at early (*i.e*. upon stimulus identification) and later phases of sensory processing including working memory (Gazzaley, 2011). At these later stages of processing attention can determine which stimuli will gain access to working memory (Awh, Vogel, & Oh, 2006).

As attended items permit the encoding in working memory, it is important to determine whether such asymmetries are also evident in working memory. Working memory is a construct that defines the ability to maintain and manipulate information in mind for brief periods of time which would help to guide the subsequent behavioural response (Baddeley, 2003). In this approach the two factors crucial for the retention in working memory are visual load, which will dictate the formation of the working memory content, and time interval needed to maintain the items in memory prior to making a behavioural response. The current study investigates whether either the magnitude or direction of lateral biases is altered when encouraging processing in later cognitive stages mainly in working memory. Experiment 3 investigates whether altering the visual load within the stimuli would induce differential lateral biases dependent on the visual load. Experiment 4 the time interval required to retain the information in working memory was manipulated. The increased delay to respond could result in initiation of working memory to maintain the information for future response. Taken together this combined approach may provide a glimpse into behavioural biases while engaging working memory mechanisms.

Experiment Three

Introduction

The locus of selection of perceptual information varies depending on the amount of visual information presented concurrently and the cognitive demands associated with its processing (Lavie 1995; Lavie, Hirst, de Fockert, Viding, 2004; Lavie & Tsal, 1994). As a result, it is thought that the bottleneck of attentional selection is the filtering mechanism which prevents cognitive resources from being overloaded, but yet assuring a maximum intake of information (Rauss, Pourtois, Vuilleumier, & Schwartz, 2009).

The attentional load (Bahrami, Lavie, & Rees, 2007; Rees, Frith, & Lavie, 1997; Schwartz, Vuilleumier, Huttin, Maravita, Dolan, & Driver, 2005), as indicated from previous fMRI studies (Bahrami et al., 2007; O'Connor, Fukui, Pinks, & Kastner, 2002; Pinsk, Doniger, & Kastner, 2004; Schwartz et al., 2005), is determined by the type and amount of information entering the processing system. Attention has been shown to impact neuronal networks at the earliest stages of processing including the primary visual cortex (V1) (Rauss et al., 2009). In this experiment, participants performed either an easy or a highly demanding task at fixation while EEG recordings of responses. The findings revealed that attentional load modulated C1 amplitude regardless of the visual distracters. Interestingly, these effects were dependent upon the visual field that was tested.

Working memory is also impacted by the amount of visual information coming in. Recent evidence shows that visual working memory has the capacity of about four objects, independent of the number of features which can be attached to each object (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001). However, Alvarez and Cavanagh (2004) indicated that the amount of information stored in working memory is dependent on the information load. They found that the capacity varied substantially across the examined stimulus classes which ranged from distinct objects, to shapes, to colour combinations. The stimuli were briefly presented on a computer screen, followed by a presentation of array of stimuli within the same category. The array varied in the number of presented objects. The goal was for the participants to determine whether the presented object was present in the array or not as quickly as possible. The participants in Alvarez & Cavanagh study showed the capacity to retain 4.4 objects in a simple colour category, but only 1.6 objects in a more complex, shaded cube category (Alvarez & Cavanagh, 2004), therefore contradicting the findings by Luck and Vogel, (1997) and Vogel, Woodman and Luck, (2001) which indicated that the limitation of working memory capacity was four objects. Furthermore, Alvarez and Cavanagh, (2004) indicate an inverse relationship between the number of objects that can be stored and the information load per object. More capacity must be allocated to stimuli that are more complex and, as a result, fewer objects can be stored in memory.

In this experiment, lateral and vertical asymmetries were investigated while manipulating visual load using a greyscale task. Greyscale tasks have been found to be highly effective while investigating perceptual asymmetries (Orr & Nicholls, 2005), where as the circular array is a novel task. Therefore, for the ease of interpretation of the findings, the greyscales were used as this task is more established in the literature. In this task, two rectangular stimuli are presented above and below a central fixation point. One stimulus has the darker side on the left and progressively increases in brightness towards the right. Conversely, the second stimulus is the mirror image of the first and decreases in brightness from left to right. The control of the darkness gradient is attained by manipulation of the black and white pixels within the stimuli which therefore impacts the visual load. Although the two stimuli are equiluminant, participants are expected to continuously select the greyscale with the darkest side on the left. Using this robust paradigm, the visual load was manipulated by increasing or decreasing the number of black and white pixels within the stimuli while maintaining the overall pixel density.

It has been indicated that the upper and lower visual fields relate to viewing distance and the corresponding visual stream processing (Previc, 1990). The upper visual field shows to correspond with the processing within the extrapersonal space. The lower visual field corresponds with the peripersonal space facilitating object manipulation. Further, it is indicated that these relationships are mediated by the corresponding visual streams. The upper visual field and the extrapersonal space are mediated by the ventral stream and the lower visual field and peripersonal space information is processed by the dorsal stream (Previc, 1990). Therefore, presenting the greyscales to the upper and lower portion of the screen, while maintaining fixation on the center, relatively directs the information processing to the upper and lower visual fields, respectively. Rauss et al., (2009) indicated that the impact of the visual load was directed selectively to the upper visual field. Therefore, in the current experiment it is expected that the lateral biases will be impacted more when the information is presented to the upper visual field as compared to the lower visual field.

Method

Participants

Twenty-nine University of Saskatchewan undergraduate students took part in this study. Eleven males and 18 females were recruited from the Psychology Participant Pool and were granted one course credit to complete this 30 minute experiment. The average age was 20 years old and ranged from 18 to 36 years of age. All participants reported to have normal or corrected to normal vision. There were two self-reported left-handers (one male and one female). The remaining participants reported to be all right handed. This experiment as conducted with the ethical approval of the Behavioral Research Ethics Board at the University of Saskatchewan.

Design and Procedure

The stimuli used in this experiment consisted of a pair of rectangles extended horizontally along the screen. Each rectangle contained a number of pixels that varied in density depending on the left or right side of the rectangle. For example, one rectangle had more black pixels on the left side and this density would decrease towards the right side. Conversely, in the same rectangle, the number of white pixels would increase from left to right. Therefore, the overall image would show a greyscale with one lateral side darker than the other. These greyscales were presented simultaneously on the top and bottom of the fixation point. To determine the visual load, the greyscales were modified as follows: for decreased visual load, the original greyscale was divided in half (approximately 100 pixels wide and 750 pixels long), preserving the overall density of black and white pixels. As control, the original greyscale without any modification was used. Finally, to increase the visual load, two of the original greyscales were combined into one (approximately 400 pixels wide and 750 pixels long), therefore, the overall number of pixels would double, but the density would be held constant throughout all the stimuli (Figure 3.1). Greyscales were presented as mirror images, meaning if one greyscale was darker on the left side growing progressively lighter toward the right, then the second presented greyscale would have been lighter on the left growing progressively darker towards the right. Overall, the greyscales were equiluminant (Figure 3.1).

As per Figure 3.1, the fixation point appeared for one second on a grey background prior to the presentation of the greyscales in the center of the screen. The participants were required to maintain their gaze on the fixation point. Immediately following the presentation of the fixation point, the greyscales would simultaneously appear for 1 second. Then a prompting screen would appear, requiring the participants to determine which one of the two greyscales seemed overall darker to them. The participants responded using a key press. This was a forced choice task and the trials did not advance until a response was made. All participants were able to complete the task in the allotted time.

The images were presented on an 17 " Sceptre CRT DragonEye monitor with 36 x 28 cm dimensions (width x length) running a 1280 x 960 resolution. Participants were sitting approximately 60 – 80 cm from the screen. The greyscale arrays were presented between 30 mm and 75 mm above and below the fixation point depending on the condition.

There were 12 practice trials to ensure that the participants were comfortable and familiar with the task. Immediately following these training trials, 192 test trials were administered randomly. There were 64 trials for each visual load condition. The presentation order, orientation, and screen position was counterbalanced between trials and all trials were presented randomly.

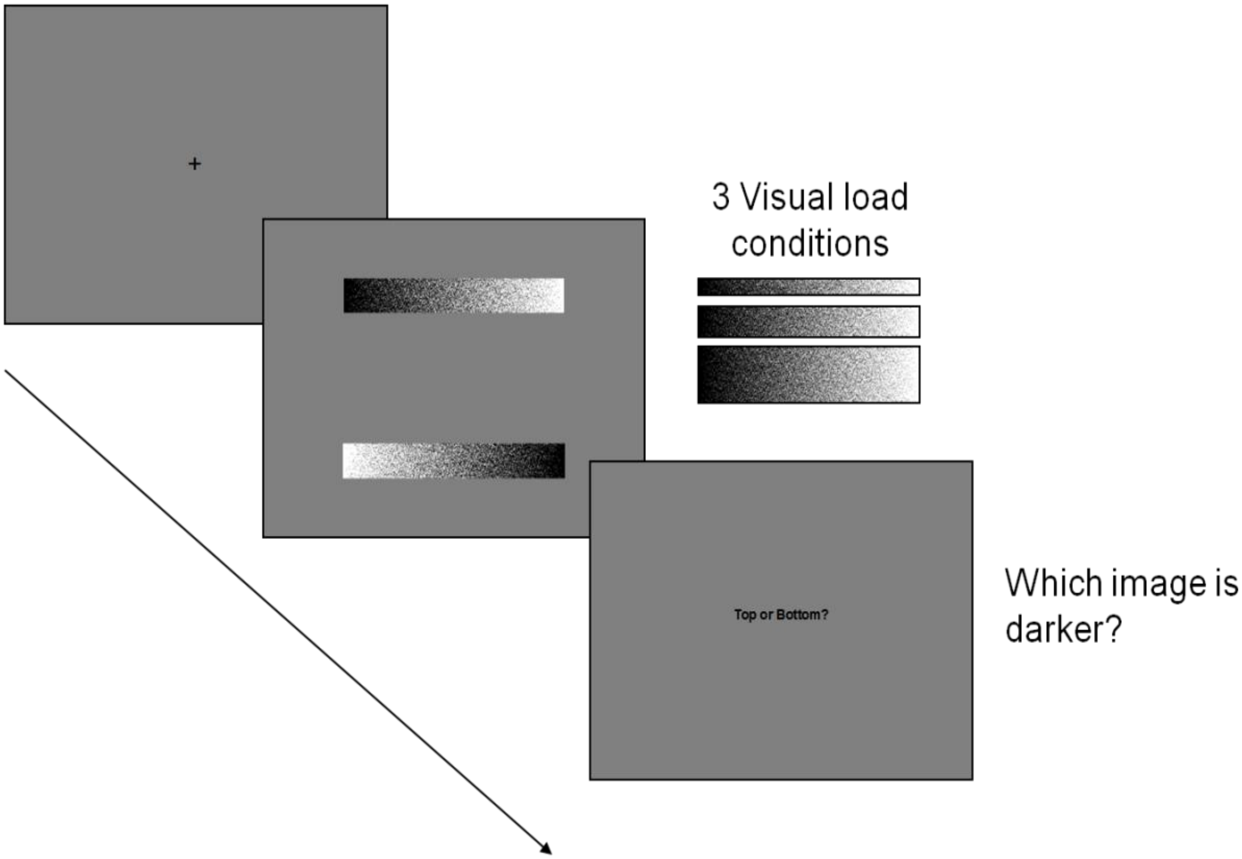

Figure 3.1. Diagrammatic representation of trial progression. The fixation point was presented for 1 s followed by stimuli presentation at various visual loads. The control stimuli were medium width. The small and large visual load stimuli were prepared such that the overall number of black and white pixels varied, but not the density. Following the stimulus presentation, participants were required to determine which greyscale was darker overall.

Results

All participants successfully completed the task and no data were excluded from the analysis. Left responses were counted when the participant selected the greyscales with the darkest side on the left. Conversely, responses were counted as right when participants selected the greyscale with darkest disks on the right side of the computer screen as overall darker. Individual laterality scores were calculated for each participant using the following formula:

[(# of left responses - # of right responses)] / [(# of left responses + 3 of right responses)]

The obtained laterality index was used as the dependent variable in the analysis. To determine whether the attained biases were statistically different from 0 (no bias) independent samples t-tests were conducted for each condition. The results showed all biases were statistically different from 0 as depicted in Figure 3.2 with an asterisk.

An overall repeated-measures ANOVA was conducted with visual load (small, medium, and large) and visual presentation on the computer screen (upper half, lower half) set as within-subjects factors. Laterality index was set as the dependent variable. The sphericity assumption was upheld and no corrections were necessary for the main effects or interactions. There was an indication that the bias for stimuli presented in the upper half of the screen was slightly stronger (*M* = -.282, *SE* ± 0.09) than that in the lower half of the screen (*M* = -0.213, *SE* ± 0.08), however this difference was not statistically significant, *F*(1, 28) = 1.569, *p* = .22. The attained bias did not increase linearly with the visual load, meaning that although the smallest bias, *M* = -0.239, *SE* ± 0.08, was attained with the smallest visual load, the largest bias was obtained in the control trials, where the stimuli was not manipulated, *M* = -0.258, *SE* ± 0.08, and not with the largest visual load, *M* = -0.239, *SE* ± 0.08. Again, this main effect was not statistically significant *F*(1,

56) = 0.262, *p* = .77. There was, however, a significant interaction of visual screen position and visual load, *F*(2, 56) = 9.548, *p* < .05.

To investigate this interaction further, paired samples t-tests were conducted to determine whether biases were impacted by visual load within either the upper or lower half of the screen. In the lower screen presentation, the bias increased in magnitude with the increased visual load, *t*(28) = 2.586, *p* = .015. Conversely, the magnitude of the bias decreased for stimuli presented in the upper half of the screen with the increased visual load, *t*(28) = 2.623, *p* = .014. Paired-samples t-tests were conducted to determine a difference between the upper and lower screen stimuli presentation for each visual load. There was a significant difference between the visual fields in the small and medium visual load conditions, *t*(28) = 2.114, *p* = .022 (one-tailed) and *t*(28) = 1.917, *p* = .033 (one-tailed) respectively. There was no difference between the screen position in the largest visual load variable, *t*(28) = 1.333, *p* = .097. Overall, the results indicate a strong leftward bias for stimuli presented in the upper and lower half of the computer screen dependent on the stimulus visual load (Figure 3.2).

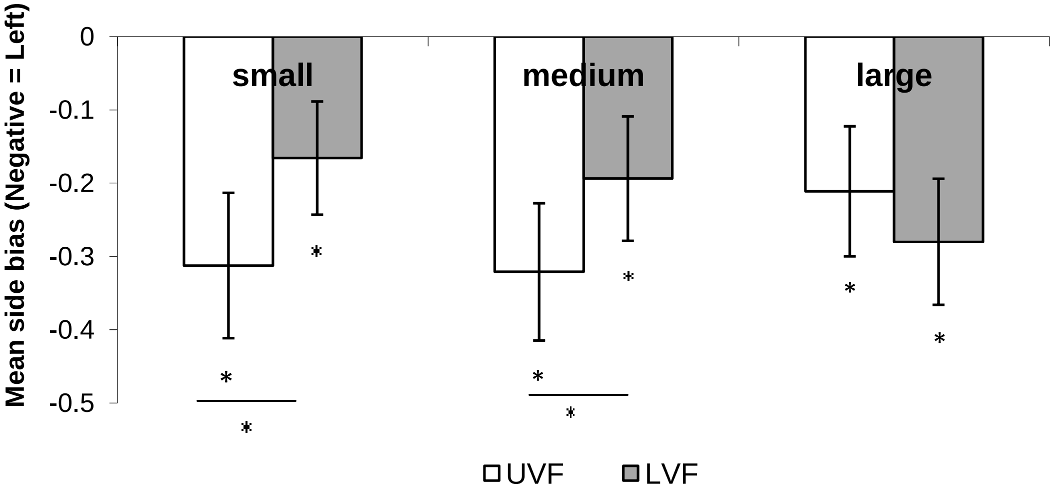

Figure 3.2. Mean bias for each visual load condition and visual field. UVF indicates upper half of the screen and LVF indicates lower half of the screen. Asterisk represents bias statistically significant from 0 (no bias) and the error bars show standard error of the mean. The biases between the UVF and LVF in the small and medium visual loads were significant, *p* = .022 and .033, respectively and are represented by the horizontal line with an asterisk. There was no significant difference between UVF and LVF in large visual load condition, *p* = .097. Furthermore, there was a significant difference between the small and large visual field load in the upper and lower visual fields, *p* = .014 and *p* = .015, respectively.

Discussion

This experiment investigated whether visual load impacts the leftward bias and whether this impact differed depending on the visual load of the stimuli. The findings showed an overall, slightly larger bias for stimuli presented in the upper half of the screen when the stimuli were presented with decreased total number of pixels. Such presentation of reduced visual information could be interpreted as small visual load, which would be consistent with current literature. Possibly, this difference emerged from the selective processing of stimuli in the upper and lower visual field (Thomas & Elias, 2010). The biases were stronger when the stimuli were presented in the top half of the computer screen with the most reduced total number of pixels. The biases obtained within the top half of the screen reduced as the total number of pixels within the stimuli increased. The opposite result was evident for stimuli presented to the bottom half of the computer screen. The biases decreased in conditions with reduced total number of pixels, compared to the condition with highest number of pixels within the stimuli.

The obtained results could be attributed to the visual load of the stimuli. The visual load could be considered as small within stimuli with the lowest amount of pixels. The visual load could increse with the larger stimuli as there would be more information the visual system would need to process. However, the opposite could also be argued, the stimuli in which there was the smallest amount of pixels could be interpreted as high visual load. With having such limited amount of information, compared to stimuli with large amount of pixels, additional capacity would need to be directed in order to categorized the limited amount of information. Thus, the stimuli with large amount of pixels could be considered as lower visual load.

Experiment Four

Introduction

The definition of working memory, as indicated by Baddeley (2003), states that the information is maintained as representation of a visual stimulus over time even after that stimulus is no longer present. Therefore, in the current experiment a delay was introduced prior to the response for 0 seconds, 1 second, 5 seconds, or 10 seconds. If there is an indication that biases are persistent in working memory, then the biases should remain with an increased response delay. If, however, there is no maintenance of the information in working memory, lateral biases should decrease with a prolonged response.

Methods

Participants

In total, 64 undergraduate Psychology students at the University of Saskatchewan took part in the study. There were 24 males and 39 females. The data from one female were not used in the study due to the participant answering their phone during the experimental trials. All participants reported to have normal or corrected to normal vision. Students received one course credit in exchange for their participation. There were seven self-reported left handed (two were males) and 57 right handed participants. The mean age of the participants was 20 years old and ranged from 18 to 29 years old. This experiment was conducted with the ethical approval of the Behavioral Research Ethics Board at the University of Saskatchewan.

