A critical exploration of the factors influencing the relationship between spatial attention scale and visual perception

Rebecca Kathleen Lawrence

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Research School of Psychology
College of Health and Medicine
The Australian National University Canberra ACT, Australia

Declaration

I submit this thesis to the Australian National University as part of my requirements for the degree of Doctor of Philosophy (Psychology). I declare that the document submitted is my own work unless acknowledged otherwise throughout the body of this thesis. This thesis includes one published research article, and three journal articles currently under review. I was the primary author on each paper. My contribution to each of these papers is outlined on the following page, as well as in 'statements of contribution' attached at the beginning of each relevant chapter. The co-authors included in these papers provided advice regarding the theories and concepts presented in these papers, assisted in data collection, and proof-read the work submitted for publication.

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Rebecca K. Lawrence

Stephanie C Goodhew

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Abstract

When viewing the world, the human visual system is exposed to a vast and complex array of sensory information. Typically, the amount of information available exceeds the brain's capacity for processing at a given point in time. Therefore, the ability to deploy spatial attention, the mechanism that selects specific regions of space for enhanced visual processing at the expense of others, is necessary for seamless functioning. The overall goal of this thesis was to understand the causes and consequences of one aspect of spatial attention: attention scaling. Attention scaling refers to whether attention resources are focused on a narrow or broad region of the visual field.

The first half of the thesis examined whether individual experiences influence attention scaling. An inhibition of return (IOR) task was used to achieve this. Compared to previous work exploring individual differences in attention scale, the IOR task directly measures changes in attention across space, allowing for a valid measurement of attention scale uncontaminated by other processes. Using the IOR task, Chapter 4 tested the effect of age on attention scale. Two experiments found that older adults (60+ years) adopted a narrower attention scale in comparison to younger adults (18-30 years). Chapter 5 then extended this work by exploring whether cultural background influences the spatial distribution of attention. In contrast to past research, this study found no cultural difference in attention distribution. Instead a reliable difference in response speed was found, where Western participants were relatively faster to respond to targets in the IOR task compared to East Asian participants. This suggests that factors other than attention drive cultural differences in cognition and response speed.

The second half of the thesis explored the effect of a narrow versus broad scale of attention for visual perception, and in particular, parvocellular versus magnocellular processing. In Chapter

6, a critical analysis of current theoretical models of attention scaling was conducted, which concluded that the specific methodology employed to manipulate attention scale uniquely influences the relationship between attention scaling and vision. Finally, in Chapter 7, the zoom lens and selective spatial enhancement models of attention scaling were directly pitted against one another. While the zoom lens model proposes that narrowing attention improves all aspects of vision, the selective spatial enhancement model purports that narrowing attention influences parvocellular, and not magnocellular processing. However, recent research favouring the selective spatial enhancement model used unfilled shapes to manipulate attention, which had the potential to shape attention as an annulus, rather than scale attention. Therefore, in Chapter 7, two new methods were used to manipulate attention, which encouraged scaling. These were a global motion inducer and a Glass inducer. Consistent with the zoom lens model, it was found that narrowing attention improved both parvocellular, and magnocellular mediated processing. Taken together, this highlights the importance of carefully operationalising spatial attention to understand best how scaling attention influences visual perception.

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Chapter 1: Thesis Introduction

When viewing the world, the visual system is inundated with complex sensory signals which cannot be processed to the level of conscious awareness simultaneously. To process information meaningfully, humans use visual attention to filter out irrelevant information and enhance the processing of relevant sensory signals. For example, when reading this thesis, attentional resources are directed towards the words on the page, while information in the peripheral visual field is filtered out. Visual attention has feature-based, object-based, and spatial elements (Carrasco, 2011). Feature-based attention refers to attentional resources being directed to the individual features of a visual scene, such as colour or texture (Carrasco, 2011; Maunsell & Treue, 2006; Sàenz, Buraĉas, & Boynton, 2003). In contrast, when directing attention to an object in a visual scene, regardless of the spatial location or features of that object, object-based attention is used (Mozer & Vecera, 2005; Scholl, 2001). Finally, spatial attention refers to the direction of cognitive resources to relevant locations and areas within the visual field for improved processing (Carrasco, 2011; Goodhew, Lawrence, & Edwards, 2017; Goodhew, Shen, & Edwards, 2016; Posner, 1980). In everyday perception, spatial, object and feature-based attention interact with one another for coherent perception (Kravitz & Behrmann, 2011). For example, different sized objects, as well as the spatial structure provided by objects can be used to alter the region over which spatial attention is deployed (Goodhew & Edwards, 2017; Taylor, Chan, Bennett, & Pratt, 2015). However, the current thesis is interested in understanding spatial attention.

There are many different forms of spatial attention. Firstly, spatial attention can be deployed with or without eye movements, referred to overt and covert attention respectively (Kowler, 2011; Posner, 1980). For example, when driving, one might overtly direct their attentional resources to the speedometer. In contrast, an individual might use covert attention playing sport to deceive an opposition team member when passing a ball.

Secondly, spatial attention can be directed either endogenously, exogenously, or via a process of selection history. Endogenous attention is attention driven by internal observer goals. For instance, when reading, one might voluntarily shift attentional resources across a page to resolve each word. In contrast, when deployed exogenously, external, environmental changes guide attention. A sudden flash of lightning might automatically capture attention. Selection history can be thought of as the influence of attention across time, or experimental trials. For example, when searching for a lost set of keys, an observer may direct attention to places they have previously found their keys. That is, over a series of visual searches, they have learnt to direct attention to a particular location to find a target (Awh, Belopolsky, & Theeuwes, 2012; Carrasco, 2011; Failings & Theeuwes, 2017; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner & Cohen, 1984; Turatto et al., 2000).

Finally, spatial attention can be shifted across the visual field (Posner, 1980; Figure 1.1), split to multiple locations simultaneously (Castiello & Umiltà, 1992; Muller, Malinowski, Gruber, & Hillyard, 2003, although see Jans, Peters, & De Weerd, 2010), shaped as an annulus (Egly & Homa, 1984; Jefferies & Di Lollo, 2015; McCalley, Bouwhuis, & Juola, 1995), or scaled to cover variable sized regions of the visual field (Eriksen & James, 1986; Goodhew, Lawrence & Edwards, 2018; Greenwood & Parasuraman, 1999, 2004). The current thesis is specifically interested in studying the dynamics of *spatial attentional scaling*. Spatial attentional scaling is the process of narrowing or broadening the spatial region over which attentional resources are allocated (Eriksen & James, 1986; Greenwood & Parasuraman, 2004; Figure 1.2). For example, one might narrow attention when threading a needle. In contrast, broadened attention might be used when playing ball sports, such as basketball or soccer, to scan for players in the peripheral visual field.

Figure 1.1. Examples of attentional shifting (above) and attentional splitting (below). Spatial attention is depicted by the yellow circles.

Figure 1.2. Example of attentional scaling. Spatial attention is depicted by the yellow circles. On the left, attention is scaled narrowly. On the right, attention is scaled broadly.

There are two main approaches typically used to study attentional scaling. These are (1) exploring individual variation in attention scaling, and (2) measuring the effects of attentional scaling on perceptual performance. While these two approaches are often studied separately, this thesis aimed to understand attentional scaling from both of these perspectives. Indeed, there is increasing interest in combining individual differences and experimental approaches in cognitive psychology, as it allows for a more nuanced understanding of fundamental cognitive process across varying situations (Goodhew & Edwards, 2019). As such, the first half of the thesis explores whether two individual factors, healthy ageing and cultural background influence attention scale. The second half of the thesis then questions how attentional scaling influences different aspects of visual perception by experimentally manipulating attention scale.

A variety of individual factors are thought to influence whether an individual distributes attention narrowly or broadly. For example, variation in attentional scaling has been linked to personality and mood differences, as well as levels of sports expertise (Hüttermann & Memmert, 2015; Hüttermann, Memmert, & Simons, 2014; Wilson, Lowe, Ruppel, Pratt, & Ferber, 2016). Furthermore, individual variation in working memory capacity is related to differences in attention scaling (Kreitz, Furley, Memmert, & Simons, 2015). Finally, individual differences in attentional scaling appear to be reflected in some clinical conditions such as Schizophrenia, Alzheimer's disease, and Dyslexia (Elahipanah, Christensen, & Reingold, 2011; Facoetti & Molteni, 2001; Greenwood, Parasuraman, & Alexander, 1997; Mann & Walker, 2003). However, the current literature is unclear on how two common individual factors, healthy ageing (younger compared to older adults), and cultural background (East Asian compared to Western culture) influence attentional scaling. There is good reason to expect that these factors affect attentional scaling, since they impact a number of other important attentional processes (e.g. Andersen & Ni, 2008; Chua, Boland, & Nisbett, 2005; Erel & Levy, 2016; Madden, 2007; Masuda & Nisbett, 2006; Verhaeghen & Cerella, 2008). To address this, Chapter 3 evaluated different methods used to measure attentional scaling, and in particular, one variable of interest, spatial attention scale (i.e. does an individual distribute attention narrowly or broadly?). This analysis highlighted the merits of using the Posner cueing paradigm (Posner, 1980) to measure differences in attention scale, as it measures attention across space. In particular, an inhibition of return (IOR) variant of the Posner task was chosen (Bennett & Pratt, 2001; Taylor et al., 2015; Wilson et al., 2016). The IOR task was used to test the effects of healthy ageing (Chapter 4) and cultural background (Chapter 5) on attention spread.

Having explored individual differences in attention scaling, the second half of the thesis then turned to study the consequences of attention scaling for vision. Understanding how attention scaling influences vision is essential for broader theoretical understandings of cognitive processes. Although early research suggested that narrowing attention scale unequivocally improved visual processing, in particular, by improving the processing of fine spatial detail, more recent work has shown that narrowing attention might have no effect on other aspects of vision, or sometime even impair visual processing (Balz & Hock, 1997; Barriopedro & Botella, 1998; Eriksen & James, 1986; Goodhew et al., 2017; Mounts & Edwards, 2017). To understand these differing effects, first, a critical review of the empirical literature explicitly exploring the impact of attention scaling on vision as mediated via two major visual pathways of the brain was conducted (Chapter 6). Factors considered in the analysis were the roles of automatic versus voluntary attention, the use of unfilled shapes to manipulate attention, perceptual and cognitive load, and the role of stimulus eccentricity. Chapter 7 then directly tested the zoom lens model (Eriksen & James, 1986), and the selective spatial enhancement model (Goodhew et al., 2016) of attention scaling. In particular, the zoom lens model assumes that narrowing attention improves all aspects of visual perception. However, to date, all of the empirical evidence supporting this model used a particular method, which may have encouraged an annulus deployment of attention, rather than attention scaling.

Therefore, the selective spatial enhancement model may not apply to attention scaling. This was addressed in Chapter 7 using two new methods of attention manipulation to test the selective spatial enhancement model. These methods, by design, directly encouraged attentional scaling. The thesis concludes with an evaluation and discussion of the overall findings of the research and proposes future research avenues (Chapter 8).

Chapter 2: Theories of Attention Scaling

For over four decades, the dynamics of spatial attention have been studied. Early models conceptualised spatial attention as a spotlight which when deployed, illuminated relevant regions of the visual field for improved processing (Eriksen & Hoffman, 1972; Norman, 1968; Posner, Snyder, & Davidson, 1980). For instance, when reading, an individual might only direct their spotlight of attention to small segments of the page at a time and shift the spotlight across the page (Figure 2.1).

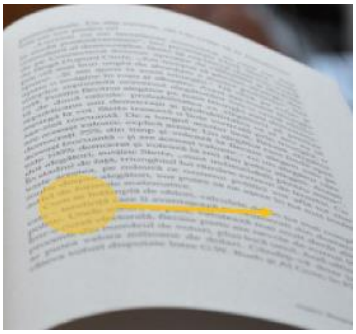

Figure 2.1. Example of a hypothetical attention ‘spotlight' directed to a segment of a page.

The spotlight metaphor has been used to explain the effects of *attentional shifting* on visual perception. Here, cueing paradigms are typically used to test how endogenous and exogenous shifting of the spotlight influences visual processing. For example, Figure 2.2 depicts a typical endogenous cueing task. At the beginning of a trial, participants are required to focus on a central fixation point. An arrow then briefly appears which indicates the probable location of a forthcoming target to be detected. It is assumed that the individual interprets the arrow cue, and shifts their attention spotlight accordingly[1]. The target then appears either at the location indicated by the cue (valid) or at the opposite location (invalid). Participants are asked to respond as quickly and as accurately as possible. Responses are typically faster, and more accurate for the validly cued compared to the invalidly cued location (Montagna, Pestilli & Carrasco, 2009; Posner, 1980). For example, Montagna et al. (2009) found that endogenous attentional shifting improved spatial acuity (the ability to detect a small gap present in a Landolt figure). Further, Hein, Rolke and Ulrich (2006) found endogenous shifts to improve the ability to perceive brief luminance changes across time.

In contrast, peripheral cueing paradigms are used to study the effect of exogenous shifts of attention on vision (Figure 2.2). Similar to central cueing paradigms, at the beginning of a trial, participants fixate gaze centrally. A brief peripheral luminance change then occurs (i.e. the cue), which automatically captures attention. Following this, the target appears at the same location as the cue (valid) or the opposite location (invalid). Response time to detect the target is measured. Target detection response time depends on the amount of time elapsed between the presentation of the cue and target. When the time between the cue and the target is less than 300ms, response times for target detection are quicker at the validly cued location compared to the invalidly cued location. However, when the time interval is longer than 300ms, response times for target detection are slower for valid, compared to invalid trials. Here, the idea is that following the cue, the attention spotlight shifts towards the cued location. However, when the target does not appear at the cued location, the attentional spotlight shifts away from the cued location to search for the target in other areas of the visual field. This effect is labelled inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985).

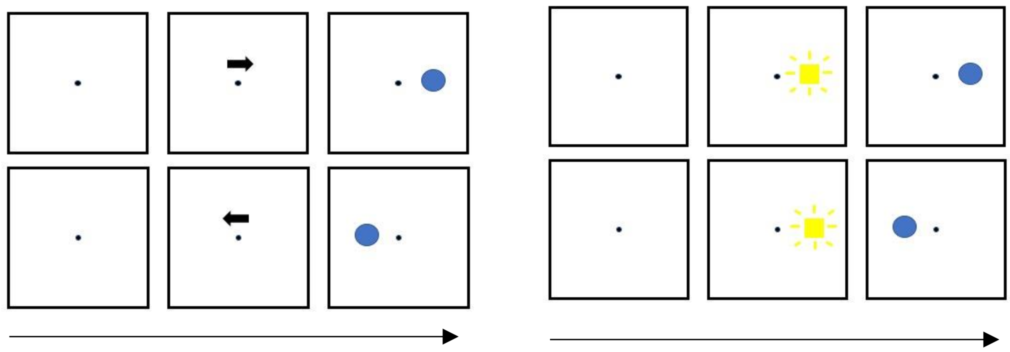

Figure 2.2. Examples of Endogenous (left), and exogenous (right) cueing paradigms. These paradigms are used to measure the effect of attentional shifting on vision.

The dynamics of attentional shifting and their subsequent effect on visual processing have been extensively studied using the spotlight model (see Carrasco, 2011 for a review). Furthermore, research suggests that there are distinct neural mechanisms underlying both voluntary and automatic covert attentional shifts, which have been associated with the dorsal frontoparietal network and the ventral temporoparietal network (e.g. see Corbetta & Shulman, 2002). For example, Grosbras and Paus (2002) used transcranial magnetic stimulation to activate the frontal eye fields of the frontoparietal network. The authors found that stimulation to the right frontal eye fields enhanced orienting response speeds in an endogenous cueing task.

However, numerous studies since have demonstrated that the deployment of spatial attention is not as simple as a ‘spotlight'. Instead, depending on task demands, attention can be split to several locations simultaneously (Castiello & Umiltà, 1992; Holcombe & Chen, 2013; Muller et al., 2003; see Jans et al., 2010 for an alternate view), deployed in the shape of an annulus (Egly & Homa, 1984; Jefferies & Di Lollo, 2015; McCalley et al., 1995), or scaled in size (Eriksen & James, 1986; Greenwood & Parasuraman, 1999, 2004). The current thesis is interested in the dynamics of attentional scaling. Attention scaling refers to the region over which attentional resources are distributed. For example, a relatively narrow scale of attention might be adopted when reading, whereas a broader scale of attention might be utilised when playing sports.

A large corpus of behavioural and neuroimaging research suggests that individuals are able to alter the region over which their attention resources are distributed. For example, Eriksen and James (1986) have found that when directed to scale attention narrowly or broadly, participants' visual processing capacity is altered in behavioural tasks measuring response times for target detection. Likewise, Wilson et al. (2016) have shown that there individual differences in personality predict whether someone is likely to scale attention narrowly or broadly. Finally, although there is overlap in the neural networks which appear to govern both attention scaling and shifting, such as the frontoparietal network (e.g. Chen, Marshall, Weidner & Fink, 2009; Ronconi, Basso, Gori & Facoetti, 2014; Zeng, Weidner, Fink, & Chen, 2017), some neuroimaging research suggests that attention scaling involves distinct neural processes to that of attentional shifting. For example, Fu, Caggiano, Greenwood and Parasuraman (2005) studied event related potentials (ERP) associated with early attentional processing (i.e. the P100 and N100 amplitudes; e.g. Di Russo, & Spinelli, 1999; Hillyard, Hink, Schwent, & Picton, 1973). Specifically, ERPs were recorded when participants either shifted or scaled attention during an orientation processing task. To manipulate attention scale, different sized attentional cues were used to alter the distribution of attention. Overall, the authors found that attentional shifting effected the amplitude of the P100 and N100 component, however, attentional scaling selectively influenced the P100 component, while having no influence on the N100.

The aim of the current thesis is to understand attentional scaling using behavioural measures of cognition and vision. The following three sections of this chapter introduce three theoretical models of attentional scaling, key to the formulation and testing of ideas in this thesis. These models are the gradient model of attention, the zoom lens model, and the selective spatial enhancement model.

2.1. Gradient Model of Attentional Scaling

Rather than operating similar to a spotlight, the gradient model has been used to characterise spatial attention (LaBerge, 1983; LaBerge & Brown, 1989; Shulman, Sheehy, & Wilson, 1986). Here, instead of assuming that the same magnitude of processing enhancement occurs across the entire attended region, the gradient model assumes that processing resources gradually dissipate around the attended area. For example, as shown in Figure 2.3, when deploying attention, resources might be most strongly focused on the target (i.e. the black rectangle). However, attentional resources would also spread to areas surrounding the target. A gradient can be used to characterise the rate of drop-off in processing resources surrounding the attended region. When there is a quick rate of decline in processing resources surrounding an attended location, a steep gradient has been adopted. In contrast, when the decline is more gradual, a shallow attention gradient has been utilised. Critically, this gradient can be used to infer the attentional scale of an individual. It is assumed that a steep gradient reflects a narrow attention scale, while a shallow gradient reflects a broad attention scale (e.g. Wilson et al., 2016)

Figure 2.3. Gradient Model of Attention. Here, an individual might be focusing their attentional resources on the target, the unfilled black square. The orange circle represents attention. While attentional resources are most concentrated on the target (deep orange), these resources still spread out to surrounding locations (increasingly lighter orange colour).