Design and Procedure

The stimuli presented in this experiment consisted of two rectangular greyscales with an incrementing black-to-white pixel ratio distributed along the horizontal plain of the rectangle. One of the greyscales was darker on the left side and would become progressively lighter towards the right side. The second presented stimulus was mirror-reversed, where the brightest side was on the left side with an increased darker pixilation towards the right side. Overall, the two stimuli were equiluminant. The greyscales were presented on the top and bottom of the fixation point (30 mm away from fixation point) on a grey background. The greyscale stimuli has been widely used to investigate perceptual asymmetries and show exceptional sensitivity to left/ right variation of spatial processing between the hemispheres (Mattingley, Berberovic, Corben, Slavin, Nicholls, & Bradshaw, 2004; Nicholls, Bradshaw, & Mattingley, 2001).

As seen in Figure 3.3, the fixation point was presented for 1 second prior to the presentation of the greyscales. The participants were required to maintain their focus on the fixation point throughout the trial. Once the fixation point disappeared, two greyscales (approximately 100 mm) were presented simultaneously on the grey background for 1 second. Following this, fixation point would appear and remain for 0 s, 1 s, 5 s, or 10 s. In the 0 second time interval, the screen prompting a response would appear immediately after the greyscales were presented. Once the prompting screen appeared, the participants were required to determine which greyscale seemed overall darker to them. They were required to respond using designated keys on the computer keyboard. They were to press the "top" key if they judged the top greyscale as darker and the "bottom" key for the bottom array. All responses were forced choice and the trials did not advance until a response was made. None of the participants took a significantly long amount of time to respond and thus no one timed out of the task.

Prior to the presentation of the test trials, each participant completed eight training trials to ensure they felt comfortable with the task and understood what was required of them. A 128 test trials immediately followed the training, with the same procedure. There were 32 trials for each delay interval. All trials were counterbalanced for the left/ right greyscale orientation and top/ bottom screen position. Furthermore, training and test trials were presented in blocks where training trials preceded test trials. Within the block, the trials were presented randomly. Participants had 30 minutes to complete the task. As mentioned earlier, no participant took longer than the allotted time. Upon completion of the trials, each participant was debriefed and thanked for their participation.

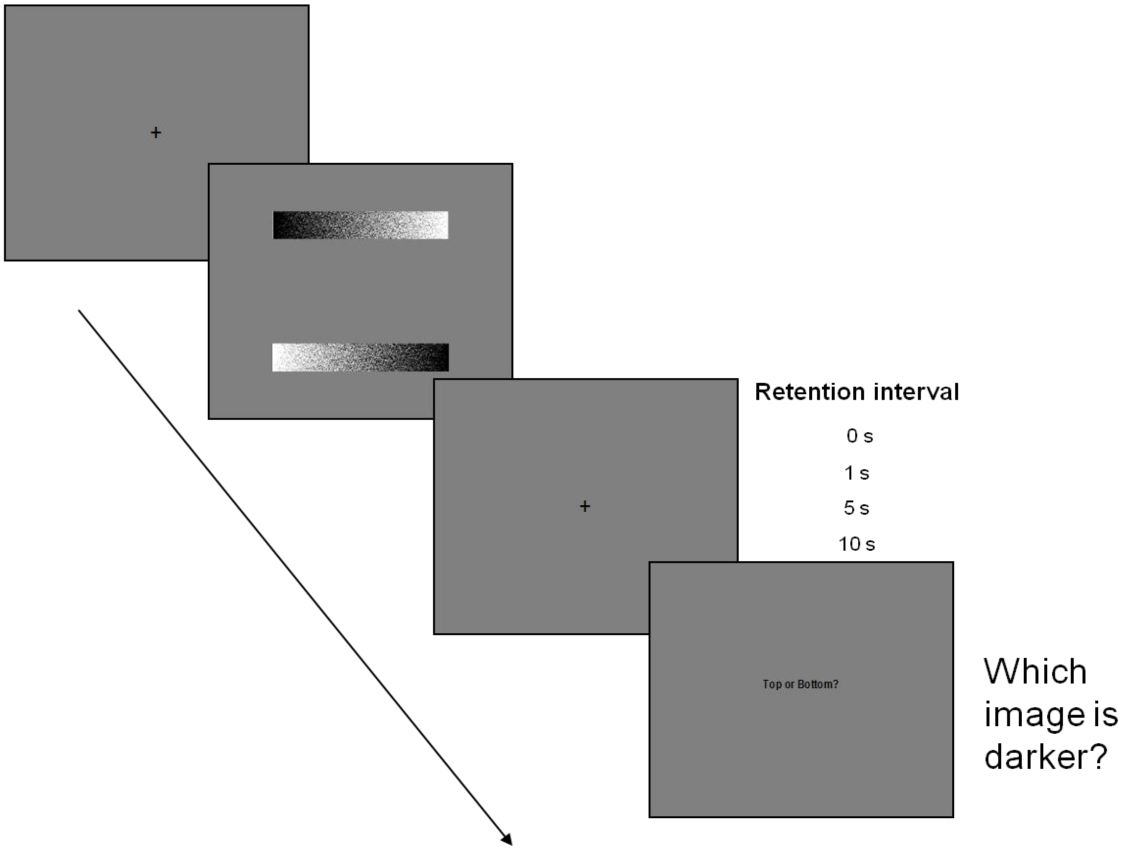

Figure 3.3. A diagram representing trial progression. First, the fixation point was presented, followed by the stimuli presentation for 1 second. Once the stimuli were presented, there was a time interval of 0, 1, 5, or, 10 seconds before participants indicated, using key press, which greyscale seemed overall darker to them.

Results

All but one participant successfully completed the task. The data from one female were excluded from the experiment due to an interruption during the experiment. Individual laterality scores were calculated for each category and used as the dependent variable. Independent samples t-tests were calculated to determine whether the biases are significantly different from 0 (no bias). Only the presentation with 0 second time interval showed to be significant for both the upper and lower visual fields, $t(62) = 2.989$, $p = .002$ (one-tailed) and $t(62) = 1.738$, $p = .043$ (one-tailed), respectively. There was a significant bias in the upper visual field at 1 second time interval, $t(62) = 2.025$, $p = .023$ (one-tailed). No other lateral biases were statistically different from 0.

An overall repeated-measures analysis of variance (ANOVA) was conducted with time (0 s, 1 s, 5 s, and 10 s) and visual screen position (upper and lower) as within-subjects variables and laterality index as the dependent variable. The sphericity assumption was violated for the time condition, X^2 (5) = 0.626, $p < .05$ and for the visual screen position x time interaction X^2 (5) = 28.407, $p < .001$, $\varepsilon = 0.811$ and the Greenhouse-Geisser correction was used to compensate the degrees of freedom. There was a significant main effect of time, $F(2.337, 144.863) = 4.076$, $p = .014$. The main effect of visual field was not statistically significant, $F(1, 62) = 1.759$, $p = .19$. Finally, the time x visual field interaction was not significant, $F(2.320, 143.816) = 1.165$, $p = .32$.

Further tests were conducted to investigate the significant effect found in the time condition. As seen in Figure 3.4, the strongest bias ($M = -.148$, $SE \pm 0.05$) was obtained when participants were required to respond immediately following the stimulus presentation. Interestingly, the weakest biases were obtained at 5 and 10 second time intervals prior to response (*M* = -0.028, *SE* ± 0.04 for both time intervals). A paired samples t-test shows that the bias between 0 and 1 second intervals is significant, *t*(62) = 1.906, *p* = .03 (one-tailed). However, biases at 1 and 5 second intervals were not significantly different from one another, *t*(62) = 1.372, *p* = .087 (one-tailed). These findings indicate that these lateral biases are strongest during immediate response. However, once the participant is required to wait to respond, the bias disappears. This effect shows to be instigated at less than a 1 second delay in response.

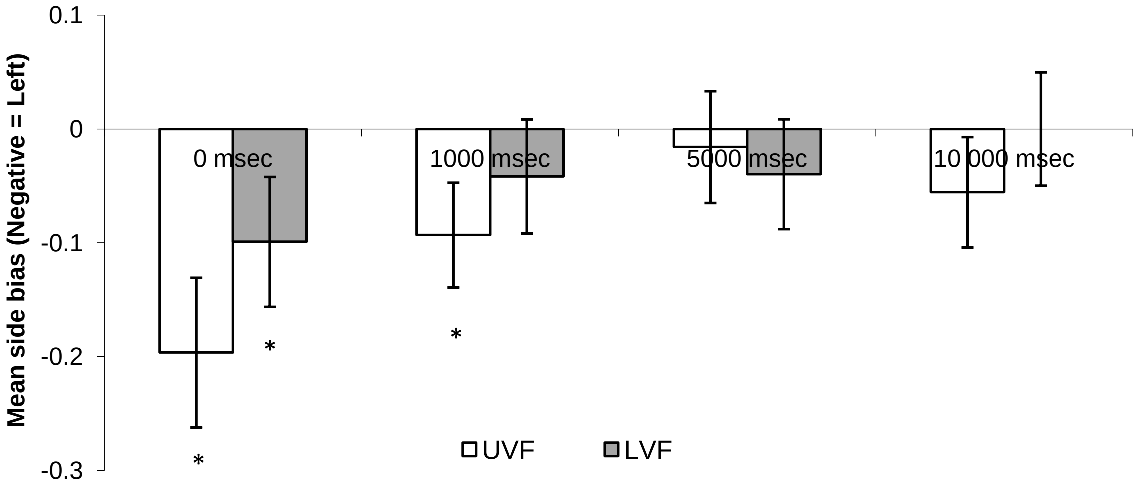

Figure 3.4. Mean bias for each time condition and visual field. UVF indicates stimuli presented to the upper half of the computer screen and LVF indicates stimuli presented to the lower half of the screen. Asterisks represent biases significantly different from 0 (no bias). Error bars represent standard error of the mean. Strong leftward biases are obtained with shorter response time interval and disappear with longer time interval.

Discussion

To investigate whether lateral biases persist with increased response delay, the participants were tested using a greyscale task with a delayed response to the stimuli. If working memory processes were utilized in this task, then the results should show maintenance of biases in longer response delay trials. The findings in the current study showed strong leftward biases when the delay interval was 0 seconds, indicating that the participants responded immediately once the greyscales were presented. These biases decreased substantially with increased response delay and at 5 second delay, biases were not different from zero (no bias). Therefore, the findings in this experiment showed that the biases disappeared when the information was required to be stored for a period of time. This decrease in bias occurred as early as 1 second of delay between the presentation of the stimuli and response and it became not significant at 5 seconds.

Discussion for Experiments 3 and 4

Perceptual asymmetries have been attributed to attentional processes. In this study, it was investigated whether asymmetries will persist when challenging the attentional processes by increasing the visual load and inducing the maintenance of information by delaying response. In experiment 3, the visual load was increased by increasing the overall number of pixels presented in the greyscale task. The results showed an increased bias in the UVF which diminished with the increased visual load. Conversely, an increased leftward bias was observed in the LVF with an increased visual load.

Experiment 4 investigated whether biases persist when retaining the brightness judgment information by delaying the response. Strong leftward biases were observed in the UVF and LVF when the response on judgment was provided immediately after stimuli were presented. The biases decreased with an increased time delay. Even at 1 second delay, the biases already diminished and only leftward bias in the UVF was statistically significant. Biases at 5 and 10 second delay intervals were not different from zero. These findings indicate that possibly visual load, but not delayed response time may impact processes other than perception or attention.

The biases obtained in experiment 3, when manipulating the visual load did not differ between the three conditions. Interestingly, there were significant differences between the UVF and LVF in these conditions. It seems that there is an opposite effect between the upper and lower visual fields with an increased visual load. The biases increase in magnitude in the LVF with increased load and diminish in the UVF. It seems that the most obvious explanation for this effect is that with the increased size of the stimuli, it is feasible that more information was provided to either visual field. For example, the smaller stimuli were viewed more in the UVF than the larger stimuli. However, as the stimuli were presented on top and bottom of the screen, the information was equally distributed to be viewed by both visual fields. Although it is feasible that the participants made eye movements despite the fact that they were instructed not to do so this could have created a confound variable. The effects would have been equally distributed between the two visual fields resulting in no difference between the stimuli presented in the upper and lower half of the screen. Although the findings found no main effect of screen position, there was a significant interaction between screen position and the visual load. As the information presented in the upper half of the computer screen can lead to increased processing in the upper visual field (UVF) and processing of stimuli on the lower half of the screen can lead to selective relative processing of this information in the lower visual field, it is reasonable to indicate that the observed effect in this study could be due to the visual field processing. This is further supported based on the findings in experiments 1 and 2 which also showed differences based on the horizontal distribution of the stimuli. As well, these differences are observed with varying noise presentation, processing of which is shown to differ based on the visual field.

The processing of information differs in the UVF and LVF, where LVF advantage is observed in spatial resolution tasks (Carrasco, Williams, & Yeshurun, 2002; Rezec & Dobkins, 2004) and contrast sensitivity at low to moderate spatial frequencies (Cameron, Tai, & Carrasco, 2002; Carrasco et al., 2002; Lundh, Lennerstrand, & Derefeldt, 1983; Rijsdijk, Kroon, & van der Wildt, 1980). Such advantage in LVF is attributed to the neuronal properties of the visual pathway transferring information. As the amount of contrast and spatial resolution increased with the increased number of pixels presented in the largest stimuli; this would favour LVF processing. Conversely, the UVF advantage would begin to diminish and thus the bias would have also diminished.

The obtained effects are explained by early visual processing without the involvement of later stage processing. Possibly, the introduced visual load manipulation was not significant enough to bring out changes in biases which would be a result of later processes such as working memory. Recent research indicates that working memory can maintain information of about 1.6 to 4.4 stimuli depending on the number of objects and visual load (Alvarez & Cavanagh, 2004). As only two stimuli were presented at a time, it was important that the information is involved enough to substantially increase the visual load for any relevant changes in biases to be observed.

In addition to increased visual load, working memory processes are involved when visual representations must be maintained over a period of time for future use (Baddeley, 2003). As such, experiment 4 was conducted to investigate whether lateral biases will also be apparent once the response is delayed. Findings showed decreased biases with the increased response delay. In this experiment, it is feasible that the method in which the stimuli were presented resulted in the obtained results. As indicated by Regan and Beverly (1985), when an observer is asked to compare two sequentially presented stimuli, there are four stages that are involved for the maintenance of representation even after it is no longer visually present. The first stage is the encoding of the visual features of the first stimulus. Following this is the maintenance of the representation of the visual stimulus during the delay. The third stage is the encoding of the second stimuli. Finally, the fourth stage is the comparison of the two representations. In the current experimental set up, the time delay was introduced only after both stimuli were presented. There was not enough time permitted for the maintenance of the first stimuli representation. Furthermore, there was too much time permitted in the delay to maintain, not the presentation of the stimuli, but the conclusion of the brightness judgment made while the two stimuli were presented. Possibly the presentation of the stimuli in close temporal proximity impeded the involvement of working memory (Montaser-Kouhsari & Carrasco, 2009). This explanation supports the drastic demise of lateral biases with increased response delay in experiment 4.

Taken together, the main purpose of these two experiments was to investigate whether perceptual asymmetries play a role with more demanding visual load presentation and increased response time delay; two factors derived from the definition of working memory. The findings obtained in these experiments show weak evidence for the presence of lateral biases in later stages of information processing. Therefore, further investigation needs to be conducted addressing the methodological and theoretical shortcomings obtained this current study using the circular array task requiring an integration of stimuli therefore increasing the possible involvement of working memory processes.

CHAPTER FOUR

LEFT AND RIGHT REPRESENTATIONAL BIASES INCREASE WITH INCREASED PROCESSING WITHIN WORKING MEMORY

Introduction

Pseudoneglect (Bowers & Heilman, 1980) has been shown to be a robust behavioural bias attributed to the right parietal region processing spatial information. Most commonly, this bias is associated with line bisection tasks, where participants are asked to bisect a horizontal line presented across their left and right visual field (Bowers & Heilman, 1980). The results show that participants slightly, but consistently, err towards the left of the midpoint therefore misrepresenting the left side of their visual space. This effect has been shown to be modulated by handedness, gender, age, and stimulus type (Jewell & McCourt, 2000 for review) further increasing its complexity.

In addition, perceptual asymmetries have been observed in greyscale tasks (Nicholls, Bradhsaw, & Mattingley, 1999; Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004). In this task, two stimuli showing an incremental brightness change from one side to another are presented on a computer screen as greyscales. Participants reliably select the greyscale with the darkest side on the left, as compared to its mirror image, to be overall darker despite that the two are equiluminant (Nicholls et al., 1999). Similar lateral biases have also been shown in the judgment of size, numerosity (Nicholls et al., 1999), distance (Krupp, Robinson, & Elias, 2010) and spatial frequency (Niemeier, Singh, Keough, & Akbar, 2008; Singh, Stojanoski, Le, & Niemeier, 2011).

It is well accepted that leftward biases rise due to an increased right hemisphere activation when processing attentional visuospatial tasks (Bultitude & Aimola-Davies, 2006; Corbetta, Miezin, Shulman, & Petersen, 1993; Corbetta & Schulman, 1993; Fink, Marshall, Weiss, & Zilles, 2001; Fink, Driver, Rorden, Baldeweg, & Dolan, 2000; Singh-Curry & Husain, 2009) and are attributed to be a behavioural manifestation of both attentional and perceptual mechanisms working together (Porac, Searleman, & Karagiannakis, 2006). The increased attentional processing amplifies the contralateral hemispace resulting in misjudgment of the leftward stimuli when compared to the rightward one (Porac et al., 2006).

According to the perceptual approach, the perceptual and geometric factors of the stimulus, such as a line, affect the representation of space (Fleming & Behrmann, 1998; McCourt & Garlinghouse, 2000). Porac et al., (2006) using simple horizontal lines with non-target dots, were able to manipulate the position of the target by changing the mean position of all stimuli in close proximity. This manipulation targeted the differential properties of the perceptual and attentional processes. The results supported the notion that both perceptual and attentional processes must play a role for these biases to occur. The stimulus manipulation affected the responses without the use of illusions indicating a perceptual influence. Furthermore, the results were also consistent with other findings showing bisection errors as a result of attention shifts due to cue use. Taken together, Porac et al. (2006) concluded that both processes are involved in the formation of asymmetries in line bisection.

Aside of behavioural biases, perceptual and attentional mechanisms have a profound impact on other cognitive abilities, such as working memory and vice versa (Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006; Dell’Acqua, Sessa, Toffanin, Luria, & Jolicoeur, 2010; Downing, 2000; Makovski, Sussman, & Jiang, 2008). Models of selective attention indicate an efficient encoding of relevant targets among an overwhelming quantity of sensory information. Additionally, working memory models highlight the temporary maintenance of information in a limited capacity system which promotes efficient access and updating of information (Awh &

Jonides, 2001; Awh et al., 2006). The closely intertwined relationship between attention and working memory is indicated by an overlap in information processing goals where both mechanisms enable goal driven processing by increasing the accessibility of relevant information from the background of distracters (Awh & Jonides, 2001; Awh et al., 2006). Awh and Jonides (2001), indicate that observers, when processing spatial information, can direct their attention towards a specific location enabling faster and more efficient processing. They highlight that this process is the key component of rehearsal in spatial working memory which recruits top-down process modulating the earliest stages of visual analysis. Thus both mechanisms signify the reciprocal relationship between earlier and later visual processing.