The gradient model of attention was initially studied by Laberge (1983), who measured the distribution of attention when participants completed a letter/word processing task. Firstly, participants were presented with a display that contained either a word or non-word of equal length. They were required to report the central letter or the entire word shown. The assumption was that when participants attended to the word, they would spread their attention resources across a relatively broad area compared to when attending to the central letter. Specifically, a larger scale of attention would be required to encompass all letters in the word. Following the letter/word task, participants detected a briefly presented probe as quickly as possible. The probe could appear at any location where a letter appeared in the display. Changes in probe detection response time for the different letter locations was recorded to measure the gradient of attention during the letter and word conditions. In the central letter condition, response times were quickest when the probe appeared behind the central letter. Further, as the distance between the central letter and probe increased, response times gradually increased. This suggests that attention was focussed around the centrally attended location and spread gradually around this location as a gradient. In contrast, when attending to the entire word, response times across all possible target locations were similar, reflected in a shallow slope of attention. This suggests that attention was deployed across the whole stimulus region. Therefore, in the letter condition, the scale of attention was focussed narrowly, whereas, in the word condition, attention was scaled broadly.

Complementary to behavioural research are studies demonstrating neural correlates to the gradient of attention (Mangun & Hillyard, 1987; 1988). For example, Mangun and Hillyard (1988) measured both participants sensitivity to detect a target flashed at varying locations from fixation, as well as recording ERP responses during the detection task. This was done to ensure that previous measures using response time as a key variable of interest were related to perceptual/attentional processing. Critically, the authors found that both participants sensitivity to detect targets, as well as the amplitudes of early selective attention components P135 and N190 decreased as the distance between fixation and target locations increased. This suggests that attention resources were spread surrounding fixation as a gradient.

Task complexity, cognitive load, and variation amongst individuals all determine the 'steepness' of the attentional gradient, and subsequently, the distribution of attention (Caparos & Linnell, 2009, 2010; Cave & Zimmerman, 1997; Downing, 1988; Klein, Christie, & Morris, 2005; Lavie, 1995, 2005; Lavie, Hirst, & DeFockert, & Viding, 2004; Taylor et al., 2015). Firstly, increases in task complexity can lead to a steeper attentional gradient (Downing, 1988; Caparos & Linnell, 2009, 2010; Cave & Zimmerman, 1997). For example, Caparos and Linnell (2009) used a flanker and target discrimination task to measure the effect of low-complexity condition and high-complexity condition on the attention gradient. In the flanker task, participants were asked to discriminate a central target letter (E or F). Critically, the target letter was also flanked by a distractor letter (E, X, or F), that appeared at different distances from the central letter on each trial. In congruent trials, distractor letters were identical to the target. In incongruent trials, the distractor letters were different from the target. The attention gradient was measured by recording response times for target detection across each target-distractor distance for incongruent trials. Specifically, the longer the response time at each distance, the higher the level of interference from the distractor. To manipulate task complexity, participants also completed a secondary discrimination task. In the low-complexity condition, participants decided if the target letter had a small gap in it. In the high-complexity condition, they determined whether the gap presented appear at the top or bottom of the letter.

Overall, the distractor had a greater influence on target processing in the low task complexity, compared to the high task complexity condition. Furthermore, the distractor influenced target processing across a greater range of target-distractor distances in the low complexity condition, reflected in a shallower attentional gradient. Finally, in the high complexity condition, the attention gradient was non-linear. Instead, at small target-distractor distances, response times gradually decreased (as would be predicted by the gradient model). However, when the distractors fell approximately greater than 5° of visual angle from the target, they appeared to interfere with processing to a greater degree than did distractors appearing closer to the target. This response time pattern reflected a "Mexican Hat" distribution of attention. Taken together, this suggests that higher task complexity led to a relative narrowing of attentional scale compared to the low complexity condition.

In contrast to task complexity, variations in cognitive load can have an opposite effect on the attentional gradient (Caparos & Linnell, 2010; Chen & Cave, 2013, 2014; Lavie, 2005; 2010; Linnell & Caparos, 2011). For example, Linnel & Caparos (2011) measured the influence of both task complexity and cognitive load changes on the gradient of attention. Task complexity was manipulated using a similar procedure to that used in Caparos and Linnell (2009), while cognitive load was manipulated using a working memory task. This task required participants to memorise either one or six numbers during the perceptual task. When asked to remember only one number, cognitive load was low. In contrast, when asked to remember six numbers, cognitive load was high. Similar to Caparos and Linnell (2009), a flanking distractor letter presented at different distances from the central letter was used to measure the gradient of attention. Overall, when task complexity was low, increasing cognitive load did not influence the attentional gradient. However, under high task complexity, increased cognitive load led to a shallower gradient of attention (i.e. a broader scale of attention, and a more spread out “Mexican hat” profile of response times). This is consistent with neuroimaging research which suggests that the attentional focus has a centre surround suppression, reflecting a “Mexican Hat” (Müller & Kleinschmidt, 2004). Therefore, when measuring the gradient of attention, the perceptual and cognitive demands on observers must be taken into account, as they can have interacting effects on attentional scale.

Finally, recent research suggests that there are individual differences in the attentional gradient (Ahmed & De Fockert, 2012; Facoetti & Molteni, 2001; Rowe, Hirsh, & Anderson, 2007; Wilson et al., 2016). For example, Wilson and colleagues recently found personality differences to predict the gradient of attention (Wilson et al., 2016). Specifically, individuals who scored higher on the ‘open to new experiences' measure of the five-factor model of personality (Digman, 1990) tended to have a shallower attentional gradient. In contrast, individuals who scored higher on the ‘conscientiousness' trait, tended to have a steeper gradient. Furthermore, those with a lower working memory capacity are likely to adopt a steeper attentional slope compared to those of high working memory capacity (Ahmed & De Fockert, 2012). Finally, a positive mood is related to a shallower gradient, and broader distribution of attention (Rowe et al., 2007). Further, in an ERP study, Moriya & Nittono (2011) found that positive mood increased the amplitude of the P100 component, which was reflected in participants adopting a broader gradient distribution of attention. Taken together, this research highlights the possibility that variation across other variables (i.e. ageing and cultural background) might also influence the gradient of attention.

2.2. Zoom Lens Model of Attentional Scaling

The gradient model of attention aids in explaining how attention might be scaled across space for different individuals under varying task demands. In contrast, the zoom lens model aims to describe the effect of attentional scaling on visual processing (Eriksen &

James, 1986; Eriksen & Yeh, 1985). In particular, the model suggests that attention is scaled to different sizes to improve visual processing relative to task demands. When scaled narrowly, limited capacity attentional resources are focussed on a concentrated region of the visual field for enhanced processing. In contrast, when scaling attention broadly, these resources are spread out across a wider area, with reduced visual processing capacity across the attended area. As such, the zoom lens model suggests that there is a trade-off between attention scale and the magnitude of perceptual enhancement within the scope of attention.

Eriksen and James (1986) initially tested their zoom lens model using a letter detection task. Here, participants searched for a target letter which appeared in an eight letter, circular arrangement. Different numbers of letter positions were cued to manipulate attention scale (i.e. more cued letters were assumed to induce a larger scale of attention). In central vision, under a smaller, more focussed attentional scale, letter processing was improved. Specifically, reaction time for letter detection was faster for narrow, compared to broad attention. Therefore, as the scale of attention becomes increasingly restricted, the processing capacity of the visual system increases within that region, inferring an inverse, relationship between attentional scaling and visual processing capacity (Barriopedro & Botella, 1998; Castiello & Umiltà, 1990; Eriksen & James, 1986).

The zoom lens model has also been tested using spatial resolution tasks, which require participants to resolve fine spatial detail (Balz & Hock, 1997; Goodhew et al., 2017, 2016). For example, Balz and Hock (1997) used a line alignment task to measure the effect of attention scaling on spatial resolution. A luminance change procedure was designed to narrow or broaden attention. At the beginning of a trial, participants were instructed to detect a luminance change appearing in either a central dot or one of nine peripherally presented dots. When the luminance change occurred in the central dot, it was assumed that attention was narrowed. When the change occurred in one of the peripheral dots, it was assumed that attention was broadened. A line segment task was used to measure spatial resolution. Specifically line segments appeared below or above the row of dots, and participants had to judge whether the segments were aligned or offset. Across two experiments, Balz and Hock found that participants' ability to complete the alignment task was lower in the broad, compared to narrow attention condition. This research suggests that focusing attention improves spatial resolution, providing further support for the zoom lens model.

Finally, neuroimaging evidence suggests that broadening versus narrowing attention has direct effects on activation levels in the primary visual cortex (Müller, Bartelt, Donner, Villringer, & Brandt, 2003; Sasaki et al., 2001). For example, in Müller et al. (2003), attention scale was manipulated using a cueing procedure. The number of areas cued was altered to manipulate attention, where a greater number of cued areas was assumed to broaden attention. Following this, participants completed a visual search task. During the cueing procedure, processing in the visual cortex was recorded using an event-related functional magnetic resonance imaging procedure (fMRI). Changes in the BOLD (blood oxygen level dependent) signal were assumed to reflect differences in neural activity. Overall, there was a correlation between neural activity, attention scale and performance in the visual search task. Under narrow attention, a smaller region of the visual cortex was activated, and performance improved. Under broad attention, the activated region was larger, and performance decreased. Further, the intensity of activation differed for narrow and broad attention, with activation being higher for the narrow compared to the broad attention condition. Similarly, Sasaki et al. (2001) measured relative levels of activation in the visual cortex using fMRI under different attenton scales, finding an inverse realtionship bewteen attentional breadth and visual cortex activation. Specifically, participants were asked to attend to local or global elements of stimuli, which was assumed to narrow or broaden attention respsecitvely. Consistent with Müller et al. (2003), the authors found that when participants attended to global elements of stimuli, activation in the visual cortex was more extensive compared to when participants attended to local elements. Therefore, it appears that changes in attention scale might have a direct effect on visual processing areas in the brain, which subsequently, influences behavioural performance.

Despite the accumulation of evidence supporting the zoom lens model of attentional scaling (Balz & Hock, 1997; Barriopedro & Botella, 1998; Castiello & Umiltà, 1990; Eriksen & James, 1986; Turatto et al., 2000), it was recently suggested that the model may not apply to all aspects of visual perception (Goodhew et al., 2016). Instead, Goodhew and colleagues proposed that attentional scaling might have different effects on vision mediated by the parvocellular and magnocellular channels of the brain. As such, a brief review of these channels is presented below.

2.3. Parvocellular and Magnocellular Visual Processing

The human visual system consists of a number of parallel processing pathways, which are specialised to process different types of sensory input (Goodale & Milner, 1992; Livingstone & Hubel, 1988; Mishkin, Ungerleider, & Macko, 1983; Van Essen & Maunsell, 1983). Two of these pathways are the parvocellular and magnocellular channels. Parvocellular and magnocellular neurons are found in the lateral geniculate nucleus (LGN) in the thalamus. The thalamus is an important hub of the visual system, transferring information from the retina to the cortex (Sherman, 2017; Sherman & Guillery, 2006). Neurons in the LGN are arranged in layers and have topographic mapping. That is, the receptive field of each cell (the region in space that the cell fires for when stimulated with sensory information), is arranged to create a map of the outer visual world (Schneider, Richter, & Kastner, 2004). Further, each cell type has different properties and is specialised to process different kinds of visual information (Denison, Vu, Yacoub, Feinberg, & Silver, 2014; Derrington & Lennie, 1984; Livingstone & Hubel, 1988). While there are three cell types in the LGN (parvocellular, magnocellular, and koniocellular), the following review focuses on the properties of parvocellular and magnocellular neurons.

Electrophysiological studies using non-human primates, as well as neuroimaging studies with humans reveal that parvocellular and magnocellular neurons differ in their sensitivities to spatial and temporal detail (Denison et al., 2014; Derrington & Lennie, 1984; Livingstone & Hubel, 1988; Nassi & Callaway, 2009; Schiller, Logothetis, & Charles, 1990). Specifically, compared to magnocellular neurons, parvocellular neurons are better able to process fine spatial detail. In particular, parvocellular neurons have smaller receptive fields, and as such, are better able to encode changes in luminance across space. In contrast, magnocellular neurons are better able to process high temporal frequencies. Compared to parvocellular neurons, magnocellular neurons have faster conduction speeds, allowing for the processing of minute changes in luminance across time. Finally, compared to magnocellular neurons, parvocellular neurons are more sensitive to colour changes. However, parvocellular neurons also have a lower contrast sensitivity compared to magnocellular neurons (Denison et al., 2014; Derrington & Lennie, 1984; Livingstone & Hubel, 1988).

Behaviourally, differences in magnocellular and parvocellular processing can be inferred using specifically designed tasks which aim to tap into the differential properties of the two cellular channels (Goodhew et al., 2017, 2016). Two of the most common tasks used are spatial and temporal gap tasks (Figure 2.4). In the spatial gap task a small circle, typically less than half a degree of visual angle in diameter, is briefly presented to a participant. Participants are asked to decide whether a tiny gap is present in the circle. Higher levels of accuracy in this task are assumed to reflect greater parvocellular activation. In the temporal gap task, a small circle appears for a single, brief period, or two circles, presented in rapid succession are shown in the same spatial location. This rapid presentation seems as though the circle is flickering, and as such participants are required to determine whether or not the presented circle ‘flickers'. Higher levels of accuracy in this task are assumed to reflect greater magnocellular activation. Furthermore, Gabors of different spatial frequency content can also be used to measure parvocellular and magnocellular processing (Figure 2.5; Goodhew et al., 2017). For example, participants might be asked to discriminate the orientation of a high or low spatial frequency Gabor. Accuracy for the two Gabor types is then compared to infer differences in parvocellular and magnocellular processing respectively.

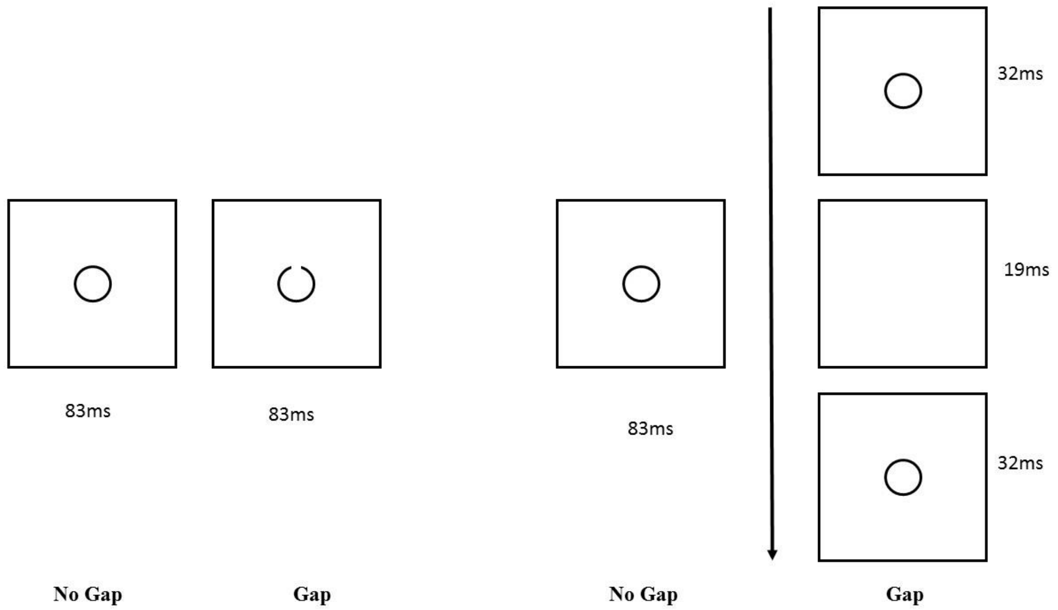

Figure 2.4. Examples of spatial (left) and temporal (right) acuity tasks. In the spatial acuity task, participants are required to detect if a small gap is present at the top of a briefly presented circle. In the temporal acuity task, participants must determine whether one or two circles were briefly presented. This circle appears as a ‘flicker' to participants. Note, figures are not drawn to scale.

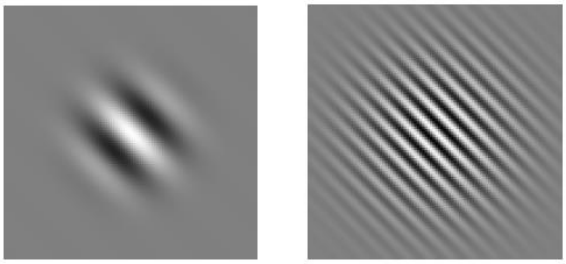

Figure 2.5. Examples of low (left) and high (right) spatial frequency Gabors that might be used in behavioural research of parvocellular and magnocellular functioning. In a Gabor orientation task, participants would be asked to determine which way the Gabor is tilted (e.g. to the left or right).

Spatial and temporal gap tasks, as well as spatial frequency tasks are widely adopted in cognitive psychology experiments to explore interactions between action, attention, and perception (Goodhew et al., 2017, 2016; Gozli, West, & Pratt, 2012; Hein et al., 2006; Yeshurun & Levy, 2003). For example, Yeshurun and Levy (2003) used spatial and temporal gap tasks to measure the effects of attentional *shifting* on parvocellular and magnocellular processing. In this study, the authors found that exogenous attentional shifts improved parvocellular-mediated spatial acuity while impairing magnocellular-mediated temporal acuity. Furthermore, Gozli et al. (2012) have shown that hand positioning (near or far from a stimulus) can improve or impair processing in parvocellular-spatial and magnocellular-temporal acuity tasks. Overall, these trade-offs in processing suggest that processing of spatial and temporal acuity is mediated by different areas of the visual system (i.e. the parvocellular and magnocellular channels).

Nonetheless, some researchers argue against the use of behavioural stimuli to infer changes in parvocellular and magnocellular processing. Skottun (2013) has suggested that it is near impossible to measure the contribution of magnocellular neurons in visual processing when using temporal resolution tasks. In particular, Skottun highlights that the magnocellular system does not uniquely mediate sensitivity to high temporal frequencies. Instead, cortical levels of the visual system also contribute to the ability to perceive high temporal frequencies (e.g. D'Souza, Auer, Stasburger, Frahm, & Lee, 2011). Furthermore, Skottun has proposed that there is considerable overlap in the different spatial frequencies that magnocellular and parvocellular neurons can process (Skottun & Skoyles, 2008; Spear, Moore, Kim, Xue, & Tumosa, 1994). Nonetheless, even if the unique contributions of parvocellular and magnocellular neurons cannot be entirely separated using behavioural stimuli, processing mediated by *predominantly magnocellular*, or *predominantly parvocellular* inputs can still be measured (Goodhew et al., 2017). Indeed, a plethora of neurophysiological evidence demonstrates that temporal processing is largely mediated, and driven by magnocellular neurons at the extremes (Butler et al., 2006; Denison et al., 2014; Öğmen, Purushothaman, & Breitmeyer, 2008).

2.4. Selective Spatial Enhancement

The selective spatial enhancement (SSE) model argues that changes in attentional scale selectively influence visual processing mediated by the parvocellular and not the magnocellular channel of vision. Goodhew et al. (2016) tested the SSE model by measuring the effects of attentional scaling on spatial and temporal resolution. Attention scale was manipulated using a shape inducer task. Here, participants were asked to determine whether either a circle or an ellipse was briefly presented. The size of the shapes was altered to change attentional scale. Based on previous research, it was thought that when the shapes were large (i.e. 20 degrees diameter), individuals would adopt a broader attention scale. When the shapes were smaller (i.e. 2 degrees diameter), individuals would adopt a narrower attention scale. Within a block of the experiment, the majority of trials were shape inducer trials that consisted of either small or large shapes. Therefore, over a series of trials, participants adopted either a narrow or broad scale of attention. On the minority of trials, to measure the influence of attention scale on spatial and temporal resolution, participants completed spatial and temporal gap tasks. Higher levels of performance in these tasks reflect increased activation of the parvocellular and magnocellular visual channels respectively.