As indicated earlier, processing of visuospatial information is often biased raising an interesting question of whether working memory biases are also evident. Emerging evidence indicates that, indeed, such biases are attainable. McGeorge, Beschin, Colnaghi, Rusconi, and Della Sala, (2007) showed a bias for visuospatial representations held in memory. In this study, adapted from Bisiach and Luzzatti (1978), participants were asked to recall the objects presented on the left and right sides of a famous to them cathedral square. The findings showed that participants were more accurate at recalling items from the left-hand side of the remembered space as compared to the right side. As this bias was representational in nature, McGeorge et al., (2007) used the term *representational pseudoneglect* to describe this specific asymmetry of visuospatial representation in memory.

Aside of these studies, there is little literature investigating the impact of perceptual asymmetries on working memory, or vice versa. Therefore, the purpose of this experiment was to add to this novel research area and further investigate lateral biases in working memory. A brightness judgment task was used, where six individual disks were presented in a circular array.

The array varied in shading from left to right and vice versa, indicating an overall graded greyscale extending across. This array was presented with its mirror image. Similar paradigm is vastly used when investigating perceptual asymmetries (Orr & Nicholls, 2005; Nicholls, Bradhsaw, & Mattingley, 1999; Thomas & Elias, 2010; 2011). Greyscale gradient presented as an array also shows comparable biases, as shown in experiments 1 and 2, when participants are required to integrate individual stimuli into one representation.

To investigate working memory, stimuli at differing inter-stimulus intervals were presented, including 0, 1, and 3 seconds. Furthermore in half of the trials, noise mask after the presentation of the first array was presented to facilitate or inhibit the formation of working memory trace. Backward stimulus masking has been shown to manipulate the formation of a working memory trace (Smith, Ellis, Sewell, & Wolfgang, 2010). Masked stimuli limit processing to the perceptual and attentional stages. However, in unmasked stimuli, the memory trace is permitted to form as evident by differences in recall accuracies of masked and unmasked stimuli (Smith et al., 2010).

In this experiment, it is expected to obtain differences in biases and recall accuracy based on whether the memory trace was permitted to form or not. More specifically, if asymmetries translate to working memory processes, then strongest leftward biases with longer inter-stimulus time intervals should be observed where memory trace was permitted to form. If, however, lateral asymmetries are restricted to attentional processes only, then a decreased bias in conditions with longer inter-stimulus intervals is expected. Stronger leftward biases should be observed when the time interval was the shortest and stimuli were masked. Furthermore, recall that is more accurate is expected, with an increased time interval and when memory trace was permitted to form, as compared to shorter inter-stimulus time interval and masking the first array.

Methods

Participants

In total 67 undergraduate students at the University of Saskatchewan were recruited from the Psychology participant pool to take part in the study. The data were collected from 61 students (12 male and 49 female) as six students failed to complete the task in the allotted time. Students received one course credit in exchange for their participation. Based on self-report all participants had normal or corrected to normal vision. The average age of the participants was 21 and ranged from 17 to 42 years old. All participants used their dominant writing hand to respond. Both right- (n = 58) and left- (n = 3) handed participants took part in the experiment. This experiment was conducted with the ethical approval of the Behavioural Research Ethics Board at the University of Saskatchewan.

Design and Procedure

Participants were seated in front of a standard desktop computer running with a 17-inch screen located approximately 1 m away from the participant. The fixation point was presented at the participants' eye level. All trials were run on the computer using E-prime software (Psychology Software Tools Inc., Pittsburgh, PA; www.pstnet.com/eprime) which recorded the participants’ responses and response times. Stimuli were presented using Sceptre CRT DragonEye 17” computer screen running 1280 by 960 resolutions.

Figure 4.1 is a schematic representation of the trial progression. Each trial began with the presentation of a fixation point for 1 second on a grey background in the center of the computer screen. The participants were required to focus and maintain their gaze on that fixation point throughout the progression of the trial. Following, a circular array was presented for 1 second on a white background on either the left or the right side of the fixation point. The array comprised of six individual greyscale disks, approximately 30 mm in diameter, arranged in a circular array so that one disk was presented on top, one on the bottom and two on each lateral side. Overall, the array was approximately 100 mm in diameter from the outermost disk circumference. The disks consisted of three shades of grey: light, medium and dark. Therefore, in each array two disks represented each shade. Black, white, and grey pixels within each disk were randomized at a rate of 75% giving an image an overall grainy appearance, but preserving the overall shade. Therefore, the overall array showed a greyscale where on one side the two disks contained darkest shades and the other lateral side contained lightest shades. For example, one array contained the darkest disks on the left and the lightest disks on the right side. The left/right mirror reversed arrays would have the opposite gradient: darkest disks on the left and lightest disks on the right. The medium shade disks were always presented as the top and bottom of the array comparable to the 12 and 6 hour on a clock.

Following the presentation of the first array, half of the trials were administered with a noise mask presented for 1 second. The noise mask consisted of black and white pixels randomly scattered throughout the screen. The other half of the trials were unmasked. The masked and non- masked trials were administered in blocks and counterbalanced between participants. Once the mask was presented, or immediately following the presentation of the first array, the fixation point was once again shown for 0, 1, or 3 second intervals. The time intervals were counterbalanced and presented randomly within each masking block. Once the time delay lapsed, a second array was shown on the opposite side of the fixation point and in the opposite greyscale orientation as compared to the first array. If the first array was presented with the darkest disks on the left side and on the left side of the computer screen, then the second array was presented with the darkest disks on the right side and on the right side of the fixation point. Therefore, the arrays were left/ right mirror reversed and were equiluminant. Array pairs were never presented to the same position or with the same greyscale orientation within the same trial. The greyscale orientation and position of arrays was counterbalanced and presented randomly.

Overall, participants received 24 training trials to familiarize themselves with the general procedure of the experiment and feel comfortable with completing the task. Test trials began immediately once the training trials were completed and each participant received 48 test trials for each *mask* and *no mask* condition. Therefore, overall each participant received 120 trials.

The goal was for participants to judge the overall brightness of the arrays by selecting seemingly overall darker image. Once they have responded with a key press, the participants were then prompted to indicate the position and orientation of the two arrays. Corresponding keys were marked on the computer’s number pad for the participants’ answers. In order to limit motor memory and response, participants were asked to keep their hands off the keyboard for the duration of the trial. This was a forced choice task and response was required to advance to the next trial. Participants had 30 minutes to complete the task. Once this time lapsed, the experiment was terminated. At the end of the experiment, whether completed or not, each participant was thanked and debriefed.

Data Analysis

The response time and responses were recorded for each trial and responses were used to calculate the bias. Total number of left and right responses was determined for each participant and each condition. A left bias was indicated when the participant selected the array with two darkest images presented on the left side. Conversely, right bias was assumed when participants selectively indicate the overall image as darker when the darkest disks are presented on the right side of the array, regardless of the screen position. Laterality index scores were calculated for each individual using the following formula:

[(# of right responses) – (# of left responses)] / [(# of left responses) + (# right responses)]

Values closer to -1 indicated a stronger leftward bias while values closer to + 1 indicated a stronger rightward bias.

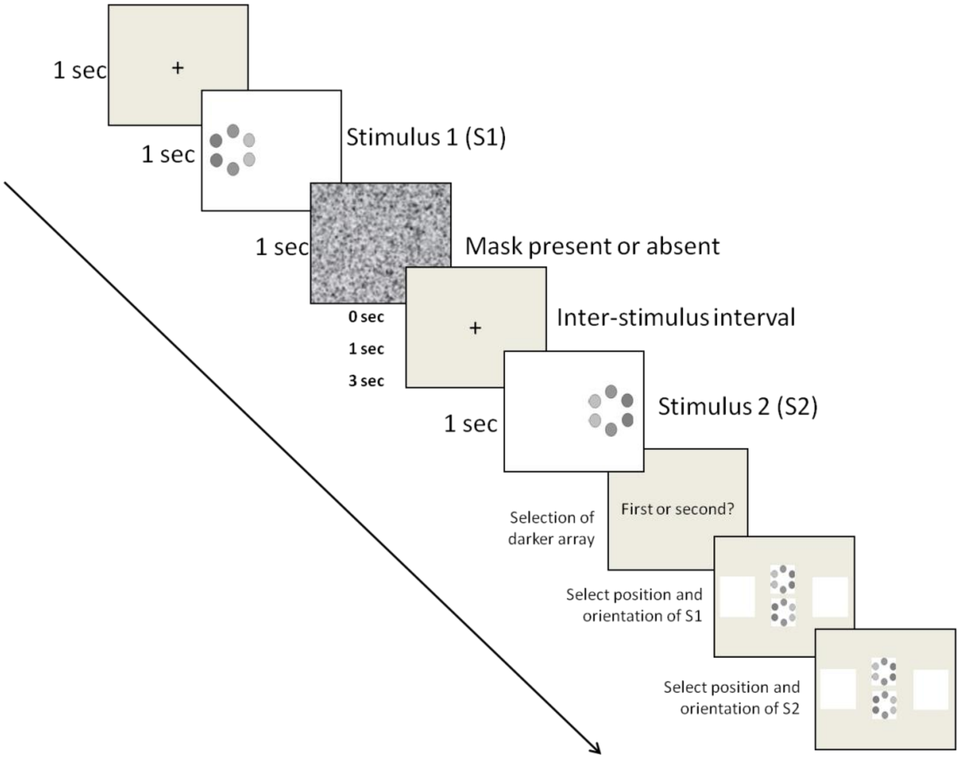

Figure 4.1. Pictorial representation of the trial progression. Participants began each trial with a fixation point. Following this they were presented with stimulus 1 (S1). In a third of the trials, following the S1 presentation, participants saw a noise mask presented for either 1 or 3 seconds. Then, the second stimulus was presented. The second stimulus (S2) was always on the opposite side and was oriented opposite to S1. This diagram is a representation of only one trial. The orientation and position of the stimuli were counterbalanced so that each position and orientation was presented as S1 and S2. Once S2 was presented, participants were prompted to determine which array was overall darker. Then they were prompted to select the position and orientation of the presented stimuli.

Results

Six participants failed to complete the task in the allotted time and their data were excluded from the analysis. Therefore, the data were analyzed from 61 participants. The laterality index was calculated using the above mentioned formula and used to evaluate the left and right biases. Mean was obtained for each individual and aggregated to attain the mean laterality index for each condition. Similarly, the accuracy of recall was attained for the first array and used to evaluate the retention of information in working memory. Both were used as dependent variables in the corresponding data analyses.

Bias Scores

Overall, the results show a strong directional bias relating to the position of presentation and the orientation of the array. One sample t-tests were conducted to determine whether biases for each condition differed from 0 (no bias) and are represented with an asterisk in Figures 4.2 and 4.3.

A repeated-measures ANOVA was conducted with stimulus position relating to the fixation point (left, right), orientation of the array greyscale (left, right), mask (present, absent), and inter-stimulus time interval (0 sec, 1 sec, 3 sec) set as within-subjects factors. The laterality index was set as the dependent variable. There was a significant main effect of position, $F(1, 60) = 5.686$, $p = .02$, $\eta^2 = .087$. Based on the left/ right screen position, the responses were evaluated, using a one sample t-test, to determine whether the obtained directional differences were statistically different from 0 (no bias). The arrays presented on the left side of the fixation point showed a slight leftward trend, ($M = -0.03$, $SE \pm 0.02$) and arrays presented on the right side of the fixation point showed a statistically significant rightward bias, ($M = 0.04$, SE ± 0.02). There was also a significant, but reversed, main effect of array greyscale orientation, $F(1, 60) = 33.545$,

$p < .001$, $\eta^2 = .359$, where arrays presented with the darkest disks on the left side showed a strong rightward bias, ($M = 0.22$, $SE \pm 0.02$) and arrays with darkest disks on the right side showed a strong leftward bias ($M = -0.21$, $SE \pm 0.02$). There was no main effect of stimulus masking or inter-stimulus time interval, $F(1, 60) = 0.025$ $p = .875$, $\eta^2 < .001$ and $F(2, 120) = 2.309$, $p = .104$, $\eta^2 = .037$ respectively. As seen in Figure 4.3, the bias was only slightly, but consistently, larger when the stimuli were not masked and the memory trace was permitted to form. Furthermore, biases show to be slightly stronger when the inter-stimulus interval was at 1 or 3 seconds as compared to 0 seconds. These effects are particularly visible when the arrays were presented on the right side of the fixation point and show to interact with other variables.

The two-way interactions of masking x greyscale orientation, $F(1, 60) = 5.809$ $p = .019$, $\eta^2 = .088$, inter-stimulus time interval x array position relative to fixation point, $F(2, 120) = 4.052$, $p = .02$, $\eta^2 = .063$, inter-stimulus time interval x greyscale orientation, $F(2, 120) = 27.988$, $p < .001$, $\eta^2 = .318$, and position relative to fixation point x greyscale orientation, $F(1, 60) = 4.924$, $p = .03$, $\eta^2 = .318$, were all statistically significant. Further analyses were conducted using t-tests with Bonferroni adjustments for multiple comparisons. Stronger rightward biases were attained in *no mask* condition as compared to *mask* condition when arrays were presented with the greyscale gradient on the left (no mask: $M = 0.7$, $SE \pm 0.03$; mask: $M = 0.18$, $SE \pm 0.03$), $t(60) = 2.445$, $p = .015$. Similarly, stronger biases were attained in the *no mask* condition ($M = -0.26$, $SE \pm 0.03$) as compared to the *mask* condition ($M = -0.16$, $SE \pm 0.03$) with darkest disks presented on the right side of the array, $t(60) = 2.674$, $p = .008$. Therefore, the interruption or facilitation of the formation of a memory trace showed to be impacted by the left/ right orientation of the presented array (Figure 4.2).

Paired t-tests were conducted to further investigate the inter-stimulus time interval and array position interaction (Figure 4.3, left panel). Leftward and rightward biases showed to increase when the inter-stimulus time interval was longer than 0 second. Participants chose the array as overall darker when it was presented on the right side of the screen only when the inter-stimulus time interval was for 1 second or longer (0 second interval: *M* = -0.01, *SE* ± 0.03; 1 second time interval: *M* = 0.09 *SE* ± 0.04, *t*(243) = 2.246, *p* = .013). For arrays presented on the left side of the screen, participants chose arrays with darkest disks on the left side to be overall darker only when the inter-stimulus time interval was 3 seconds (1 second interval: *M* = -0.01, *SE* ± 0.04; 3 second time interval: *M* = -0.08, *SE* ± 0.05, *t*(60) = 2.073, *p* = .019).

As reported above, inter-stimulus time interval also showed to significantly interact with the greyscale orientation within the array (Figure 4.3, right panel). Hence, further tests were conducted to investigate. As indicated earlier, there were two possibilities of greyscale orientation: *left to right*, where darkest disks are on the left side of the arrays and *right to left*, with darkest disks on the right side of the array. In the *left to right* orientation, participants showed a rightward bias indicating that arrays in which the darkest disks were presented on the right side and not the left showed to be overall darker. Similarly, in the *right to left* condition where darkest disks are presented on the right side of the array, the participants chose arrays with darkest disks on the left side to be overall darker (leftward bias). In both cases, there was a significant increase in bias magnitude when the inter-stimulus time interval was introduced at 1 second or longer. There was a significant difference in bias when comparing *left to right* array orientation at 0 and 1 seconds (0 second: *M* = 0.08, *SE* ± 0.04; 1 second, *M* = 0.33, *SE* ± 0.04, *t*(60) = 6.089, *p* < .001). Similarly, leftward biases increased significantly in magnitude at 1 second time interval (0 second: *M* = -0.08, *SE* ± 0.04; 1 second, *M* = 0.25, *SE* ± 0.04, *t*(60) =

4.213, $p < .001$). In both, the *left to right* and *right to left*, greyscale orientations biases increased at 1 second time interval and remained strong at the 3 second interval.

In position x greyscale orientation interaction was also statistically significant. Participants showed a strong rightward bias ($M = 0.25$, $SE \pm 0.03$) and chose the array presented on the right side with the darkest disks on the right of the array to be overall darker compared to its mirror image. Similarly, participants also indicated that arrays presented on the right side of the screen with the darkest disks on the left to be overall darker ($M = -0.31$, $SE \pm 0.03$). These opposing greyscale orientation biases showed to be highly statistically significant, $t(60) = 10.337$, $p < .001$. Similar but smaller in magnitude pattern was obtained when the arrays were presented on the left side of the computer screen. Participants chose the array with the darkest disks on the right to be overall darker ($M = 0.19$, $SE \pm 0.03$) as compared to its mirror image. Similarly, participants also chose the array presented on the left side of the screen with the darkest disks presented on the left side ($M = -0.11$, $SE \pm 0.03$) more often as compared to its mirror image. Both biases showed to be statistically different, $t(60) = 10.337$, $p < .001$. As indicated, the magnitude of the bias showed to vary with the side to which the stimuli were presented. However, this showed to be statistically significant only when the stimuli were presented on the right ($t(60) = 5.266$, $p < .001$) and not the left ($t(60) = 1.337$, $p = .182$) side of the computer screen.

The masking x inter-stimulus time interval, $F(2, 120) = 1.146$, $p = .321$, $\eta^2 = .019$, and masking x screen position interactions, $F(1, 60) = 0.505$, $p = .48$, $\eta^2 = .008$, were not statistically significant.

The sphericity assumption was violated for the masking x time interval x greyscale orientation interaction ($X^2(2) = 7.339$, $p = .025$, $\varepsilon = 0.921$), and for time interval x stimulus position x greyscale orientation interaction ($X^2(2) = 9.276$, $p = .01$, $\varepsilon = 0.897$). For both interactions the Greenhouse-Geisser correction was used to adjust the degrees of freedom. The only statistically significant three-way interaction was inter-stimulus time interval x stimulus position x greyscale orientation, $F(1.746, 104.760) = 3.856$, $p = .029$, $\eta^2 = .06$. The masking x inter-stimulus time interval x stimulus position, $F(2,120) = 0.939$, $p = .391$, $\eta^2 = .015$, masking x inter-stimulus time interval x greyscale orientation, $F(1.791, 107.434) = 0.373$, $p = .67$, $\eta^2 = .006$, and masking x stimulus position x greyscale orientation, $F(1, 60) = 0.092$, $p = .762$, $\eta^2 = .002$, interactions were not statistically significant. Finally, the four-way interaction was also not statistically significant, $F(2, 120) = 0.653$, $p = .52$, $\eta^2 = .011$.

In summary, the results showed the screen position, to which the stimuli were presented and the orientation of the array, have the greatest impact on the direction and magnitude of the bias. The inter-stimulus time interval showed to interact with, both, the stimulus position and the greyscale orientation, as stronger biases were found at longer time intervals. Finally, masking showed to have an impact only on the orientation of the greyscale, where stronger biases were found when the memory trace was permitted to form and no mask was presented.