In line with the SSE model, Goodhew and colleagues (2016) found that narrowing attention improved performance in the spatial gap task, while having no impact on performance in the temporal gap task. This selectivity provided preliminary evidence that changes in attention scale uniquely influence visual processing mediated by the parvocellular visual pathway, to the exclusion of the magnocellular visual pathway. This finding was then replicated using spatial frequency stimuli (Goodhew et al., 2017). Again, attention scale was manipulated using a shape inducer task. However, instead of interleaving gap trials with the inducer stimuli, an orientation discrimination task with Gabors of high and low spatial frequency were used to reflect parvocellular and magnocellular processing respectively. Narrowing attention improved parvocellular mediated, high spatial frequency orientation discrimination. However, magnocellular mediated, low spatial frequency orientation discrimination was unaffected.

Finally, an early study conducted by Goto Toriu and Tanahashi (2001) found that differences in attention scale seem to selectively influence contrast sensitivity for high spatial frequencies, while having less, or no impact on low spatial frequencies. In this study, participants were asked to detect patterns of disk targets which appeared in differing sized rings surrounding fixation. The small rings were intended to narrow attention, while the large rings were intended to broaden attention. Critically, during this task, participants were also asked to respond if they noticed a Gabor patch of varying spatial frequency content appear at fixation. Overall, a difference in contrast sensitivity for narrow versus broad attention appeared for Gabors with relatively high spatial frequencies. However, for lower spatial frequencies, the effects of attention were minimised. Therefore, in support of the SSE model, there is some preliminary evidence that attentional scaling shows some selectivity for visual processing.

2.5. Summary

Spatial attention scaling is a fundamental process required for coherent perception of the visual world. Three major models of attentional scaling relevant to the current thesis are the gradient model of attention, the zoom lens model, and the SSE model. The gradient model of attention describes the different ways in which attention can be scaled across space. When attention is scaled to a small region of the visual field, the gradient spread of attention resources around that region is steep. When attention is broadly scaled, the gradient of attention is shallow. Task complexity, cognitive load, and individual experiences can shape the gradient of attention. In contrast, the zoom lens model explains the effect of changing the spatial scale of attention on visual processing. It proposes that narrowing attention improves all aspects of visual processing compared to broad attention. Finally, the SSE model suggests that attentional scaling has a selective effect on visual processing mediated by the parvocellular pathway while having no impact on processing mediated by the magnocellular visual pathway.

2.6. Notes

1. It is important to recognise a growing body of studies which suggest that arrow cues elicit exogenous shifts of attention (Ristic & Kingstone, 2006; Stevens, West, Al-Aidroos, Weger, & Pratt, 2008). In particular, research suggests that arrows are over-learnt stimuli and thus when viewed, automatically shift attention to the location indicated by them. Therefore, instead of using arrow cues, many studies use numbers which are arbitrarily associated with various locations to measure endogenous orienting

Chapter 3: Methodological Approaches to Measuring Individual Differences in Attention Scaling

On a moment to moment basis, experience shapes how individuals deploy spatial attention and interact with the visual world. For example, action-video-game players are thought to have higher attentional capacity compared to non-action video game players (Green & Bavelier, 2006). Similarly, sports expertise can alter the distribution of attention, where soccer players are more able to spread their attentional resources to greater eccentricities (Hüttermann et al., 2014). Finally, both mood and personality can influence whether one scales attention narrowly or broadly (Hüttermann & Memmert, 2015; Wilson et al., 2016). Nonetheless, it is currently unclear if (and how) two other experience related factors might influence attentional scaling. These are healthy ageing and cultural background. Therefore, the first aim of this thesis is to understand the influence of these two factors on attentional scaling using behavioural methods. To that end, the following chapter critically evaluates the primary behavioural methods used to study individual differences in attention scaling so to identify the most appropriate paradigm to use for the current thesis.

There are two major approaches to studying individual differences in attentional scaling. These are (1) measuring differences in the flexibility of attention scaling processes, and (2) determining the spatial attentional scale adopted by different individuals (Figure 3.1). The flexibility of attentional scaling is the ease of broadening attentional scale from small to large, or large to small (e.g. Jefferies & Di Lollo, 2009). In contrast, individual differences in attentional scale are measured by determining whether an individual has scaled their attention resources over a narrow or broad area of the visual field. This has been referred to as an individual's attentional distribution, or attentional spread (e.g. Lawrence, Edwards, &

Goodhew, 2018). The first half of this thesis explores individual differences in spatial distribution of attentional scale.

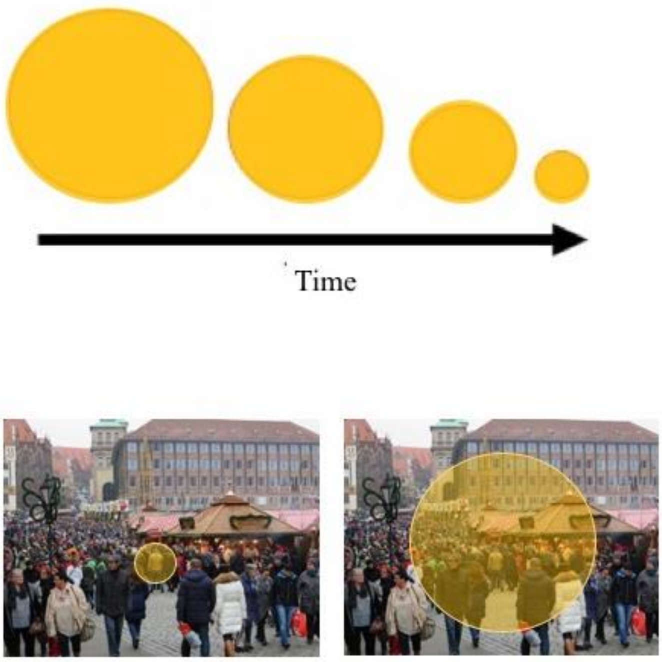

Figure 3.1. Attentional flexibility can be thought of as the ability to focus or broaden attention across time (above), whereas spatial attention distribution refers to whether in a given situation, an individual distributes attention narrowly (left), or broadly (right).

A variety of methods have been used to infer individual differences in attention distribution. This chapter evaluates three of the primary measures used, to determine the most appropriate method to use for exploring age, and cultural differences in attention distribution. The measures are the Eriksen flanker task (Eriksen & Eriksen, 1974), the Navon letter task (Navon, 1977), and the Posner cueing paradigm (Posner, 1980). These tasks measure response time differences across varying experimental conditions and can be used to infer the visual region over which attention has been scaled. Although it has been claimed that all three methods validly measure attention scale, it is argued here, that compared to the flanker and Navon tasks, the Posner cueing task is the most appropriate operationalisation of attention distribution.

3.1. The Eriksen Flanker Task

The flanker task was originally developed by Eriksen and Eriksen (1974) and can be used to infer individual differences in attention distribution by measuring changes in distractor processing. Specifically, participants are required to respond to a centrally presented target letter, which is surrounded by either response congruent (compatible) or incongruent (incompatible) distractors (Figure 3.2). Compared to congruent trials, responses are slower for incongruent trials, suggesting interference from the incompatible distractor letters. In particular, the assumption is that greater interference from distractor letters reflects a relatively broader distribution of attention, because any letters falling within the focus of attention should be processed, and thus influence responding. The distance between the target and distractor letters can also be varied to map out the bounds of the distribution of attention. For example, Rowe et al. (2007) used a flanker task to test how changes in mood influence attention distribution. When induced with a positive mood, distractor letters were processed at greater target-distractor separations, suggesting a broadening of spatial attention. Similarly, Lin and Han (2009) have used the flanker task to test how interdependent versus independent thinking styles alter attention distribution. Interdependent thinkers are context sensitive, and see themselves as part of a group. In contrast, independent thinkers see themselves as individual entities and have lower context sensitivity (Markus & Kitayama, 1991). Interestingly, compared to those primed with independent thinking styles, interdependent priming led to greater distractor interference, suggesting that those who have interdependent thinking styles are more likely to distribute spatial attention broadly.

Figure 3.2. Example of a compatible (above), and incompatible (below) trial in a typical flanker task. Here, participants would be required to discriminate the central target letter A, when compatible or incompatible distractors flank it. Participants are typically faster to respond for compatible compared to incompatible trials. The level of distractor interference can be used to infer the distribution of attention.

Despite this, the underlying mechanisms driving flanker congruency effects remains unclear. There is a growing debate over whether distractor processing in flanker tasks is due to differences in spatial attention scale per se, or due to variation in cognitive control across time (Avital-Cohen & Tsal, 2016; Gaspelin, Ruthruff, & Jung, 2014; Lachter, Forster, & Ruthruff, 2004). For example, instead of distributing attention broadly across all letters (i.e. as a gradient), an individual might occasionally lose control of attentional resources focussed on the target letter and spread their attention to distracting targets. This loss of control could lead to similar distractor interference scores to those predicted by overall differences in attention spread, but be driven by a different attentional mechanism. Furthermore, there is uncertainty regarding whether endogenous, exogenous, or a combination of both types of attentional mechanisms drive flanker effects. For example, recent research has shown that observers are able to direct top-down attentional resources to both the processing of the central target, as well as the flanking distractor, rather than the distracter letters being incidentally processed when falling within the distribution of attention (Avital-Cohen & Tsal, 2016). In this study, participants completed a flanker task which contained conceptually ambiguous distractors. The target letter was always an S or O; however, the flankers were perceptually uncertain because they could be interpreted as either an S or the number five, or O, or the number zero. Critically, the authors found that the flankers only interfered with processing when perceived as letters and not numbers. This selective interference effect meant that top-down interpretation of the distractor stimuli was influencing cognitive processing of the central target. Finally, it is possible that rather than measuring the tendency of an individual to scale attention narrowly or broadly, the flanker task encourages participants to adopt a narrow scale of attention. The target almost always appears at the centre of the visual display. As such, the optimal method to perform the flanker task is to narrow attention as much as possible. Therefore, the task may measure how well an individual can narrow attention scale. Taken together, it is unclear whether flanker tasks operationalise individual differences in attention spread. Therefore, it was deemed an inappropriate method to use for exploring age and cultural differences in attention scale.

3.2. The Navon Task

Apart from the flanker task, Navon figures (Navon, 1977, 2003) have been used to measure spatial attention distribution (e.g. Lin, Lin & Han, 2008). Navon figures consist of smaller local elements which when arranged, form a larger global figure. For example, smaller "T's" may be arranged to form a global letter "H" (Figure 3.3). The smaller local elements can be compatible or incompatible with the larger global figure. In a typical Navon task, participants identify the stimuli presented at either the local or global level, and response times for target identification are measured for congruent and incongruent trials. Typically, responses are slower in incongruent trials, and in particular, when the incongruent letter appears at the global, compared to the local level. These interference scores can then be used to infer how visual attention was deployed in the task. Furthermore, divided attention variants of the Navon task have been used to measure attention distribution (e.g. McKone et al., 2010). Here, participants are asked to discriminate between two stimuli, which can appear at the global or local level. As participants are not instructed to attend globally or locally, this allows participants to distribute attention freely, without task constraints. Global preference scores (i.e. mean local response time score minus mean global response time score) are then calculated and compared across individuals to infer attention distribution. The larger the global preference score, the more likely it is a participant has adopted a broader attentional distribution.

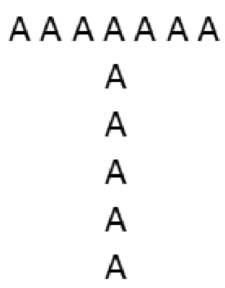

Figure 3.3. Example of a Navon figure. Series of local elements (letter As) combine to form a global figure (letter T). Typically, a participant is asked to identify a letter presented at the global or local level. An individual's response times are compared for target detection at the global and local level to infer attention distribution. When an individual is relatively faster to identify letters at the global level, they are said to have distributed attention broadly.

Navon figures have been used to explore differences in attentional distribution for clinical conditions such as autism (Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), as well as mood (Gable & Harmon-Jones, 2010), and cultural background (McKone et al., 2010). However, similar to the flanker task, the use of Navon letters is sub-optimal when attempting to infer spatial attentional distribution directly. In particular, the processing of Navon letters might require categorical/feature-based, and not spaced-based attention. For example, when detecting a local target, rather than deploying spaced-based attention to varying sized regions in the visual field, an observer may adopt a single mode of space-based attention (i.e. broad scale), and then use feature-based attention to select the local features targets for selective processing (Robertson, Egly, Lamb, & Kerth, 1993). Therefore, rather than reflecting differences in space-based attention (i.e. changes in the spatial scale of attention), global preference scores might reflect individual differences in the deployment of feature/categorical attention (i.e. selecting global or local features for processing, regardless of the spatial distribution of attention).

3.3. Posner Cueing Paradigm

Finally, the Posner cueing task has been used to measure attention distribution. However, rather than being designed to measure attention distribution, the Posner task was initially developed to measure attentional *shifting* (Posner, 1980; Posner & Cohen, 1984; Posner et al., 1985). Figure 3.4 depicts a basic Posner cueing task measuring exogenous shifts of attention. At the beginning of a trial, a participant is required to fixate centrally. On the left and right of fixation, there are typically two possible locations in which a target can appear. After a fixation period, a luminance change occurs at one of the two locations, which automatically grabs attention. This luminance change is called the attentional cue. Following the cue, a target appears at either the same location as the cue or at the opposite location. The participant is required to detect the target as quickly as possible. When there is a short time interval between the cue and target (i.e. <300ms), participants are faster at detecting a target that appears at a cued, compared to un-cued location. This response time benefit is labelled attentional facilitation and is theorised to reflect an orienting of attention towards the cued location. However, at longer time intervals between the cue and target appearance (i.e. >

300ms), participants are faster to detect a target appearing at the un-cued compared to the cued location. This response time slowing is called inhibition of return (IOR) and allows for efficient use of attention resources in visual search (Klein & MacInnes, 1999; Posner et al., 1985).

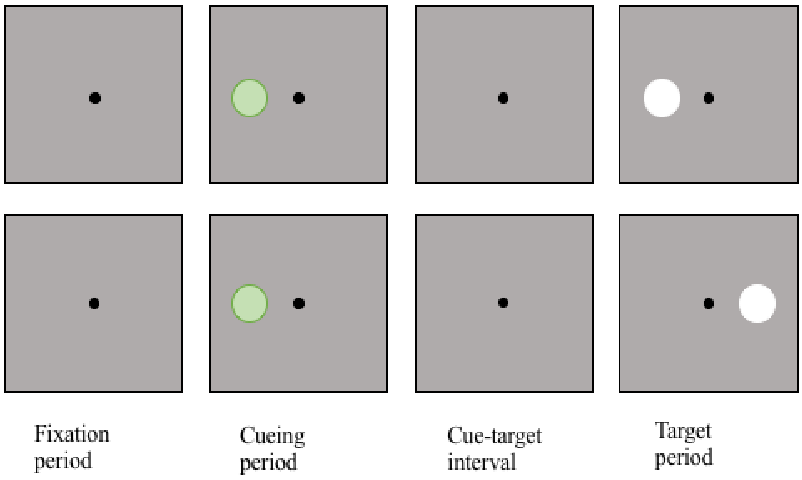

Figure 3.4. Example of a typical Posner cueing task measuring exogenous shifts of attention. The panel above shows a valid trial, while the panel below shows an invalid trial. Firstly, the presentation of a transient cue (green circle) automatically captures attention. Following a cue-target interval, the target to be detected (white circle) appears at the valid or invalid location.

The basic Posner cueing task has been adapted to infer individual differences in attention distribution (e.g. Figure 3.5; Bennett & Pratt, 2001; Downing, 1988; Henderson & Macquistan, 1993; Klein et al., 2005; LaBerge, 1983; LaBerge & Brown, 1989; Langley, Gayzur, Saville, Morlock, & Bagne, 2011; Wilson et al., 2016). In a cueing paradigm, processing resources are directed to the cued location. However, attentional resources also spread around the cued location (i.e. gradient model of attention; Laberge, 1983). Therefore, by measuring target detection response times across the different distances between the cue and target, estimates of an individual's attention distribution can be made (Figure 3.5). For example, in an attentional facilitation task, it is expected that response times would be quickest at the cued location, and gradually slow as the distance increases. This change in response time reveals the gradient of attention distribution around the cue. If the rate of change in response times increases quickly across cue-target distances, it is inferred that attention was tightly constricted to the cued location, and the observer adopted a small attention scale. However, if response times increase more gradually, this implies that attentional resources were more broadly distributed around the cued location, indicating a large attentional spread. This rate of change is quantified by calculating the gradient, or slope, of response time across distances (Wilson et al., 2016). As shown in Figure 3.6, A steep attentional slope reflects a relatively faster rate of change in response time across distance (i.e. narrow attention), while a shallow attentional slope reflects a relatively slower rate of change in response time across distance (i.e. broad attention).

As well as measuring gradient change in attentional facilitation, the gradient of attention inhibition around a cued location can be measured. Here, rather than response times increasing with cue-target distance, they decrease, and the rate of change in response time can still be used to infer attention spread. For example, using an IOR task, Wilson and colleagues (2016) measured how different personality factors influence the spatial attention distribution. Participants completed a personality questionnaire which measured the five-factor model of personality (Digman, 1990). The personality factors Conscientiousness, Neuroticism, Openness to Experience, Extraversion, and Agreeableness, were measured. Following this, participants completed the attentional inhibition task, which had four possible cue locations, and 121 possible target locations. This large sampling space allowed the authors to measure how the gradient of attentional inhibition changed across cue-target distances with a high level of granularity. Overall, the authors found that there was a relationship between the personality factor Openness to Experience and attentional distribution. Specifically, those who scored higher on the Openness to Experience trait were found to have a shallower slope quantifying the gradient of attention, which was interpreted as those individuals having a broader attentional distribution.

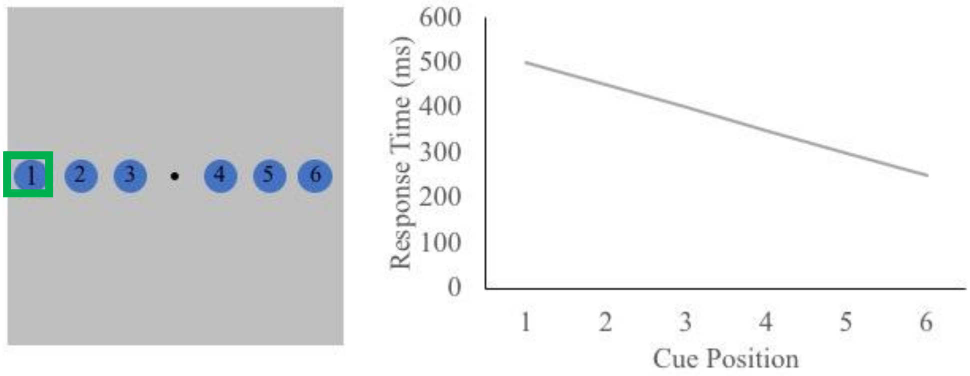

Figure 3.5. The relationship between distance and response time when measuring attentional inhibition. Left: Experimental paradigm. The green square represents the cue. The blue circles represent different distances at which the target may appear. Right: Hypothetical results. As distance increases, response times gradually decrease. The slope is assumed to reflect attentional distribution.