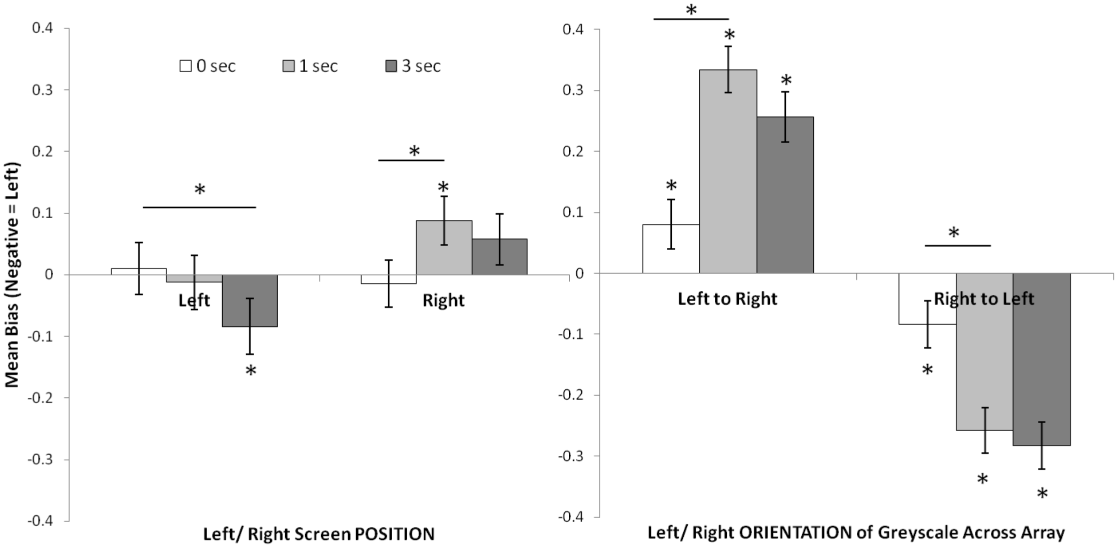

Figure 4.2. Mean bias for position of presentation and array orientation for each inter-stimulus time interval. The left panel shows the presentation position relative to the fixation point. The right panel shows the greyscale orientation. *Left to right* indicates that the darkest disks were presented on the left side and the array was progressively lighter towards the right. *Right to left* indicates that the darkest disks were presented on the right and the array was progressively lighter towards the left side. The asterisks represent statistical significance from zero. The horizontal line with an asterisk represents statistical difference between conditions. Post hoc tests were conducted only for the represented conditions to determine whether there is a statistical difference between 0 and 1 s inter-stimulus time interval (0 and 3 s for the left position - left panel).

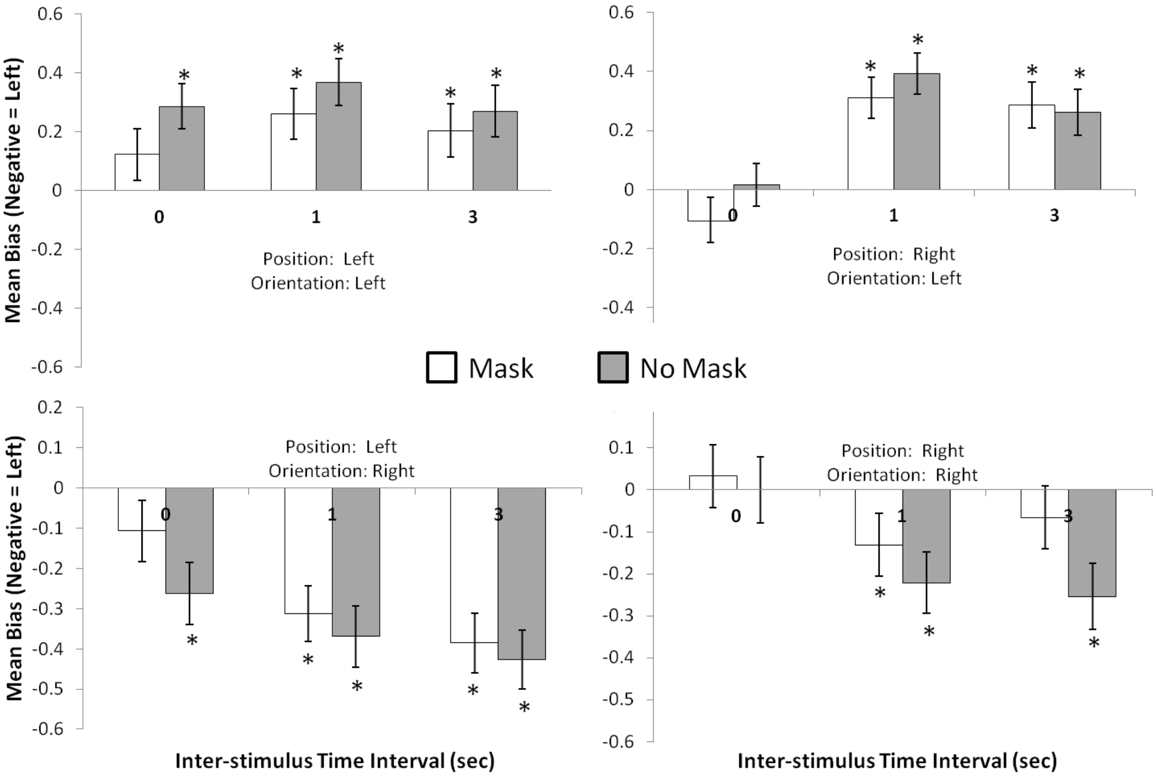

Figure 4.3. Mean bias for each array orientation and position. The asterisks represent a bias statistically different from 0. Error bars represent standard error of the mean. The horizontal axis represents the time delay (0, 1, and 3 s).

Recall accuracy of array orientation

Recall accuracy was calculated for the first presented array to determine whether that stimulus was retained in memory for the duration of the trial. The recall accuracy of the second array was not calculated. The participants were able to determine the orientation and position of the second array based on the presentation of the first array. Therefore, they did not have to remember the exact properties and could have used a strategy to correctly select the second array.

Overall, the participants recalled the orientation of the greyscale gradient with accuracy between 77% - 86%, depending on the condition. A repeated-measures ANOVA was conducted to analyze the data with mask (mask, no mask), inter-stimulus time interval (0 s, 1 s, 3 s), position of array presented as it relates to the fixation point (left, right), and greyscale orientation within the array (darkest disks located on either the left or right side of the array) set as within-subjects variables. The recall accuracy of the greyscale gradient orientation was set as the dependent variable.

Overall the results showed that masking ($F(1, 60) = 0.644$, $p = .42$, $\eta^2 = 0.01$), greyscale orientation ($F(1, 60) = 0.138$, $p = .71$, $\eta^2 = 0.002$), and inter-stimulus time interval ($F(2, 120) = 0.844$, $p = .43$, $\eta^2 = 0.014$) did not show a statistically significant main effect. However, the results showed the position relative to the fixation point variable to nearly reach statistical significance, $F(1, 60) = 3.167$, $p = .08$, $\eta^2 = 0.05$. There was a slight rightward trend for recall accuracy. Participants seemed to recall the correct orientation of the greyscale slightly more accurately when it was presented to the right of the fixation point, $M = 82.2\%$, $SE \pm 0.02$, as compared to the left of fixation point, $M = 80.5\%$, $SE \pm 0.02$.

Sphericity assumption was violated only for the position x time interaction, $X^2(2) = 0.886$, $p = .028$, $\varepsilon = 0.92$, and the Greenhouse-Geisser correction was used to adjust the degrees of freedom. The only near statistically significant interaction was position x time, $F(1.796, 107.751) = 2.553$, $p = .088$, $\eta^2 = .04$. The least accurate recall of the greyscale orientation occurred at 1 second inter-stimulus interval when stimulus was presented on the left side, $M = 79.8\%$, $SE \pm 0.02$. Conversely, the highest accuracy was attained when the stimulus was presented on the right side of the fixation point with 1 second inter-stimulus interval at $M = 83.8\%$, $SE \pm 0.02$. Although participants do not show a statistically varying recall accuracy of greyscale array orientation, there is an indication that the arrays presented on the right of the fixation point slightly increased recall accuracy over those presented on the left.

Recall accuracy of array position relative to fixation point

Similarly, to recall accuracy of the greyscale orientation, only the responses to the first presented array were considered in the analysis. Overall, the position of the array was recalled with the range of 93% to 99% accuracy. This range was much higher than the recall accuracy of the greyscale orientation within the array (77% - 86%). In an overall repeated-measures ANOVA, again the mask (masking, no masking), inter-stimulus time interval (0 s, 1 s, 3 s), position of array presented as it relates to the fixation point (left, right), and orientation of the array (darkest disks located on either left or right side of the array) were set as within-subjects variables. Recall accuracy of the position relative to fixation point was set as the dependent variable.

The results (Figure 4.4) showed a main effect of the mask and time interval to reach significance. The arrays presented with a mask show to be more accurately recalled ($M = 96.7\%$, $SE \pm 0.49$) as compared to non-masked arrays ($M = 94.8\%$, $SE \pm .54$), $F(1,60) = 10.763$, $p =$

.002, $\eta^2 = .15$. Furthermore, there was a significant main effect of inter-stimulus time interval, $F(2, 120) = 4.387$, $p = .014$, $\eta^2 = .07$. In a further t-test analysis, there was a difference between the 1 and 3 second inter-stimulus time interval, $t(1) = 0.016$, $p = .014$. The mean recall accuracy of position at 3 seconds was 96.8%, *SE* ± 0.005, as compared to the 1 and 0 second intervals, 95.2% *SE* ± 0.006, and 95.3% *SE* ± 0.006 respectively.

The main effects of stimulus position ($F(1, 60) = 0.917$, $p = .34$, $\eta^2 = .01$) and greyscale orientation ($F(1, 60) = 0.970$, $p = .33$, $\eta^2 = .02$) were not statistically significant. The sphericity assumption was violated for the mask x inter-stimulus time interval ($X^2(2) = 19.956$, $p < .001$, $\varepsilon = 0.794$) and the stimulus position x inter-stimulus time interval ($X^2(2) = 6.120$, $p = .047$, $\varepsilon = 0.94$, and the Greenhouse-Geisser correction was used in both cases to adjust the degrees of freedom. Two-way interactions of mask x stimulus position ($F(1, 60) = 0.032$, $p = .86$, $\eta^2 = .001$), mask x greyscale orientation ($F(1, 60) = 1.224$, $p = .28$, $\eta^2 = .02$), stimulus position x greyscale orientation ($F(1, 60) = 0.391$, $p = .53$, $\eta^2 = .006$), mask x inter-stimulus time interval ($F(1.554, 93.242) = 0.236$, $p = .73$, $\eta^2 = .004$), stimulus position x inter-stimulus time ($F(1.821, 109.263) = 0.428$, $p = .63$, $\eta^2 = .007$), and greyscale orientation x inter-stimulus time interval, ($F(2, 120) = 0.242$, $p = .79$, $\eta^2 = .004$) were not statistically significant.

Additionally, the sphericity assumption was violated for the stimulus position x greyscale orientation x inter-stimulus time interval interaction, $X^2(2) = 6.635$, $p = .036$, $\varepsilon = 0.93$, and the Greenhouse-Geisser correction was used to adjust the degrees of freedom. The three way interactions of mask x stimulus position x greyscale orientation ($F(1, 60) = 0.806$, $p = .34$, $\eta^2 = .013$), mask x stimulus position x inters-stimulus time interval ($F(2, 120) = 1.782$, $p = .17$, $\eta^2 = .03$), mask x greyscale orientation x inter-stimulus time interval ($F(2, 120) = 0.124$, $p = .88$, $\eta^2 = .002$), stimulus position x greyscale orientation x inter-stimulus time interval ($F(1.808, 108.464)$

$= 0.064$, $p = .92$, $\eta^2 = .001$) were not statistically significant. As well, the four-way interaction was also statistically insignificant, ($F(1.646, 98.771) = 1.233$, $p = .29$, $\eta^2 = .02$).

In summary, these findings indicated that masking plays a role in recall of stimulus position by enhancing accuracy of recall of the masked stimuli. Furthermore, by increasing the inter-stimulus time interval to 3 seconds, recall accuracy of the stimulus position increased in both the masked and non-masked conditions. There was no indication of the greyscale orientation and stimulus position relative to the fixation point effects relating to recall accuracy. Furthermore, there were no statistically significant interactions.

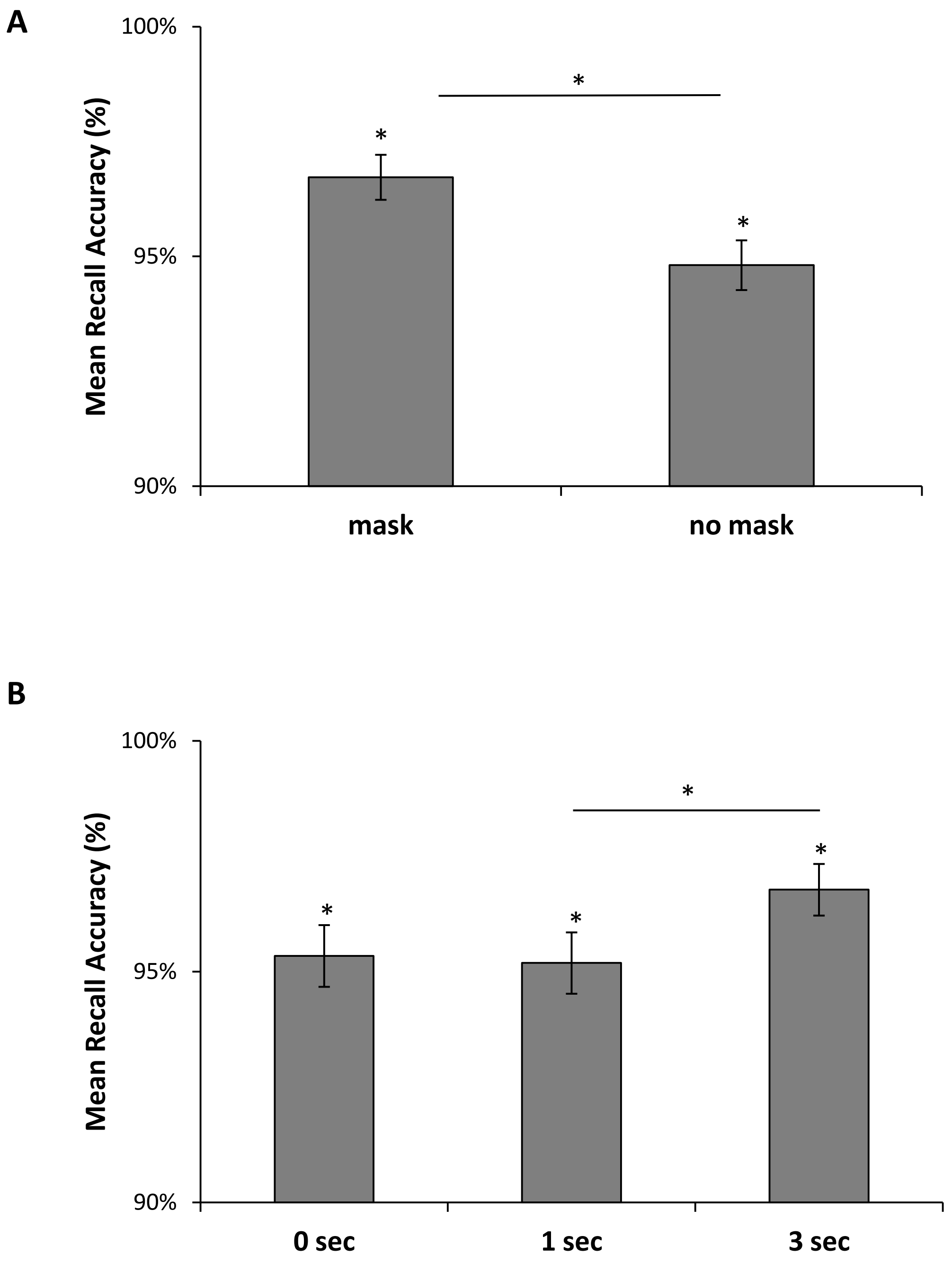

Figure 4.4. Average accuracy of recall of first array's position. Panel A depicts the increased accuracy of recall when maskign the first array. Panel B depcts the increased recall acuracy at the 3 second inter-stimulus time interval. Astersk represents accuracy score significantly different from chance (50%). Horizontal line with asterisk represents conditions with statistically different accuracy scores.

Discussion

Although lateral asymmetries have been attributed to perceptual and attentional mechanisms, recent evidence shows presence of similar biases in working memory processes. The purpose of this experiment was to investigate the impact of working memory load on perceptual asymmetries. With the implementation of inter-stimulus time intervals and stimulus masks, I was able to observe lateral response biases in conditions requiring implementation of later processes such as working memory. Lateral biases were impacted by the screen position, greyscale gradient orientation of the presented arrays, and the inter-stimulus time interval. Also, recall accuracy of the array's position was impacted by masking and inter-stimulus time interval. Interestingly, a high level of interaction between biases was observed. These findings are first, to my knowledge, to show in greater detail the relationship between working memory and perceptual asymmetries by combining paradigms frequently used to investigate perceptual asymmetries and working memory in isolation. I have combined these paradigms to show a more interactive relationship between these perceptual, attentional, and working memory processes. Furthermore, these findings support of the orientation-activation hypothesis extending the implementation of this hypothesis to other mechanisms such as working memory.

Lateral biases obtained in this study show to be affected by the position and orientation of the presented array. Arrays presented on the left of the fixation point yielded a small leftward trend, whereas arrays presented on the right of the fixation point revealed a statistically significant rightward bias. Interestingly, the rightward bias showed to be stronger as compared to the left. Conversely, arrays presented with the darkest disks on the left side yielded rightward biases. Leftward biases were shown when the darkest disks of the array were presented on the right side of the computer screen. The time interval showed to have significant impact on the magnitude of the bias, in most cases. Stronger biases were observed when the stimuli were presented at least 1 second between one another.

Time interval also showed to have a significant impact on recollection accuracy of the array position where left/ right position of the array was more accurately recalled at 3 seconds, indicating possible involvement of later processes. Interestingly, there was reversed recall accuracy in masked and non-masked conditions. Masked stimuli showed to have an increased accuracy when recalling the position of the array as compared to the trials where working memory trace was permitted to form. Possibly, the inherent attentional nature of the task is observed here. Perceptual asymmetries have been attributed to earlier visuospatial processing, at perceptual and attentional stages (Porac et al., 2006). Therefore, it is not surprising that an increased response was obtained in the condition favouring attentional process. However, what is important to note is that although accuracy dropped when the memory trace was permitted to form, it did not drop close to or below chance levels, therefore indicating that later processes are involved as well. Furthermore, it is also important to note that recall accuracy increased again at three second time interval. Therefore, it is possible that a change in processing occurred, which is also supported by the boost of representational bias at the increased time intervals, but this hypothesis requires further study.

Further evidence indicating that the effect observed in current experiment is representational bias is seen when considering inter-stimulus time intervals. With short inter-stimulus intervals, the bias did not significantly differ from zero, especially when the first presented array was masked. Biases in perception are normally evident when stimuli are presented briefly with no inter-stimulus intervals (Thomas & Elias, 2011; Nicholls et al., 2004). In this study, if perceptual biases were playing a major role, stronger leftward biases when the stimuli were presented at the 0 second inter-stimulus interval should have been observed. However, there was barely any bias obtained, only the left position with left and right orientation indicated biases significantly different from 0 (no bias). This indicates that the processes yielding this type of response bias occur with increased processing time, further limiting extended involvement of perception which is assumed to operate at the earliest stages of visual processing (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Dosher & Lu, 2000; Lee, Itti, Koch, & Braun, 1999; Lu & Dosher, 1998, 2000). Therefore, it appears that biases in both masking conditions are representational in nature and a result of activation at later stages of processing.

Possibly, the observed effect could have been also attributed to the effects of location codes while encoding the stimuli, known as the Simon effect (Simon & Berbaum, 1989). Typically in a Simon tasks, non-spatial stimulus features are assigned to spatially defined responses, such as a key press. A response becomes faster in cases when the location of the stimulus and the location of the response key are located on the same side (Rubichi, Nicoletti, Iani, & Umilta, 1997). There are two assumptions which must be present to indicate a Simon effect. One assumption is that a spatial code is generated for the irrelevant stimulus location. It is assumed that there are multiple spatial codes generated for the single stimulus (Rubichi et al., 1997). The second assumption is that the Simon effect occurs at the response-selection stage; however there is also evidence indicating that the Simon effect occurs as a result of an attentional shift (Rubichi et al., 1997).

In the current study, when considering the position of the array relating to the fixation point and the left/ right greyscale orientation, as per Simon effect there should be a stronger response bias towards the left when the array was presented on the left side, with the darkest discs on the left side of the array. In this presentation, the Simon effect would be the strongest towards the left as the position cues and response would be with the strongest stimulus-response pairing. Furthermore, there should be a strongest rightward bias in the condition where the arrays with the darkest discs were presented on the right side and on the right side of the fixation point. However, as seen in Figure 4.3, biases are obtained in the opposite direction; rightward biases occurred when the greyscale was presented on the left side of the fixation point with the darkest discs on the left side.

The left/right position bias is consistent with the predictions derived from the activation-orientation hypothesis (Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). Perceptual asymmetries have been attributed to be behavioural outcome of several proposed accounts including visual scanning habits and motor bias (see Nicholls & Roberts, 2002, for review), but the activation-orientation hypothesis is the one with most support (Reuter-Lorenz et al., 1990). This hypothesis states that the distribution of attention is biased in the direction opposite to the more activated hemisphere. The origins of this hypothesis stem from the notion that the visuospatial attention is distributed across the left and right visual fields by two opposing gradients which are controlled by the contralateral hemisphere (Kinsbourne, 1970). The key aspect of this hypothesis resulting in pseudoneglect is that the rightward-orienting influence of the left hemisphere is more powerful than the leftward-orienting influence of the right hemisphere. This prevalence of rightward biases is revealed in neurologically intact participants in tasks which require induced orienting uncertainty (Reuter-Lorenz et al., 1990). Furthermore, the right hemisphere has been found to be relatively more active when processing spatial information. The right hemisphere attends to the left and right side of space whereas the left hemisphere attends mainly to the right side of space (Heilman and Van Den Abell, 1980; Mesulam, 1981).

Task-specific requirements, in this study, led to an increased hemispheric activation therefore leading to contralateral allocation of attention. In spatial attention tasks, such as the line bisection or greyscale tasks the right hemisphere is relatively more activated as it is dominant for processing visuospatial information. Therefore, the contralateral behavioural bias that is emitted is that of pseudoneglect. The activation-orientation hypothesis indicates that the left half of the horizontal line in line bisection, for example, is the focus of greater attention. Therefore it is perceived as longer, relative to the less attended right side of the line (Bultitude & Aimola Davies, 2006). Similarly, in imagery task, mental line bisection, recognition memory tasks, and feature binding, there has been a left visual space advantage as compared to the right. It is also important to note that under some circumstances the hypothesis also calls for rightward biases, for example conflict in processing as a result of induced by orienting uncertainty (Reuter-Lorenz et al., 1990) which explains the findings obtained in this experiment. Although the relationship between representational bias and the activation-orientation hypothesis has not yet been directly established, current study and previous findings indicate that the principles in this hypothesis can also be extended to representational bias.

The current study explores lateral biases combining backward masking and brightness judgment paradigms typically used in isolation to investigate working memory and perceptual asymmetries respectively. This novel approach to investigate biases shows that processing of orientation and position information in later stages yields biases in opposite direction as to those in earlier stages of processing. These biases increase when favoring working memory processing and show to be representational in nature. This is the first study, to my knowledge, to show such effects over the course of different time interval indicating possible changes in stages of processing.

CHAPTER FIVE

THE IMPACT OF WORKING MEMORY STORES ON PERCEPTUAL ASYMMETRIES

Introduction

It is well established that visuospatial attention in neurologically normal population is distributed asymmetrically, showing a modest but consistent leftward bias. This systematic overestimation of the left versus right visual fields is widely observed in judgments of size, brightness, numerosity, (Nicholls, Bradshaw, & Mattingley, 1999) distance (Krupp, Robinson, & Elias, 2010) and tasks including line bisection (Jewell & McCourt, 2000; McCourt & Garlinghouse, 2000; McCourt, Garlinghouse, & Reuter-Lorenz, 2005), greyscale (Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004; Nicholls, Bradshaw, & Mattingley,1999; Thomas & Elias, 2011; 2010), and gratingscales (Niemeier, Stojanoski, Singh, & Chu, 2008; Singh, Stojanoski, Le, & Niemeier, 2011). This evidence provides a glimpse into the consistency and prevalence in misjudgment of the visual space brought upon by perceptual and attentional processing (Porac, Searleman, & Karagiannakis, 2006) by the posterior parietal areas in the right hemisphere (Bultitude & Aimola-Davies, 2006; Corbetta & Shulman, 2002; Corbetta, Miezin, Schulman, & Petersen, 1993; Posner & Rothbart, 2007; Kinsbourne, 1970).

Neuroimaging studies showed an increased activation in visuospatial attention networks when viewing information in the left visual field (Siman-tov et al., 2007). More specifically, the left visual field superiority has been shown in the areas previously associated with covert visuospatial attention. This network consists of components within the dorsal (intraparietal sulcus and frontal eye fields) and ventral frontoparietal systems, as well as subcortical structures including thalamus, basal ganglia, and brainstem (Siman-tov et al., 2007). Functionally, this attentional mechanism seems to alter perception such as the appearance of contrast (Carrasco, Fuller, & Ling, 2008; Carrasco, Ling, & Read, 2004), and spatial frequency (Abrams, Barbot, &

Carrasco, 2010). Furthermore, increased attention has shown to improve performance at cued locations (Carrasco et al., 2004).

Although spontaneously directed towards the left side of space, visuospatial attention has been shown to be directed by exogenous transient cues (Posner, 1980). Recently, in Sosa, Clark, & McCourt (2011) visual cues were presented prior to presentation of a line stimuli at either the left or right side, ensuring that the line was not perceptually extended. The participants were required to bisect the line. The findings indicated that visual attention was recruited to the spatial location of the cue which modulated line bisections. The authors indicate that the speed of neural processing is increased in the cued portion of the stimuli and the processing of the data occurs faster than in remote regions of the visual space (Sosa et al., 2011). Similar spatial cueing effects have been shown in other line bisection tasks where lateral biases are altered in direction dependent on the cue position relative to the line in normal population (McCourt et al., 2005; Milner, Brechmann, & Pagliarini, 1992; Reuter-Lorenz et al., 1990) and in patients with damage to the right parietal region responsible for processing visuospatial attention (Bultitude and Aimola-Davies, 2006; Halligan and Marshall, 1989; Harvey, Milner, & Roberts, 1995; Mennemeier, Vezey, Chatterjee, Rapcsak, & Heilman, 1997). However, contradictory findings regarding the impact of cues has been reported by Jewell and McCourt (2000). In a meta-analysis, the authors reported an overall rightward bias independent of the position cue. Therefore, the impact of spatial cues in relation to perceptual asymmetries remains rather controversial.

Possibly cue use in visuospatial tasks recruits other neuronal processes aside of perception and attention which may affect lateral biases. As such, recent evidence showed that leftward biases are not restricted to perceptual and attentional processes, but also to working memory. McGeorge, Beschin, Colnaghi, Rusconi, and Della Sala, (2007) showed biases in an imagery task, where participants imagined themselves in a familiar to them cathedral square and recalled the objects located on their left and right sides. Independent of the view point, faster and more accurate recalls were observed to objects located on the left side of space as compared to the right. Furthermore, Della Sala, Darling, and Logie, (2010) showed biases in a feature binding task in which participants were more accurate recalling the colour and shape of the bound features when presented on the left side of the computer screen. Finally, Darling, Logie, and Della Sala, (2012), in the classic line bisection paradigm showed leftward bias when participants bisected horizontal lines from memory. These findings indicate that visuospatial working memory itself is a subject to bias (Darling et al., 2012). Therefore, once the information is finally processed at the visuospatial working memory stage, it is unclear whether working memory process itself contributes to these biases or whether these biases are a sole result of perception and attention. More interestingly, it remains unknown whether the reverse also occurs. Does the spatial information retained in working memory impact the attentional and perceptual system resulting in a modified behavioural bias? It is this question which is investigated in the current experiment.

To begin addressing our question, it is important to be able to direct the processing of information to attention or working-memory stages. It is assumed that attention affects the efficiency with which stimulus information is transferred to visual short-term memory. In spatial cueing paradigm, cues are used to guide attention to a particular region within the visual field (Posner, 1980). A number of studies (reviewed in Smith, Ellis, Sewell, & Wolfgang, 2010) indicated a *mask-dependent cueing effect* where cues increase detection sensitivity, or accuracy, only when stimuli are backwardly masked and the processing of the cued target is prematurely disrupted. If, however, the stimuli are unmasked, recall accuracy for cued and miscued stimuli does not differ, indicating completion of information processing to working memory (Smith et al., 2010). These findings point out that the magnitude of attentional input depends on the use of visual masks where interruption (backward) masking disrupts the perception of spatially and temporally proximate targets (Smith et al., 2010) and disrupts further transfer of information to visual short-term memory. Therefore, it is feasible that with the use of backward masking, to relatively control information processes in attentional and working memory stages.

The current study investigated the impact of previously retained spatial information, consisting of only one of the features found within the comparison stimuli, on perceptual asymmetries. Previous studies indicate that greyscale tasks are highly sensitive to detect perceptual asymmetries (Nicholls et al., 1999; Orr & Nicholls, 2005). However, these classic greyscales pose a limitation as the stimuli lack sufficient flexibility necessary to address this question. Greyscales are designed such that the stimuli are presented linearly and cannot be easily broken down into components which can be presented individually. Therefore, I modified the task to overcome this limitation. A pair of equiluminant circular arrays was created out of six individually shaded disks, which showed an overall greyscale gradient. The arrays were presented on the computer screen for participants who determined which array seemed overall darker. The design of the arrays permits a separation of specific position or shade information within the array, which can be used as working memory stimuli. This method allows selective encoding of only one feature within the array and unravels the importance of each feature in the overall judgment of brightness. With the use of backward masking paradigm, it was reasonable to address how working memory processes impact the direction and magnitude of biases by controlling the formation of working memory trace.

It is expected to find different impact on biases based on the retention of shade or position information within the array. If the position is retained, then we should see a variability of biases depending on which position in the array was presented and where attention was directed. Stronger biases relating to the 'to be remembered' position should be observed; for example, stronger leftward biases should result when the retained position in on the left side of the array and stronger rightward biases when the retained position is on the right side. There should be no difference in bias when retaining the top and bottom positions as compared to the control (no retention) conditions. If the general hypothesis that retained information will act to recruit attention towards that region of space is upheld, then retaining shade information should not bring up differences in biases. The dark, medium, or light shades are equally likely to be presented on either the left or the right side of the screen. However, previous findings indicate that attention is spontaneously directed towards the left side of space (Niemeier et al., 2008). Also, there has been reported dissociation between object and space biases (Orr &Nicholls, 2005) with leftward object biases and central space biases. Therefore, it can be reasoned that if in this paradigm the shade is perceived as an object, an increased leftward bias should be seen when the darkest shade is retained as the attention would spontaneously be directed to the left. Finally, if perceptual asymmetries are limited to attentional processes then stronger biases in the masked condition when the memory trace formation is inhibited should be attained. However, if there is an involvement of working memory, then modifications in biases magnitude and direction would be prevalent. These differences should be exacerbated in *no masking* condition as compared to *masking* condition.

Methods

Participants

One hundred undergraduate Psychology students (43 males and 57 females) from the University of Saskatchewan took part in this experiment. There were 47 participants (21 males and 26 females) in the *no mask* condition and 53 participants (22 males and 31 females) in the *mask* condition. There were only two participants who self-reported as left-handed; one male in the *mask* condition and one female in the *no mask* condition. All students were recruited from the Undergraduate Participant Pool and in exchange for their participation, received one course credit. Based on a self-report all participants had normal or corrected to normal vision. The mean age of the participants was 20 and ranged from 18 to 46 years. All participants made their responses with their dominant writing hand. This experiment was conducted with the ethical approval of the Behavioural Research Ethics Board at the University of Saskatchewan.

Design and Procedure

Figure 5.1 represents the schematic representation of the trial progress. Prior to presentation of the stimuli the participants were required to focus their gaze on the fixation point presented in the center of the screen on a grey background. Following this presentation, the participants viewed one of two possible images: a position or shade. These stimuli consisted of one of the features within the circular array. The circular array was comprised of six positions in which disks with three shades were placed so that an overall greyscale gradient was attained. Only one position or one shade was presented at a time and the participants were required to retain that that information for the duration of the trial. In the position condition, a rectangle appeared in one of the six positions of the circular array. Conversely, in the shade condition, a circular dark, medium, or light grey shade appeared in the center of the screen. In some of the trials, the participants would receive no stimuli, which they were required to retain, and those trials served as control. This retention stimulus was presented for 1 second once it disappeared; one group of the participants received a mask where a screen with random noise, in the form of white, black and grey pixels appeared for 1 second. The second group would not receive this mask and the trials would advance.

Following the retention stimulus presentation (and mask in the corresponding group), two circular arrays were presented consecutively for 1 second each in the center of the computer screen. The arrays, (approximately 20 in diameter) comprised of six individual disks (approximately 3 cm in diameter), showing a varying, overall, left/ right greyscale gradient where one side of the array was a darker shade of grey than the other. Overall, the array pairs were isoluminant. The array presentation was counterbalanced for orientation, e.g. the first array was presented with darker disks on the left and the second array was presented with the darkest disks on the right side of the screen and vice versa. The task was for the participant to determine which one of these presented arrays seemed overall darker to them and press the corresponding key on the computer keyboard. As this was a forced choice task, the trials did not advance until a response was made. All participants completed the task in the allotted 30 minutes and no data were excluded for that reason.

Following the judgment of array brightness portion of the trial, a set of prompting questions appeared where the participant, by pressing the corresponding key, was asked to select the position or shade that was presented at the beginning of the trial. In the position condition, a set of six squares (approximately 2 x 2 cm) corresponding to the spatial position of each of the disks of the greyscale array was presented centered on the computer screen. Similarly, in the shade condition, the three shades (approximately 3 cm in diameter) were presented in a column centered on the screen. The shades of the array varied in their position where during half of the trials, the darkest disk appeared on the top of the column. In the other half of the trials, the darkest disk appeared at the bottom of the column. The mid-shade disk always appeared in the middle of the screen. The participant was required to select the image they saw at the beginning of the trial. The trial did not advance until a response was made.

The training and test trials were identical in sequence. Training was provided to ensure that the participants were comfortable with the general procedure, and comprised of 20 trials representing each trial combination. Immediately following the training, the participants were given the test trials. The position and shade test trials were administered in blocks and counterbalanced between participants for order of presentation. In the *position* condition there were 84 trials where the participant was asked to remember one of the six positions (bottom, bottom left, top left, top, top right, bottom right) representative of each of the shaded disk locations that comprised the circular array. Twelve trials did not require the participant to remember any information. In the *shade* condition, the participants were presented with one of the three shades (light grey, medium grey, dark grey) comprising the circular array. The shade was presented as disk in the centre of the screen. There were 48 trials requiring the participant to remember one of the shades and 12 control trials where no to-be-remembered position was presented. In both conditions, these trials served as control trials. Test and control trials were counterbalanced for the left/ right orientation of the array and left/ right position on the computer screen. All trials were administered randomly using a desktop computer which was running E-prime software (Psychology Software Tools Inc., Pittsburgh, PA; www.pstnet.com/eprime).

Upon completion of the experiment, the participants were thanked and debriefed.

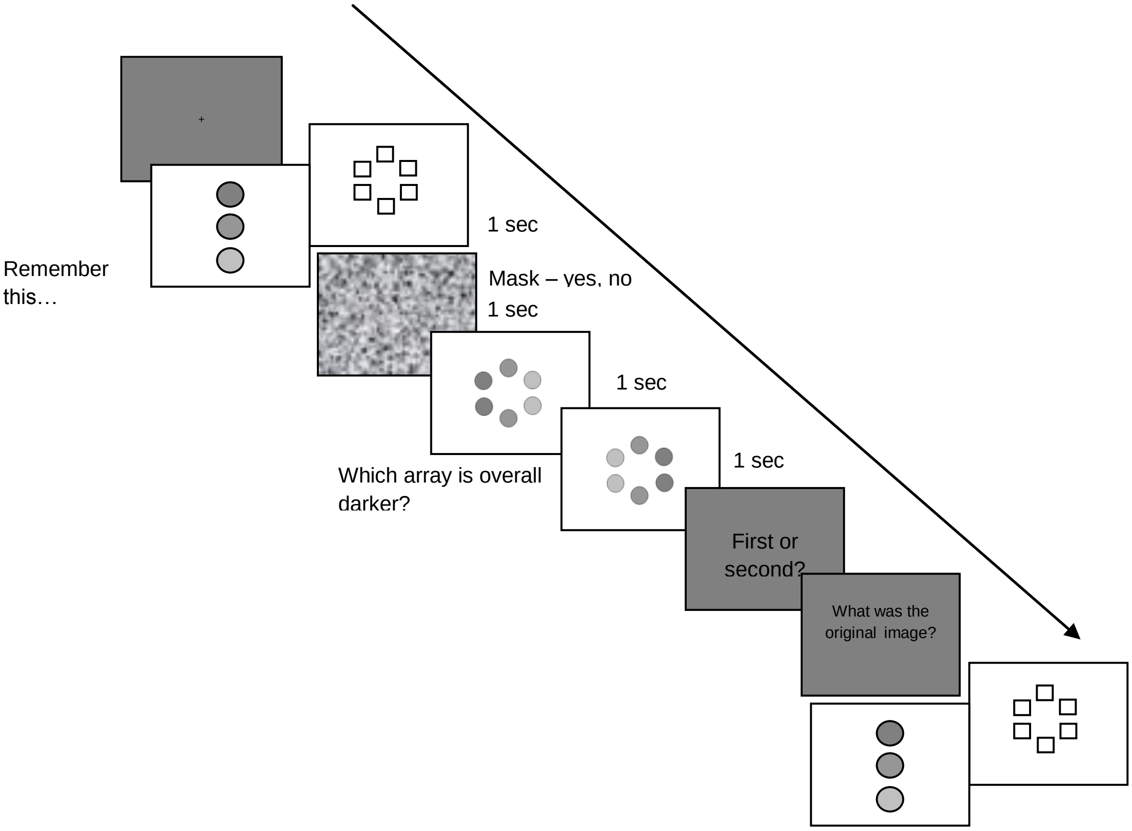

Figure 5.1. Schematic representation of trial progression. To-be-remembered stimuli were presented to the participants as only one shade or position. In this schematic all of the position and shade stimuli are shown. This is not representative of the trials, as for the to-be-remembered trials only one position or shade stimuli was presented. Noise mask was presented only to one group of participants. The other group received the to-be-remembered followed immediately by the array presentation. Following the memory stimuli presentation, participants viewed a pair of circular arrays presented one after the other. When the "First or Second" prompting screen was presented, the participants selected which array appeared overall darker to them. The trial did not advance until a response was made. Following this response the participants had to select which shade or position they saw (if any) at the beginning of the trial. This too was a forced choice task.