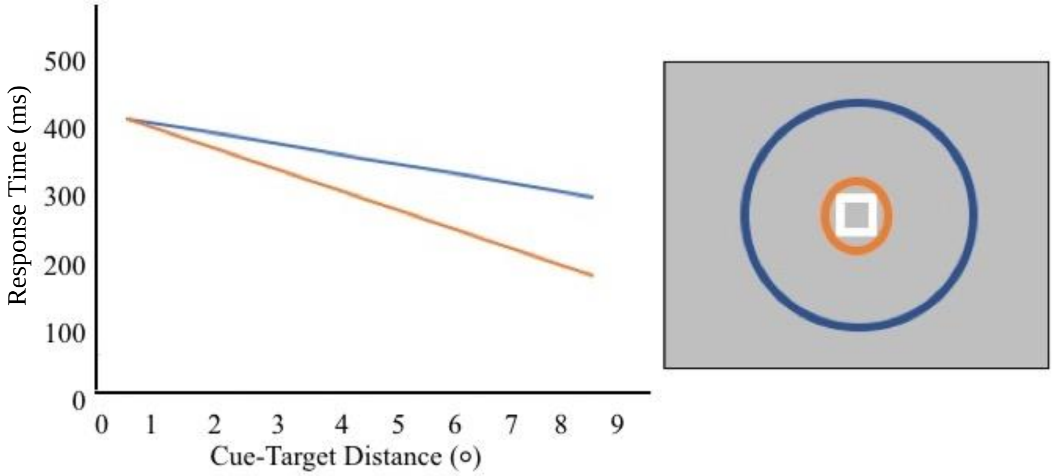

Figure 3.6. Hypothesised relationship between slopes obtained in the IOR task, and attention distribution around a cued location. The white rectangle (right) represents the cued location.

The use of the Posner cueing paradigm to measure attention distribution has noticeable merits compared to the flanker and Navon tasks. In particular, the task uniquely measures space-based attention. This is because the features of the cue and target in the Posner task are relatively meaningless for completing the task. Instead, participants must direct their spatial attentional resources to various locations in the environment to detect the target. Furthermore, the use of an inhibition variant of the Posner task allows for a clean separation of the measurement of the flexibility of attentional scaling, and attentional scaling distribution. In particular, attentional scaling is a relatively sluggish process (Benso, Turatto, Mascetti & Umilta, 1998; Jefferies & Di Lollo, 2009; Turatto et al., 2000). With long cue-target intervals, the IOR task allows enough time for attentional scaling to develop in response to the attentional cue and allows for the appropriate measurement of attention scale. This is particularly important given that there are known differences in attentional flexibility with healthy ageing, as well as across different cultural groups (Caparos, Linnell, Bremner, de Fockert, & Davidoff, 2013; Jefferies et al., 2015). Furthermore, individual differences in processing speed have been observed across different age groups, and individuals of different cultural backgrounds (Anstey, Dear, Christensen, & Jorm, 2005; Verhaeghen & Cerella, 2008; Boduroglu, Shah, & Nisbett, 2009). Therefore, the Posner cueing task is an appropriate operationalisation to use for comparing age and cultural differences in attention distribution.

3.4. Summary

The above analysis highlights the strengths of using the Posner cueing paradigm to infer age and cultural differences in attentional scale. While the flanker task has been used to infer attention distribution, it is unclear whether scores obtained in the flanker task are due to differences in attentional distribution, or attentional control. Similarly, individual scores in the Navon task may be due to differences in categorical/feature-based attention, rather than spatial attention. In contrast to the flanker and Navon tasks, the Posner cueing task allows for a direct measurement of attention across space and allows for the measurement of attentional scale as opposed to attentional scaling flexibility. Therefore, it was determined that the Posner cueing task was the most appropriate tool to use to measure individual differences in attention distribution, in particular, by measuring variation in the gradient of attentional inhibition. Chapters 3 and 4 use the Posner cueing task to test how healthy ageing and cultural background influence attentional scale.

Chapter 4: Changes in the Spatial Spread of Attention with Healthy Ageing

4.1. Foreword

Having determined that the Posner cueing task was an appropriate measure to test individual differences in spatial attention scale, next, the thesis aimed to explore how healthy ageing influences attention distribution. Knowing how growing older influences the spatial spread of attention is essential for our ageing society. Both visual and cognitive impairments occur with healthy ageing (Anstey, Eramudugolla, Hosking, Lautenschlager, & Dixon, 2015; Madden, 2007; Owsley, 2011, 2013), and changes in attention processes are thought to be a central factor underlying these impairments. Specifically, differences in attentional distribution are related to working memory capacity, and it is known that working memory capacity declines with age (Kreitz et al., 2015; Mattay et al., 2006). Furthermore, changes in attentional processing with age are thought to underscore effective functioning in critical daily activities, for example, driving (Wood, 2002). Therefore, it is essential to understand the effect of attention distribution for theoretical and practical reasons. Here, using the inhibition of return (IOR) task, attention distribution was compared for younger adults (aged 18-30 years), and older adults (aged 60+ years).

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Australian National University

Statement of Contribution

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I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

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Authors: Rebecca Lawrence, Mark Edwards & Stephanie Goodhew

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Stephanie Goodhew 01/03/2019.

M. Edwards 01/03/2019

Rebecca Lawrence 01/03/2019

Candidate – Print Name | Signature | Date

Endorsed

Stephanie Goodhew 01/03/2019

Primary Supervisor – Print Name | Signature | Date

M. Edwards 01/03/2019

Delegated Authority – Print Name | Signature | Date

4.2. Abstract

Spatial attention is a necessary cognitive process, allowing for the direction of limited capacity resources to varying locations in the visual field for improved visual processing. Thus, understanding how ageing influences these processes is vital. The current study explored the relationship between the spatial spread of attention and healthy ageing using an inhibition of return task to tap visual attention processing. This task allowed us to measure the spatial distribution of inhibition, and thus acted as a marker for attentional spread. Past research has indicated minimal age differences in inhibitory spread. However, these studies used placeholder stimuli, which may have restricted the range over which age differences could be reliably measured. To address this, in Experiment 1, we measured the relationship between the spatial spread of inhibition and healthy ageing using a method which did not employ placeholders. In contrast to past research, an age difference in inhibitory spread was observed, where in comparison to younger adults, older adults exhibited a relatively restricted spread of attention. Experiment 2 then confirmed these findings, by directly comparing inhibitory spread for placeholder present and placeholder absent conditions, across younger and older adults. Again, it was found that age differences in inhibitory spread emerged, but only in the placeholder absent condition. Possible reasons for the observed age differences in attention are discussed.

Keywords: spatial attention, ageing, attention distribution

4.3. Introduction

Selective spatial attention allows for the allocation of the brain's finite cognitive resources for efficient processing of relevant visual information, while filtering out irrelevant visual noise (Broadbent, 1982; Carrasco, 2011; Desimone & Duncan, 1995; Kastner & Pinsk, 2004; Posner, 1980; Posner et al., 1980). The aim of the current study was to clarify the relationship between healthy ageing and the dynamics of one aspect of selective spatial attention: the distribution of attention across space. This is important because the relative distribution of spatial attention may underscore differences in visual search efficiency, perceptual sensitivity, distractor processing, and working memory capacity (e.g. Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003; Cave & Chen, 2016; Eriksen & James, 1986; Goodhew et al., 2017, 2016; Greenwood & Parasuraman, 1999, 2004; Hoyer, Cerella, & Buchler, 2011; Pringle, Irwin, Kramer, & Atchley, 2001; Theeuwes, Kramer, & Belopolsky, 2004). It is therefore imperative that the operation of attentional spread with ageing is understood in great detail. Yet current evidence for changes in attentional distribution across the lifespan is mixed. While some studies reveal substantial age differences in the capacity to spread spatial attention (Gottlob & Madden, 1999; Greenwood & Parasuraman, 1999; Greenwood et al., 1997; Hüttermann, Bock, & Memmert, 2012; Kosslyn, Brown, & Dror, 1999; Pesce, Guidetti, Baldari, Tessitore, & Capranica, 2005), others indicate none, or only small differences (Hartley & Kieley, 1995; Hartley, Kieley, & Mckenzie, 1992; Langley et al., 2011; Madden & Gottlob, 1997; McCalley et al., 1995; Quigley, Andersen, & Müller, 2012).

Previous research has demonstrated a strong link between working memory capacity and visual attention (Bleckley et al., 2003; Kreitz et al., 2015). Likewise, there are well known declines in working memory capacity with age (Hedden & Gabrieli, 2004; Mattay et al., 2006; Verhaeghen & Salthouse, 1997). Therefore, the contradictory effects of ageing on attentional spread are surprising. That is, if changes in working memory capacity do underlie changes in attentional spread, one would expect more consistent age differences in the literature, with older adults showing differences in the distribution of attention across space (Rolle, Anguera, Skinner, Voytek, & Gazzaley, 2017). Here, similar to Rolle et al. (2017), and Erel and Levy (2016) we believe that one reason for these contradictory findings are the different methods which have previously been used to claim age equivalency in the spatial distribution of attention. Specifically, we believe that these methods may not have been sensitive enough to uncover the potentially subtle, and fine-grained changes in attentional processing across the lifespan.

A key method utilised to explore the dynamics of visual attention is the spatial-cueing paradigm (Posner, 1980; Posner & Cohen, 1984). Here, attention is oriented via a non-informative peripheral cue to a potential target location. Following this, a target is presented at either the same (valid) or different (invalid) location to the cue. Target detection response times are then compared between validly and invalidly cued locations. When the target is presented shortly after the cue, a facilitation effect is observed, where response times are faster for the validly cued compared to invalidly cued location. However, if the target is presented approximately 300ms or more following the cue, an inhibitory effect is observed, where target detection response times are comparatively slower. This is labelled Inhibition of Return (IOR), and is theorised to reflect an effective reorienting of visual attention to novel spatial locations (Berlucchi, 2006; Klein & MacInnes, 1999; Posner et al., 1985).