Results

All participants completed the task and their results were included in the data analysis. The total number of responses to the left and right sides was calculated for the laterality index of each condition using the following formula: [(# of right responses) – (# of left responses)]/ [(# of left responses) + (# right responses)]. A negative laterality index score indicated a leftward bias and a positive score indicated a rightward bias. The strength of the bias was determined by how close they obtained value was to ± 1. The mean laterality index was calculated for each individual and then condition. Similarly, recall accuracy was calculated for position and shade feature and averaged for each condition based on individual means. Laterality index and recall accuracy were used as the dependent variables in the analyses.

To determine whether a relative difference of tasks, retaining shade or position information, posed a difference, an analysis of covariance (ANCOVA) was performed with the type of retained information set as the covariable. The results showed no significant difference between the tasks, $F(1, 197) = 0.413$, $p = .52$, $\eta^2 = .002$.

Biases While Retaining Position Information

Strong rightward biases were observed when participants were asked to remember position information especially when the memory trace was permitted to form (no mask). A one sample t-test was conducted for each condition to determine whether the biases are significantly different from 0, or no bias. The biases were significant when retaining the *bottom*, *top*, *top right*, and *bottom right* positions within the array (Figure 5.2, panel A). Interestingly, no significant bias was attained when retaining the left positions neither for the *top* or the *bottom* positions of the array. Additionally, in the control condition, where no retention of information was required, there were no statistically significant biases, but a rightward trend in the no mask condition.

Additionally, when retaining the *top* or *bottom left* position, only slight leftward biases were attained (Figure 5.2, Panel A).

As observed in Figure 5.2, biases between the *mask* and *no mask* conditions appear to vary when the retention stimuli are located on the *bottom* and *bottom left* positions. As such, independent samples t-tests were conducted to investigate this further. Indeed, there were significant differences when the *bottom* and *bottom left* positions were retained and compared between *mask* and *no mask* conditions, $t(98) = 2.061$, $p = .042$ (*bottom* position retained) and $t(98) = 2.178$, $p = .032$ (*bottom left* position retained). However, this difference between masking groups did not result in a significant main effect in the mixed-factors ANOVA. The presentation of mask was set at the between-subjects variable and the retained information type as within-subjects factor. The sphericity assumption was violated for the position variable, $X^2(20) = 236.230$, $p < .05$ $\varepsilon = 0.428$, and the Greenhouse-Geisser correction was used. As indicated, there was no significant main effect of masking, $F(1,98) = 2.707$, $p = .103$ $\eta^2 = .027$. However, a significant difference between masking conditions was obtained using an independent samples t-test, $t(1) = 3.190$, $p = .001$, to confirm the effect was not due to unequal sample sizes.

A significant main effect of position was obtained from the mixed-factorial ANOVA, $F(2.569, 521.752) = 4.169$, $p = .01$, $\eta^2 = .118$. The strongest rightward bias was obtained when the participants were required to retain the *bottom right* position information ($M = 0.189$, $SE \pm 0.05$) and a leftward bias was obtained when retaining *top left* position information, ($M = -0.022$, $SE \pm 0.06$). Paired t-tests were conducted using the Bonferroni adjustment for multiple comparisons to investigate whether there are further differences between biases. No other significant differences between the conditions were detected. There was no significant interaction between position and mask, $F(6, 251.752) = 0.771$, $p = .49$, $\eta^2 = .008$.

Overall, the data indicate that biases are smaller when the retention stimuli were masked as compared to non-masked stimuli. This difference is statistically significant when the stimuli were presented in the *bottom* and *bottom left* positions but not in other positions. Also, the biases show to vary in magnitude and direction depending on the remembered spatial position within the circular array. Leftward trends in the *bottom* and *top left* positions when the stimuli were masked, despite that most of the position conditions yielded rightward biases, especially in the no mask condition.

Biases While Retaining Shade Information

Rightward trend was attained for the shade conditions in the *mask* and *no mask* groups. One-sample t-tests were conducted for each condition and group to determine whether the biases are statistically different from 0, or not bias. Rightward bias showed to be nearly statistically significant only when the dark shade was retained and no mask was presented in the dark shade retention, $M = 0.08$, $SE \pm 0.05$, $t(46) = 1.535$, $p = .07$ (one-tailed test) (Figure 5.2, panel B).

Mixed-factors ANOVA was conducted with the *mask* and *no mask* group set as the between-subjects variable and the shade as within-subjects factor. The laterality index was set as the dependent variable. There was no significant effect of mask, $F(1, 98) = 0.026$, $p = .9$, $\eta^2 = 0$, or shade, $F(3, 249) = 0.374$, $p = .77$, $\eta^2 = .004$. There was no significant interaction between mask and shade, $F(3, 249) = 0.656$, $p = .579$, $\eta^2 = .007$. Overall, there were no significant effects between the different shades and masking groups (Figure 5.2, panel B).

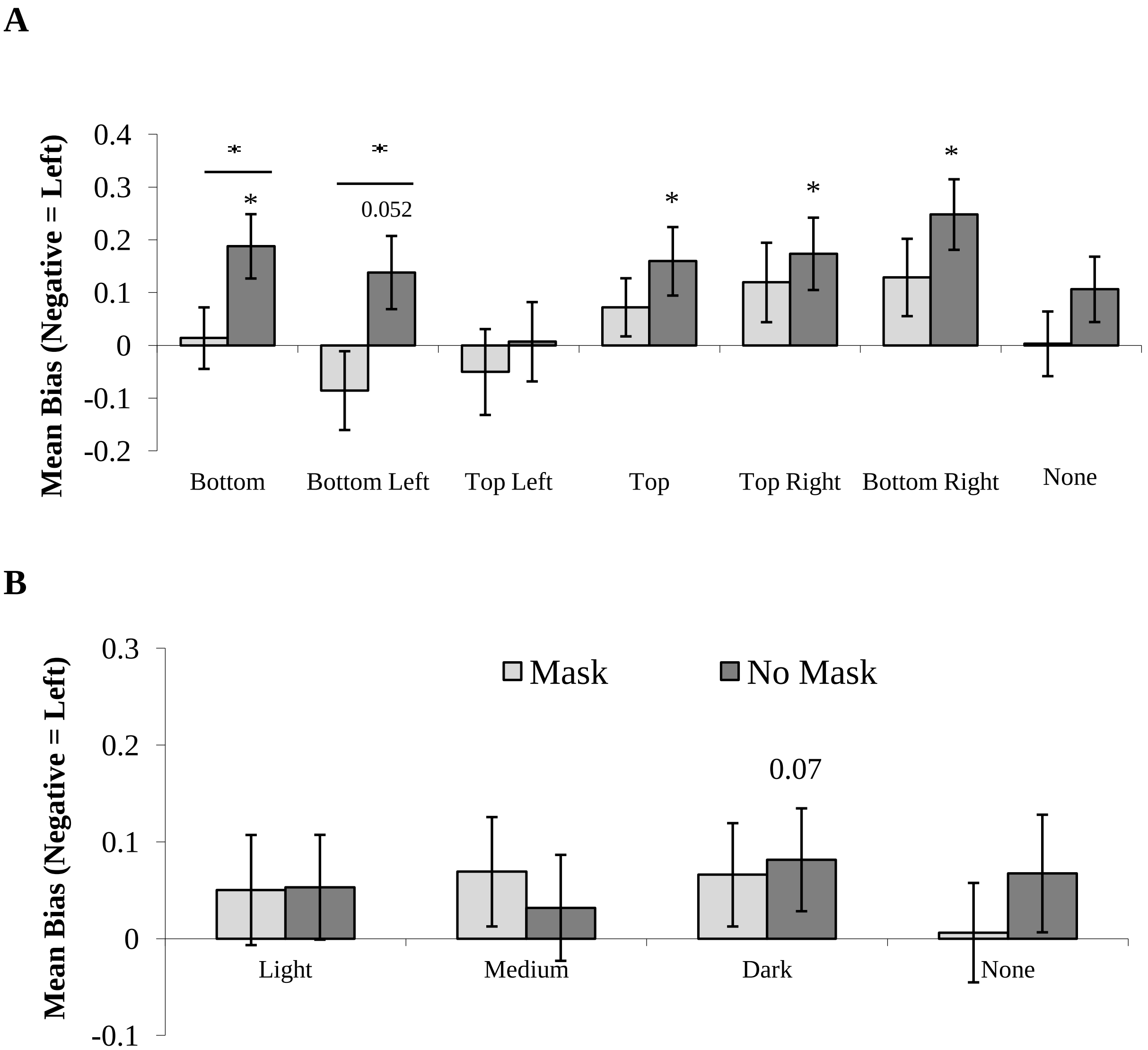

Figure 5.2. Mean bias for each to-be-remembered position (A) and shade (B) stimuli for masked and non-masked conditions. Error bars represent standard error of the mean. In (A) directional notations indicate which position within the array was to be remembered. In (B) the notation represents the shade of the disk. In both panels, 'none' represents the control trial where no to-be-remembered stimuli were presented, only the brightness comparison task was performed. Error bars represent standard error of the mean. Asterisks represent mean significantly different from no bias (0) in 2-tailed t-test. The horizontal line and asterisk represents the significant difference between mask and no mask conditions in categories.

Recall Accuracy of Position Information

Recall accuracy was investigated to determine whether the participants maintained the requested information throughout the duration of the trial. All conditions showed a high recall accuracy which ranged from 85% to 96%. Separate one sample t-tests were conducted to determine whether these percentages were statistically different from chance (17%). All conditions within the *mask* and *no mask* groups showed statistically significant effects with $p < .05$.

To establish a statistical difference between accuracy and retention of the position information, a mixed-factors ANOVA was performed. *Mask* and *no mask* groups were set as between-subjects variables and retained position set as within-subjects factor. There was no significant main effect of masking, $F(1, 98) = 2.088$, $p = .152$, $\eta^2 = .021$. However, a significant difference was attained when the *mask* and *no mask* groups were compared in a separate analysis using an independent samples t-test to test for different sample size in the groups, $t(598) = 3.099$, $p = .001$. As seen in Figure 5.3, panel A, the recall accuracy was slightly higher for items not preceded by a mask, therefore the working memory trace was permitted to form.

The sphericity assumption was violated for the position variable, $X^2(14) = 211.751$, $p < .05$, $\varepsilon = 0.49$ and the Greenhouse-Geisser correction was used to adjust the degrees of freedom. The results show significant main effect of position, $F(2.451, 240.170) = 4.868$, $p = .005$, $\eta^2 = .05$. Additionally, there was a significant position x masking group interaction, $F(2.451, 240.170) = 3.032$, $p = .04$, $\eta^2 = .03$. These differences show to be different when retaining the *bottom* and *top* positions within the array, $t(46) = 2.045$, $p = .047$ and $t(46) = 2.277$, $p = .027$ respectively. Recall accuracy was greater when the presented positions were not masked. These findings indicate that participants were not as accurate in recalling the *top* and *bottom* positions when stimuli were masked as compared to the non-masked stimuli. There was no difference in recall accuracy of the lateral positions. Furthermore, a slight increase in recall accuracy showed to be distributed across the various positions information when the memory trace was permitted to form.

Recall Accuracy of Shade Information

Recall accuracy of shade, although still high, was relatively lower than that of position retention. The recall accuracy range for shade was between 70% and 76%. Separate one sample t-tests were conducted to determine whether these percentages were statistically different from chance (33%). All conditions within the *mask* and *no mask* groups showed statistically significant effects with $p < .05$ (Figure 5.3, panel B).

The analysis was similar to that performed on recall of position, except that the three shades were set as within-subjects factors. The results show no significant main effect of mask, $F(1, 98) = 0.261$, $p = .61$. The sphericity assumption was violated in the main effect of shade condition, $X^2(2) = 14.851$ $p < .001$, $\varepsilon = 0.876$ and the Greenhouse-Geisser correction was used to adjust the degrees of freedom. There was no significant effect, $F(1.751, 171.634) = 0.833$, $p = .423$, $\eta^2 = .008$. Also, there was no significant shade x group interaction, $F(1.751, 171.634) = 0.211$, $p = .787$, $\eta^2 = .002$. These results show slightly lower recall accuracy as compared to the position, however, as in position recall, there are no significant differences in accuracy between mask groups and shade conditions.

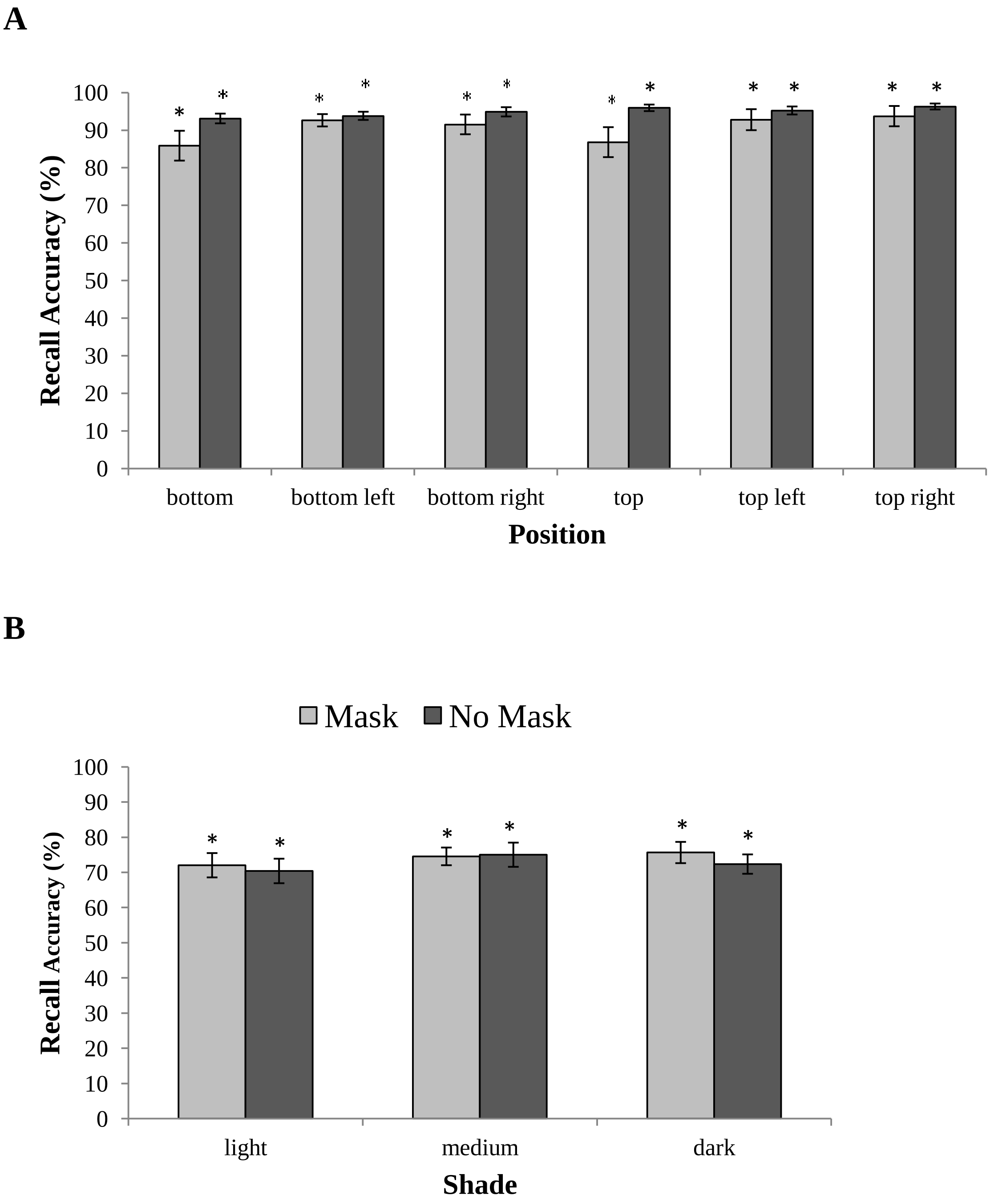

Figure 5.3. Recall accuracy of (A) the position and (B) shade information. Error bars represent the standard error of the mean. Asterisk represents statistical difference in recall accuracy from chance: 16.7% for position and 33.3% for shade information.

Discussion

This study investigated the impact of previously encoded information on perceptual asymmetries. The encoded information related to two properties within the array: the position of the individual disks and their shade. Participants were required to retain either one of the three shades or one of the six positions within the array and then complete a brightness judgment task. Two circular arrays were presented consecutively on the computer screen and participants selected the seemingly darker array. Once this judgment was completed, the participants were prompted to select the displayed retention stimulus presented prior to the judgment of brightness. Backward masking of the retention stimuli was used to permit or inhibit the formation of a working memory trace. Overall, the findings indicate a strong rightward bias in the brightness judgment while retaining position information. Furthermore, these biases seem to increase when the 'to-be-remembered' position is presented on the right as compared to the left side of the array. Recall accuracy of position shows to be higher in presenting the *bottom* and *top* positions in the *no mask* condition, but not in lateral positions.

Although there was a trend of rightward bias in brightness judgment while retaining shade information, it was not statistically significant. Also, there was no significant effect between *masked* and *no masked* groups in shade or position conditions. Therefore, the results show that perceptual asymmetries may be impacted by the retention of position information while performing independent brightness judgment task. These biases show a different pattern than expected with a spontaneous deployment of attention and seems to be consistent with an overall rightward bias outlined by Jewell and McCourt (2000) as a result of attentional cueing and shown experimentally by Reuter-Lorenz et al., (1990).

Overall the findings in this study coincide with the predictions of the activation-orientation hypothesis (Kinsbourne, 1970; Reuter-Lorenz et al., 1990). According to this hypothesis, visual input will produce an activation imbalance favouring the stimulated hemisphere and attention should shift contralateral to the stimulated hemisphere. The right hemisphere is dominant for attention and has the ability to attend to both, the left and right, sides of space. The left hemisphere, however, attends relatively more towards the right side. The differential lateral orienting strength may underline the relevant behavioural asymmetries (Reuter-Lorenz et al., 1990). Attentional biases due to activation in the left hemisphere are more robust than the leftward bias emitted by the activation in the right hemisphere. The orienting strength, according to Reuter-Lorenz et al., (1990), is associated with the forcefulness and selectivity. The force of one opponent overcomes the force of the other. If the pull of the left hemisphere was stronger than that of the right hemisphere, rightward orienting bias would prevail. Furthermore, when orienting conflict is introduced, rightward biases become more robust then the leftward biases (Reuter-Lorenz et al., 1990). Possibly, the rightward biases obtained in this experiment were attained as a result of this orienting conflict.

Retention of Shade Information and Bias

The obtained rightward trend indicates a relatively higher involvement of the left hemisphere over the right indifferent of whether memory trace was permitted to form or not. In this experiment the 'to-be-remembered' shade was presented centrally preceding brightness judgment of the circular arrays. The arrays were extended across the computer screen and presented so that the lightest and darkest shades were shown equally often on the left and right sides of the screen. The medium shade, in-between the lightest and darkest was always shown in the center of the screen. It is feasible that the random presentation of the shades as well and the equal number of shade presentations on the left and right sides of the array resulted in the null outcome. However, the findings indicate an overall rightward trend therefore; it is unlikely that the manner in which the stimuli were presented was the sole contributor of the obtained finings.

As per the activation-orientation hypothesis (Reuter-Lorenz et al., 1990), possibly both hemispheres were simultaneously activated and resulted in a maximized conflict between them. However, the rightward trend indicates that the left hemisphere might have been stimulated slightly more than the right. Similar findings have been reported by Reuter-Lorenz et al., (1990), where participants were asked to report the presence or absence of a lateral square in addition to performing line bisection task. The participants were informed that on any given trial it was equally likely that the square was present or absent. The findings showed an overall larger bias elicited by the rightward cue than that elicited by the left cue. When the lateral cue was absent, the difference between the biases diminished for both visual fields (Reuter-Lorenz et al., 1990, experiment 4). In their task the locus of orientation was not predictable and intended to induce orienting uncertainty. Similarly, the shade stimuli were presented randomly within the block and impossible for participants to predict. Therefore, as in Reuter-Lorenz et al., (1990) it is feasible that this conflict resulted in induced orienting uncertainty and overall slight rightward bias. Attention seems to bias the competition to favour some inputs over others. Therefore, this indicates that there are competitive interactions between the representations between the left and right extent of the line (McCourt et al., 2005) which further supports the activation-orientation hypothesis (Reuter-Lorenz et al., 1990).

Retention of Position Information and Bias

When presenting the spatial position, I hypothesized that the bias would be much stronger in masked as compared to non-masked condition. In the masked condition I found that the biases were directed towards the left and the right, but not statistically significant. Again, the activation-orientation hypothesis can be used to explain the biases obtained in the current experiment. This explanation relates to the competition between the hemispheres in processing the tasks. Greater left hemisphere activation is produced as compared to the right hemisphere activation showing an overall rightward bias.

However, this explanation raises some concerns. What would result in the left hemispheric pull that leads to the rightward bias? Once again, I can claim that the rightward biases are a result of hemispheric conflict. However, if this were the case, I would see more uniform rightward biases between the masked conditions. One explanation is that there could be some verbal encoding of the cue. Verbal encoding should eliminate any differences between the conditions and lead that biases between mask and no mask conditions were identical. The stimulus was presented for a long enough time that the participant would be able to engage in verbal coding of the image. I obtained significant differences between the mask and no mask group when participants were required to encode the position presented on the left side of the screen. As this was not the case, I can state that verbal encoding is not a reasonable explanation of the results from this experiment.

Considering the nature of the task in this experiment; the array is comprised of six individual disks and the participants are asked to integrate these disks and judge brightness of the overall array. Possibly, this integration requires a different set of lateralized processes which would result in the rightward biases. However, experiments in Chapter 2, investigating perceptual asymmetries in this circular array showed overall leftward bias. Two circular arrays were presented on the computer screen and the participants judged the brightness of the overall array to determine which seemed overall darker. The findings from this experiment showed an overall leftward bias, where participants judged the array as overall darker when the darkest disks were presented on the left side as compared to their mirror image. These findings are consistent with other studies using various tasks including line bisection, greyscale and gratingscales as stimuli (Jewell & McCourt, 2000; McCourt & Jewell, 1999; Nicholls et al., 1999; Niemeier et al., 2008). Although conclusive neuroimaging studies would have to be conducted to state for certain, the behavioural consistency between these tasks indicates that the circular array task is comparable to those used so far. Therefore, the presentation of circular array over other stimuli does not completely explain the obtained results either.

The findings indicate that the obtained biases might be a result of different mechanism than that responsible for leftward biases. Leftward spatial biases are observed in tasks including greyscales, gratingscales, line bisection tasks, and in circular array task where the goal is to judge the stimuli presented across the left and right visual space. Therefore, in the current task, if the response was not impacted by the content of the retained stimuli, I should expect to see leftward biases as well, but I did not. Even in control condition there was a rightward bias trend. This indicates that the observed biases are not similar to those found in other greyscales. Similar conclusion was reached by Railo, Tallus, and Hämäläinen (2011) who also attained rightward biases in a cued visual task. Directional cue was presented for 220 milliseconds followed by a target. Mask was presented or not after the target stimuli. Left and right handed participants were required to detect the presentation side of the target and rate the visibility of the target. The results showed a difference between the hemifields in no mask condition and deteriorated during strongest masking condition (60 ms SOA) (Railo et al., 2011). These findings concur with the current results where strongest biases were attained in *no mask* condition.

Lateral biases have been shown to be present in other mechanisms including memory. McGeorge et al., (2007), in memory recall of objects present in a familiar to participants cathedral square, showed increased accuracy for objects located on the left side relative to the point of view. This lateral asymmetry was termed *representational bias* to highlight the specific asymmetry of visuospatial representation in memory. Similarly, Dickinson and Intraub (2009) demonstrated that items within an unfamiliar naturalistic scene are recalled more accurately when presented on the left side. Cocchini, Walting, Della Sala, and Jansari, (2007) assessed the representation of space behind the participants in a virtual reality task. The right side of the space was perceived as smaller when compared to the left side of space. Recently, lateral asymmetries have also been shown in working memory for novel materials. In the feature binding task, participants showed an increased accuracy in matching color, shape, location, and identity of the stimuli presented to the left side of the computer screen as compared to the right (Della Sala et al., 2010). Furthermore, leftward biases have also been reported in tactile (Brooks et al., 2011) and visual (Darling et al., 2012) bisection of stimuli from memory. These studies point out presence of biases in processes other than perception or attention.

The findings show that when the 'to-be-remembered' position was presented on the left side, there was an inconsistency between masked and non-masked conditions. Rightward biases were obtained in the no-mask condition, however, in the masked condition, the biases were not significant and there was even a slight trend towards the left. Furthermore, the differences between the masked and no-mask conditions for these positions were statistically significant. These findings indicate that the mechanism involved in processing this information responsible for these biases may yield biases which show to be toward the right direction as opposed to left. Furthermore, there is an indication that the retained content is responsible for this effect as it was observed when memory trace of the to-be-remembered stimuli was permitted to form completely.

When considering the control condition, a straightforward brightness judgment in circular array task, no leftward bias was attained. At first this is concerning, as one would expect that this condition would have elicited leftward biases. However, this would not be the case if this comparison was conducted using the same mechanism as the remainder of the conditions. In fact, there is evidence that such generalization within a task does occur. Trials within a block of presented primed stimuli impact the visual search within the block (Kristjánsson & Driver, 2008). Considering this evidence, it is not surprising that rightward biases were obtained in the control trials as well. Finally, overall higher recall of the remembered position was obtained when the memory trace was permitted to form as compared to when it was not. This indicates that throughout the brightness judgment task, working memory was maintaining the content of the remembered stimuli. This indicates that the mechanism by which this retained information is processed may work in parallel from that of spontaneous attentional direction, where the bias is stronger in the top left corner. Therefore, the findings show that the implementation of the mask modulates the magnitude and direction of lateral biases.

The current study adds to this body of literature by showing that the information maintained in working memory modifies the direction and magnitude of lateral biases obtained by completing a separate visual attention task. Furthermore, this study shows an overall rightward bias in brightness judgment task while maintaining either specific position or shade features of the circular array. More importantly, the rightward bias shows to be stronger when the memory trace is permitted to form and weaker when the memory trace is inhibited. Lateralization of orienting and executive attention networks shows to be lateralized to the right hemisphere, therefore, would elicit leftward behavioural bias. These obtained findings show support to the activation-orientation hypotheses. However, it is likely that the rightward bias is not solely a result of attentional activation but also of engagement of additional neuronal mechanisms such as working memory. The support for this conclusion lies in the increased bias when a memory trace was permitted to form. Therefore, this study indicates that aspects of the activation-orientation hypothesis may be applicable to working memory mechanisms.

CHAPTER SIX

GENERAL DISCUSSION

Summary of Results and Discussion

Left and right asymmetries have been attributed to perceptual and attentional asymmetries in processing visuospatial information. Recent evidence indicates that asymmetries have also been shown while engaging working memory processes. Although the relationship between attentional and working memory processes is well established, it remains elusive how these asymmetries in early visual processes impact the formation of working memory. Furthermore, it is also unknown how working memory impacts asymmetries. In this discussion, several questions are addressed in order to better understand how working memory impacts, and is impacted by, perceptual and attentional asymmetries.

In the current body of work, the relationship between perceptual asymmetries and working memory was investigated using two approaches. The first approach is based on the definition of working memory. Working memory permits stimuli to be maintained for processing and manipulation, even once the stimuli is no longer available to view. From this perspective it is evident that there are two factors which can be manipulated in an investigation of working memory: visual load and time interval. A novel circular array task was designed to investigate the manipulation of the visual load within attention and working memory. To manipulate the visual load, the greyscales used were modified so that the number of black and white pixels varied, but the overall pixel density was maintained. The time interval between stimulus presentation and retention may allow for working memory processes to take effect. In the second approach, the formation of the visual memory trace was controlled with the use of masks. The content of the memory trace was manipulated and its impact on the attentional and perceptual asymmetries was investigated.

As noted above, the manipulation of visual load within working memory might indicate lateral asymmetries in later stages of processing. Two experiments were performed to investigate this factor. In experiment 1, the investigation of the integration of a series of distinct stimuli into one array was judged for brightness. Variable noise, in the form of black, white and grey pixels was introduced within each array to manipulate the visual load. The participants judged the arrays presented to the lower visual field as darker overall when compared to the arrays presented in the upper visual field. Furthermore, arrays containing relatively low noise levels which were presented to the upper visual field yielded a rightward bias. A similar effect was observed in findings from experiment 3 the visual load was manipulated such that the total number of black and white pixels was manipulated but the overall pixel density remained constant. The greyscales were presented and the participants were required to select the greyscale which was darker overall. Here, there were significant differences between the upper and lower visual fields when the visual load was manipulated. Interestingly, in the upper visual field, the leftward bias decreased in magnitude when the visual load was increased from small to large. Conversely, leftward bias increased in the lower visual field when the visual load was increased.

These findings indicate the presence of rightward biases, as well as leftward ones, under specific conditions. Although asymmetries are evident when participants are required to integrate a series of distinct disks into one array, it remained unknown, whether the overall greyscale must be preserved for these biases to be observed. Therefore, in experiment 2, the novel task, in which circular arrays were used for the judgment of brightness, was ideal for testing this effect as the individuality of the disks permits an investigation of whether distinct objects can be perceptually integrated for a judgment of brightness similar to greyscales. As such, the overall array was disrupted so that two of the disks were switched in position. Again, the arrays were presented to the upper and lower visual fields. The results showed leftward biases when the arrays were presented to the lower visual field and rightward biases were attained when the arrays were presented to the upper visual field. Furthermore, the arrays correlated and the magnitude of the bias was related to the manipulation of the disks within the array. This relationship was consistent for the upper and lower visual fields. Therefore, within each visual field, the relative position of the stimuli impacts the processing.

Another important factor in this approach is to determine whether working memory permits the manipulation of visual stimuli which are no longer visually available. As such, one important factor here is, again, that of time. Hence, in experiment 4, a pair of greyscales was presented simultaneously and participants judged which one seemed overall darker to them. However, to investigate whether asymmetries will be retained over a period of time, the participants were instructed to withhold their response for a certain time interval. Lateral biases were investigated in the upper and lower visual fields. There were strong leftward biases in both upper and lower visual fields, when participants were required to respond immediately or with a 1 second delay after the presentation of the greyscales. The longer the response delays, the smaller the bias. Furthermore, the bias completely disappears in both visual fields after a 5 second time delay indicating a stronger attentional rather than working memory impact.

Overall, these findings indicate that leftward and rightward biases are evident when manipulating visual information either by manipulating the visual load or by integrating several distinct stimuli into one. Therefore, there is evidence that working memory processes also play a role in attaining biases in responses. Admittedly, however, the above outlined studies do not exclude that attention processes might be solely responsible for the attained results. Therefore, the final two experiments presented in this dissertation experiments 5 and 6 investigated the relative contribution of attentional and working memory processes to biases in responding and will be discussed later in this section.

In experiment 5, the time interval premise, where one stimulus is presented after the other at a predetermined and varying inter-stimulus time interval, was once again taken into consideration. It is possible that the reason why no biases were observed at longer time intervals was because the participants did not retain the stimuli within memory. It is feasible that once the participants made the judgment between the two arrays, which could have been mainly an attentional process, they had to retain that decision of judgment and not the stimuli for the required time interval. Therefore, it was not the stimuli, but the decision of the judgment that had to be retained. Regan and Beverly (1985) suggest when an observer is asked to compare two sequentially presented stimuli; four different stages are involved: 1) Encoding the visual features of the first stimulus; 2) Maintaining the representation of the stimulus during the delay; 3) Encoding the second stimuli; and 4) Comparing the two representations. Therefore, it is possible that the presentation of the stimuli in close temporal proximity impedes the involvement of working memory. In fact, this is also the conclusion reached by Montaser-Kouhsari and Carrasco (2009).

It is important to note that attentional and working memory processes work together and it is possibly not feasible to concretely distinguish between which process is involved in which task and to what extent when the stimuli are presented for longer intervals. However, with the use of backward stimulus masks, it is possible to control the relative involvement of these processes. The formation of the working memory trace occurs once the stimulus is presented, however, with the subsequent presentation of the noise mask, this memory trace formation is interrupted and further processing in working memory is inhibited. Therefore, in the last two studies backward masking paradigm was used to be able to differentiate working memory from attentional processes. The fourth study, as stated earlier, investigates the hypothesis that the delayed presentation of the second stimulus may involve working memory processes. Therefore, the stimuli were presented with a variable inter-stimulus interval. Half of the trials contained a noise mask presented immediately following the first stimuli. The findings indicate the presence of biases which increased in magnitude at the longest inter-stimulus time interval without the use of a mask. Furthermore, in the recall task, the participants were highly accurate in recalling the first presented array, which indicates the encoding of the stimuli within the working memory processes. These findings show that biases are evident when information is maintained within working memory.

Experiment 6 was conducted to address whether the biases are related to the position or the shade of the disks within the array. First, the participants were required to remember a position or shade within the array. This stimulus was masked in half of the trials. The participants were required to conduct a brightness judgment task. Once this task was completed, the participants were then asked to recall the memorized stimulus. The findings of this study indicate that the contents of the working memory content (no mask condition) impact left/right biases only if the position information is maintained. Interestingly, the largest differences between masking conditions were when the retained stimuli were presented on the left side of the array. In the condition when memory trace was not permitted to form because of the presence of a mask, the findings show a rightward bias for the stimuli that were presented on the right side. These findings are consistent with those of Jewell and McCourt (2000), who indicated an overall rightward bias for cued stimuli. Leftward visuospatial biases are associated with the spontaneous deployment of attention. In this experiment, there was a small trend of leftward bias in the masked condition, which completely disappeared when the memory trace was permitted to form. In fact, these biases turned rightward. These findings indicate a possible involvement of separate mechanisms which yields opposing, rightward biases to those attained when attention is spontaneously deployed.

Representational bias

There is evidence in the literature which hints at lateralized biases in visual memory. One such example is indicated when participants are required to select the midpoint between a pair of mentally represented numbers. Participants show a preference towards the smaller number in the pair (Loftus, Nicholls, Mattingley, Chapman, & Bradhsaw, 2009). The numbers are thought to be mentally represented with smaller numbers to the left and larger numbers to the right (Hubbard, Piazza, Pinel, & Dehaene, 2005). Therefore, because of this numeric representation and the leftward biases, the effects are arguably considered to be indicative of representational biases (Brooks, Logie, McIntosh, & Della Sala, 2011).

Leftward biases have also been observed when viewing naturalistic scenes where participants were required to match the background to a previously viewed scene. The participants placed the background slightly towards the right side, misrepresenting the absolute midline of the background towards the right. Therefore, these findings indicated a misrepresentation of space towards the right side indicating an overestimation of the size of the left side of space (Dickinson & Intraub, 2009). Similar effects were shown while assessing the representation of back space in a virtual reality task (Cocchini, Watling, Della Sala, &Jansari 2007). The right side of the space was perceived as smaller when compared to the left side of space. Misrepresentation of representational space has also been shown in sensory modalities other than vision. Brooks et al. (2011), showed leftward biases in healthy participants while listening to verbal descriptions of patterns to form a mental representation of these patterns. Participants judged these representations as fuller on the left side as compared to the right and this bias was increased when the verbal description was presented to the left ear, stimulating the right hemisphere. Similarly, tactile rod bisection task participants mis-bisected the rod erring to the left when the stimuli were presented only through touch and no visual input was available (Brooks, Della Sala, & Logie (2011).

Representational pseudoneglect (McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007) has been directly investigated using a task adapted from Bisiach and Luzzatti (1978), which investigated imagery biases in patients with neglect. Participants imagined themselves in a cathedral square which was familiar to them and recalled the objects located on their left and right sides. Independent of the view point, faster and more accurate recalls were observed to objects located on the left side of space as compared to the right. Leftward asymmetries have also been shown while binding two distinct features presented on either the left or right sides of a computer screen followed by tests of recall accuracy (Della Sala, Darling, & Logie, 2010). Finally, recent work by Darling, Logie, and Della Sala (2012), using the classic line bisection paradigm, showed a leftward bias when participants bisected horizontal lines from memory.

Della Sala, Logie, Beschin, and Denis, (2004) indicate that the best candidate involved in the representational bias is working memory. Working memory is believed to be a system providing temporary visuospatial representations and the means for manipulating and interpreting those representations (Logie, 1995). The evidence points out that the cognitive impairments of representational neglect arise from the damage to the system responsible for holding temporary mental representations. This evidence arises from the population with neglect syndrome, when patients with the right partial damage fail to report, respond to, or orient to stimuli presented in the left visual hemispace. Therefore, lateralized damage to visuospatial working memory, as in neglect patients, may result in representational neglect (Beschin, Cocchini, Della Sala, & Logie, 1997; Ellis, Della Sala, & Logie, 1996).

Although previous research indicates within this dissertation leftward biases should have been attained, this was not the case. Predominantly rightward biases were obtained especially when presenting masking conditions and permitting working memory traces to form. Therefore, the findings in the studies reported in this dissertation are in opposition to those reported by McGeorge et al., (2007) showing representational biases. However, the lack of leftward biases or presence of rightward biases is not exclusive to my studies. A limited number of recent researches indicate similar results as those found in the current body of work.

Drummond and Tlauka (2012), presented a diagram depicting a central character and target objects to university students. The objects were located in six positions (left/ right, up/down, and front/back) relative to the person depicted on the diagram. Upon learning the locations of the objects, the participants were required to recall the locations of these objects from imagined orientations. The findings did not reveal a significant difference in recall between the targets located on the left or the right sides. Furthermore, although not statistically significant, the recall latencies were shorter for the right than the left targets. Interestingly, the responses on the top were faster than those on the bottom objects, irrespective of their posture. This upward bias in memory was unaffected by the rotation of the object within the scene.

Upper and lower differences have also been shown using a spatial frequency discrimination task. Participants were required to differentiate between two Garbor patches presented at varying spatial frequency, position, and time. The results showed a better discrimination performance along the horizontal axis (upper and lower screen position) as compared to the vertical (left/ right) meridian (Montaser-Kouhsari & Carrasco, 2009). Furthermore, these findings showed that the asymmetries in performance observed in perceptual tasks requiring discrimination have also transferred over to visual short-term memory, as shown through the delayed discrimination task. Therefore, the authors conclude that the factors that alter perceptual performance also affect memory performance (Montaser-Kouhsari & Carrasco, 2009). The experiments presented in the last two chapters of this dissertation further support this conclusion. The results show an increase in bias when the memory trace of the position information was permitted to form. Furthermore, these biases showed a directional continuity between the masked and non-masked conditions indicating that these factors, which resulted in the directional bias while in earlier stages of processing, have also possibly been engaged in later stages.

Admittedly, the focus of this dissertation was to investigate the left/right asymmetries in working memory, therefore, the experiments, especially the latter, focused on this variable. However, preliminary data suggest further investigation, with the focus on the upper and lower visual field asymmetries on memory processes. Chapters 2 and 3 included the upper and lower visual fields as a variable. Interestingly, these findings indicated that in the array task, when the overall greyscale gradient is disrupted, there are substantial directional and size effects depending on the upper and lower manipulation of position stimulus within the overall array. These findings, although still requiring further study, indicate that when stimuli call for integration into an overall representation, upper and lower visual field differences are observed, which are highly integrated with the left/ right asymmetries.

Asymmetries along the horizontal and vertical axes impact the visual performance across the visual field. A variety of tasks, including letter recognition, orientation discrimination, detection, and localization, yield superior performance along the left/right vertical axis. This asymmetry arises regardless of the stimulus orientation and is present when the orientation of Garbor stimuli is close in proximity horizontally and orthogonally to the horizontal meridian (Cameron, Tai, & Carrasco, 2002; Carrasco, Talgar, & Cameron, 2001; Mackeben, 1999; Rovamo & Virsu, 1979; Rovamo, Virsu, Laurinen, & Hyvärinen, 1982). Conversely, considering upper and lower visual field differences, research indicates increased performance in the lower visual field as compared to the upper visual field. Tasks requiring orientation discrimination, texture segmentation, and Landolt-square acuity tasks indicate superior performance. In addition to the individual contributions of the upper/ lower and left/right asymmetries, these biases have been shown to interact. Tasks demonstrating a lower visual field advantage also show left visual field advantage. These tasks include global processing, coordinate spatial judgments requiring visuo-motor coordination and global motion. Similarly, tasks indicating an upper field advantage also yield rightward biases in tasks including local processing, categorical judgment or object identification, and visual search.

Finally, there is also indication that presentation time of the stimuli also impacts biases yielding stronger leftward asymmetries in the upper visual field. Therefore, as task and stimulus variability impacts visual processing at earlier stages including perception and attention, it is not much of a leap to predict that similar variables will impact later processing including that in working memory processes. A similar conclusion was reached by Montaser-Kouhsari & Carrasco (2009), relating to the quality of the stimulus, where the quality with which a visual stimulus is perceived and encoded at different locations affects the quality with which that stimulus is processed in visual short-term memory.

Future directions

The findings by Montaser-Kouhsari and Carrasco (2009), and those reported in this dissertation indicate upper and lower visual field differences in spatial memory processes. This is not necessarily surprising as upper and lower visual field differences have been associated with the differential processing in the early visual stage. A more thorough investigation of how the information is processed as a result of the horizontal distribution and its impact on memory processes could further add to this body of research. These studies would also focus on the question of whether spatial working memory itself is biased. As the visual information is acquired from the environment, it is biased by the perceptual and attentional mechanisms, but it remains unknown whether lateral memory mechanisms also contribute to this bias.

Another potential future direction is with the utilization of eye tracking and neuroimaging techniques. The eye tracking technique would be useful to investigate how the participants responded to the circular arrays which were comprised of six individual disks. It would also be useful to investigate their eye movement in the brightness judgment tasks. An interesting question here is how the participants scan the circular arrays. This question was not of focus in this set of experiments and therefore it was not pursued, however, it remains unanswered and deserves further investigation. The neuroimaging techniques would unravel the neuronal mechanisms activated when performing these tasks. So far, there are no studies using this technique to investigate representational biases in working memory tasks. Therefore, it would be fascinating to investigate the activation patterns of perceptual asymmetries using attentional and working memory paradigms in within-subjects designs.

Although the present work does have its limitations, I believe it opens the door to a fascinating research area. The findings presented here show that it is possible that earlier stages of visuospatial processing, lateral and vertical biases interact strongly depending on the visual load and overall representation of the stimuli. Furthermore, these findings also show that the content maintained in memory systems impacts perceptual asymmetries even when the memory content does not provide any substantial information which would provide any advantage in judgment. Inter-stimulus interval and stimulus masking have shown to be able to differentiate between the relative contribution of attention and memory to asymmetries under selected circumstances. Taken together, the findings support the presence of lateral biases in the interaction between spatial attention and memory systems, indicating the presence of lateralized and reciprocal communication between these systems.

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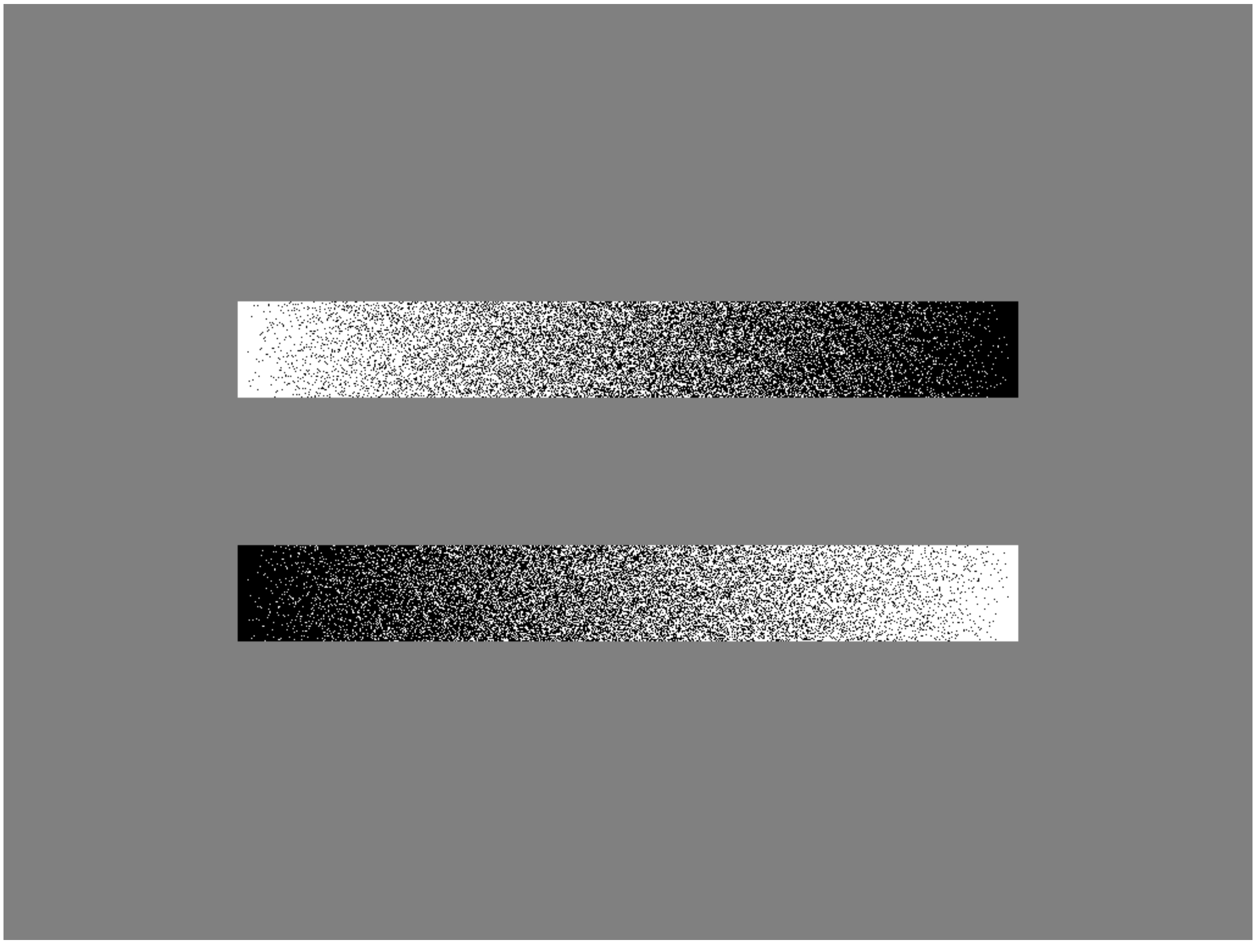
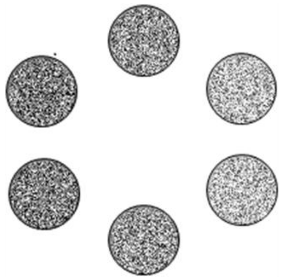
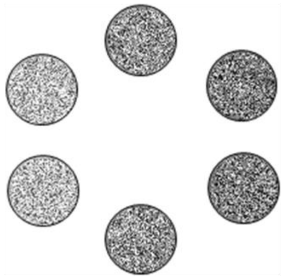
APPENDIX A. SAMPLE STIMULI FROM THE GREYSCALES TASK



This task was created by Nicholls, Bradshaw, and Mattingley (1999). This sample illustrates how this task appears when it is presented in the centre of the visual field.

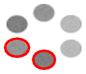
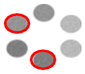
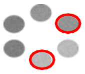
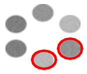
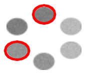
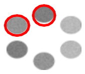
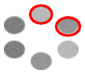
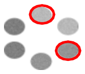
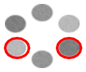
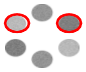
APPENDIX B. SAMPLE OF GREYSCALE ARRAY





APPENDIX C. Chapter 2, Experiment 2

Table 1. Mean biases, standard deviation and significance tests indicating biases different from chance.

	Lower visual field				Upper visual field			
Condition	*M*	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
	-.11	.43	-1.734	.089	.09	.51	1.179	.244
	-.26	.48	-3.747	.000	.20	.56	2.530	.015
	-.53	.37	-10.094	.000	.47	.38	8.495	.000
	-.41	.38	-7.476	.000	.35	.45	5.385	.000
	-.39	.44	-6.109	.000	.30	.48	4.267	.000
	-.51	.44	-8.115	.000	.29	.41	4.924	.000
	-.21	.47	-3.082	.003	.02	.48	.302	.764
	.08	.44	1.202	.235	-.13	.48	-1.904	.063
	-.33	.33	-6.912	.000	.32	.49	4.608	.000
	-.27	.33	-5.611	.000	.24	.33	5.080	.000
	-.41	.47	-6.037	.000	.35	.43	5.739	.000

APPENDIX D. Chapter 5, Experiment 6

Table 2. Mean bias, standard deviation and results of one sample t-test comparing the mean to chance (no bias) - SHADE information

Group	Cue Shade	Mean	SE	t	p value
Mask	Light	.05	.057	.884	.381
	Medium	.07	.057	1.224	.226
	Dark	.07	.053	1.237	.222
	None	.01	.051	.122	.903
No Mask	Light	.05	.054	.982	.331
	Medium	.03	.055	.583	.563
	Dark	.08	.053	1.535	.132
	None	.07	.061	1.109	.273

Mask Group df = 52. No Mask group df = 46.

Table 3. Mean bias, standard deviation and results of one sample t-test comparing the mean to chance (no bias) - POSITION information

Group	Position Cue	Mean	SE	t	p value
Mask	Bottom	.01	.058	.239	.812
	Bottom Left	-.09	.075	-1.145	.257
	Top Left	-.05	.081	-.618	.539
	Top	.07	.055	1.313	.195
	Top Right	.12	.075	1.587	.119
	Bottom Right	.13	.073	1.759	.085
	No Cue	.00	.061	.051	.959
No Mask	Bottom	.19	.061	3.083	.003*
	Bottom Left	.14	.069	1.993	.052
	Top Left	.01	.075	.094	.925
	Top	.16	.065	2.458	.018*
	Top Right	.17	.069	2.534	.015*
	Bottom Right	.25	.067	3.714	.001*
	No Cue	.11	.062	1.717	.093

Mask Group df = 52. No Mask group df = 46. Asterisk represents significant result.

APPENDIX E. CONSENT FORM

Working Memory and Spatial Attention Q61

CONSENT FORM

You are invited to participate in a research project entitled Working Memory and Pseudoneglect. Please read this form carefully, and feel free to ask questions you might have.

Researcher: Izabela Szelest, Department of Psychology at the University of Saskatchewan,
Phone: (306) 966-2527.
Supervisor: Dr. Lorin Elias, Department of Psychology at the University of Saskatchewan,
Phone: (306) 966-6670.

Purpose and Procedure: This research investigates the role of memory on attentional processes. You will be asked to compare two images and determine which one is darker (or lighter). To make a response you will press the corresponding key on the computer keyboard. As compensation, you will be granted one credit for every 30 minutes of your participation.

Potential Benefits: This study is designed to have scientific benefit in further understanding the intricate relationship between attention and memory. As a direct benefit to you, the participant, you may gain a greater understanding on how experimental research is conducted.

Potential Risks: There are no known risks associated with participation in this study.

Storage of Data: The data obtained in this study will be stored separate from the consent forms with no possibility of identification. All data and consent forms will be securely stored by Dr. Lorin Elias at the University of Saskatchewan for a minimum of five years after the study is completed. If the data is no longer needed and required to be destroyed, it will be destroyed beyond recovery.

Confidentiality: Although the data from these research projects may be published and presented at conferences, the data will be reported in aggregate form, so that it will not be possible to identify any individuals.

Right to Withdraw: Your participation in this study is voluntary, and you can answer only those questions that you are comfortable with. There is no guarantee that you will personally benefit from your involvement. The information that is shared will be held in strict confidence and discussed only with the research team. You may withdraw from the research project for any reason, at any time, without penalty of any sort and it will not affect your course credit. If you withdraw from the research project at any time, any responses you made will not be liked to your name and therefore withdrawal of data is only possible up until the completion of the experiment.

Questions: If you have any questions concerning the research project, please feel free to ask at any point; you are also free to contact the researchers at the numbers provided if you have other questions. This research project has been approved on ethical grounds by the University of Saskatchewan Behavioural Research Ethics Board on (February 26th, 2010). Any questions regarding your rights as a participant may be addressed to that committee through the Ethics Office (966-2084). Out of town participants may call collect. Results may be obtained by contacting Dr. Lorin Elias.

Consent to Participate:
I have read and understood the description provided; I have had an opportunity to ask questions and my/our questions have been answered. I consent to participate in the research project, understanding that I may withdraw my consent at any time. A copy of this Consent Form has been given to me for my records.

______________________________ (Name of Participant)	______________________________ (Date)
______________________________ (Signature of Participant)	______________________________ (Signature of Researcher)

APPENDIX F. DEBRIEFING FORM

UNIVERSITY OF SASKATCHEWAN

Working Memory and Spatial Attention Q61

DEBRIEFING FORM

Thank you so much for being a part of our study. With your help we are able to investigate the intricate relationship between memory and attention. Memory plays an essential role in our everyday lives. For example, on a cold winter morning you want to find your car keys with the remote starter so that you can start the car before running out into a freezing temperature. The most efficient way to do that is to remember where you put the keys last and then go directly to that location. Once you remember that these car keys are on your kitchen table (for example), you are able to focus your attention and search specifically at that location. Without even realizing it, you have used another major brain function – attention. Attentional mechanism is especially interesting when processing spatial information. We are more likely to notice objects which are located to our left side over the ones to our right. This is known as pseudoneglect.

Researchers attempt to further understand and explain this phenomenon. One of the explanations states that the right brain hemisphere is relatively more dominant in processing spatial information and thus favors the left side of space. Thus, common effects such as reporting a darker image on the left side from two identical images are widely observed. Although the relationship between memory and attention is overall vigorously studied, the specific relationship between memory and pseudoneglect has not yet been considered. In this current study, we are asking whether memory does play a role in pseudoneglect and if so, what the properties of this relationship are.

In this experiment, you were presented with a pair of images presented one after another at different time delays. Your task was to determine which one is darker (or lighter) and respond accordingly on the computer keyboard. These responses were recorded in the form of accuracy and reaction time. A usual response would be that an object is darker if the darker side is presented to the left side. Using this set up, we are able to determine if memory plays a significant role in altering this usual response. We are hoping to find that the images presented with the longest interval will greatly affect the bias either by augmenting or possibly even reversing it thus biasing the right side of space over the left.

If you are wondering why we were not able to provide this information before you began the experiment, the answer is that we didn’t want to alter your response in the experiment. If we had told you that we are expecting that you should see the items which were black on the left as darker, then we would not be able to conclude that this effect is valid. This is known as *demand awareness effect*. When working with humans, this effect may potentially cause serious problems with the obtained results. If you were to alter your response based on provided information, then you may not be using the same psychological process which we are interested in studying. Such research would create conflicting results and delay scientific advancement. Thus, we would also appreciate if you do not tell your friends about the rationale/ methodology of the study as they may also participate.

Once again, thank you so much for being a part of your study. It is participants like you that allow us as researchers to investigate interesting, but complex, workings of our brain. It is our hope that your participation will not only help to advance our research, but that it would also help you to better understand how the research process works. If you have any additional questions or concerns about your participation, you may contact Izabela Szelest at 306-966-2527 or Dr. Lorin Elias at 306-966-6670. If you would like to contact the Research Ethics Office, you may do so by calling 306-966-2084.