The spatial cueing paradigm can be used to quantify attentional spread by measuring the relative change in either facilitation or inhibition surrounding an attended location (e.g. Bennett & Pratt, 2001; Downing, 1988; Klein et al., 2005; LaBerge, 1983; LaBerge & Brown, 1989). That is, while the strength of attention is strongest at the location of the cue, attentional effects also spread to regions surrounding the cue. This is seen via a change in response time as the spatial disparity between the cued and the target location grows. The gradient change in attention across space can be used to infer attentional spread, and to compare both individual and group differences in spatial attention (for example, see Bennett & Pratt, 2001; Taylor et al., 2015; Wilson et al., 2016). Regression coefficients describing the slope between cue-target distance and reaction time are calculated for population groups. These coefficients are then compared between groups to infer potential differences in the 'roll-off' of attentional resources. A higher value coefficient indicates a steeper rate in the decline of visual attention across space, and therefore, a relatively restricted spread of attention, while a lower value coefficient suggests a comparatively shallower drop off in attention, implying a broader spread of visual attention resources (Wilson et al., 2016).

Although we acknowledge that there is an oculomotor component to IOR, here, we are primarily interested in the attentional component of IOR (e.g. Hunt & Kingstone, 2003; Kingstone & Pratt, 1999). That is, we wish to explore location based IOR patterns when eye movements are restricted. This will allow us to measure a form of IOR more closely related to covert orienting (e.g., see Chica, Taylor, Lupiáñez, & Klein, 2010). Similar work has recently been conducted by Wilson and colleagues (2016). Here, inhibitory slopes were used to explore potential personality differences in the distribution of attention. They measured the big five personality traits (Neuroticism, Extraversion, Openness, Conscientiousness, and Agreeableness; Digman, 1990), and then correlated these with individual IOR gradients. Importantly, by measuring a form of IOR which emphasised covert attention, the authors were able to equate their results to attentional spread. That is, the slope of IOR was seen as inferring previous preferential attending, and thus, indicative of how attention may have been initially distributed when initially oriented to a cued location. Overall, Wilson and colleagues found that personality traits Openness and Conscientiousness predict IOR slope, where those with higher Openness scores had broader attention, and those with higher conscientiousness scores had narrower attention. This demonstrates how the spatial distribution of IOR can be used to draw inferences about individual and group differences in the spatial spread of attention.

Studies comparing differences in younger and older adult's spread of attention have predominantly found only minimal changes in the gradient of both facilitation and inhibition, regardless of the manipulation of attentional spread, and have concluded that the distribution of attention surrounding a cued region is equivalent with ageing (Hartley et al., 1992; Hartley & Kieley, 1995; Langley et al., 2011). Here, we will focus on analysing previous work which measures age changes in the spread of IOR, as this is the primary measure of interest used in the current study. We have chosen to measure IOR, instead of facilitation, as the longer time course of IOR means that attention can be sufficiently spread around the cued location to measure age differences with a high level of sensitivity (Wilson et al., 2016). Likewise, as Jefferies et al. (2015) have shown that older adults take slightly longer to contract attention, the longer time course of the IOR paradigm seems most appropriate.

To our knowledge, only two studies to date have directly examined the effect of ageing on the spatial distribution of IOR (Hartley & Kieley, 1995; Langley et al., 2011). In both studies, while ageing influenced response times, such that older adults had slower target detection speeds than younger adults, it was concluded that ageing did not influence the distribution of IOR. This conclusion was reached, even though some of the experiments within these studies did in fact, find an age change in response time, as the distance between the cue and target grew (although this finding was not consistent). Given that the spatial spread of IOR can be used to infer the spread of visual attention across space, these mixed findings indicate that the spatial distribution of attention did not reliably vary as a function of age. However, both studies employed a particular methodology, which recent evidence suggests may constrain the spread of attention across space. That is, in both Hartley and Kieley (1995), and Langley et al. (2011), attention was cued via the brightening placeholder boxes (see Figure 4.1). Research examining the influence of placeholders on the spatial distribution of inhibition in a younger adult sample suggests that placeholders may limit the bounds that attentional resources spread to in the visual field (Taylor et al., 2015). In other words, the presence versus absence of placeholders can result in qualitatively different effects on visual attention (Hilchey, Pratt, & Christie, 2016; Nicol, Watter, Gray, & Shore, 2009; Taylor et al., 2015). For instance, although not directly comparing attentional slopes, Hilchey et al. (2016) found that the magnitude of IOR is often greater when placeholders are present in the display. Thus, the conclusions of both Langley et al (2011), and Hartley and Kieley (1995) may not be generalizable to placeholder absent conditions.

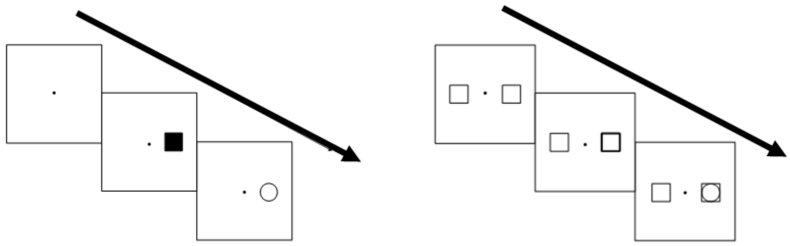

Figure 4.1. Placeholder absent (left) and Placeholder present (right) cueing paradigms. In the placeholder absent condition, a transient stimulus, the square, is presented to attract attention. In the placeholder present condition, attention is attracted through the brief brightening of a placeholder box, indicated by the bolded line. In both conditions, the participant's task is to detect the circle as quickly as possible.

More specifically, in Taylor et al. (2015), attention was cued to one of four possible locations, with target detection measured at 121 possible locations. In the placeholder present condition, possible cued locations were drawn and remained on the visual display for the duration of the trial. In the placeholder absent condition, the cue location was presented briefly, and did not remain in the visual display. Crucially, in the placeholder present condition, response times to target detection at placeholder locations were significantly slower compared to target detection outside of placeholder locations, irrespective of the placeholder cued. However, in the placeholder absent condition, response times to target detection decreased as cue-target distance increased, regardless of whether the target fell in one of the four potential cue locations. Thus, placeholder presence markedly influenced the distribution of IOR, such that attention was affixed to the location of the placeholders, lowering the sensitivity of the model to describe the cue-target distance relationship. This suggests that when measuring the gradient of spatial inhibition, the presence of placeholders may potentially conceal fine-grained changes in inhibitory spread at increasing cue-target distances, by anchoring attention to the bounds of placeholders. In turn, this may lead to inconsistent findings in the influence of attentional cueing on the distribution of inhibition.

Likewise, research emphasising the role of placeholders in inducing regions of attentional facilitation strongly indicate that the spatial structure imposed by placeholders could limit the spatial spread of attention (Egly & Homa, 1984; Jefferies & Di Lollo, 2015; McCalley et al., 1995). For example, studies conducted by Jefferies and colleagues found that observers can adopt an annular distribution of attention, inhibiting a central stream of letters, only when placeholders were continuously displayed in the visual scene. Without these placeholders, observers were relatively more distracted by the central visual stimuli (Jefferies & Di Lollo, 2015, 2017). Thus, placeholder arrays can be utilised by participants to accurately deploy attentional resources to regions most conducive to accurate task performance, thus limiting the bounds of attentional spread. Work conducted by McAuliffe, Chasteen, and Pratt (2006) further shows that the use of placeholders to cue attention in younger and older adults has significant effects on IOR patterns, compared to when no placeholders are present (although note, the spatial distribution of inhibition was not manipulated here). Here, IOR magnitudes for placeholders and no placeholders were compared between younger and older adults. Younger adults showed stronger IOR magnitudes for placeholder present conditions, while older adults showed no difference. Taken together, it is clear that to fully understand age changes in the spread of attention, these phenomena must be compared for placeholder absent conditions, which more closely measure location based IOR.

Therefore, the focus of the present study was to compare the spatial distribution of IOR when placeholders were absent from the visual display, for younger versus older adults. This experimental method is largely identical to that used by Wilson and colleagues to measure personality differences in the spatial spread of attention (Wilson et al., 2016). Here, however, age differences, rather than individual differences in personality, were the comparison of interest on this metric. Experiment 1 compared inhibitory spread for younger and older adults when placeholders were absent from the display. Experiment 2 then directly compared older and younger adults inhibitory spread for both placeholder-present, and placeholder-absent conditions.

4.4. Experiment 1

Here, we aimed to compare inhibitory spread for older and younger adults, when placeholders were absent from the visual display. As shown in Figure 4.2, on each trial, spatial attention was cued to one of four locations via the brief presentation of a small green circle. Following a delay of 1315ms, the target, a small white circle, was presented at one of 40 possible locations. This allowed for a large range of cue-target distances to be sampled, giving a highly sensitive measure of attentional spread. Furthermore, in contrast to previous studies examining age differences in the spatial spread of IOR, eye movements were recorded, and we encouraged participants to minimise eye movements during practice trials, as well as throughout the study, to be more confident that covert attention was measured. As emphasised earlier, the primary reason we have chosen to do this is because we wanted to ensure that the process we are measuring closely resembles covert attentional processes, which may be likened to the spatial distribution of attentional facilitation (although see Hilchey, Klein, & Satel, 2014 for an alternate explanation). Finally, to ensure that age differences in vision did not unduly influence our findings (see Owsley, 2011 for a review), stimulus saliency was emphasised, using brightly coloured stimuli on black backgrounds (i.e., high contrast), with stimuli presented largely within para-foveal rather than peripheral vision.

To compare attentional gradients, regression coefficients describing the relationship between distance and response time will be compared between age groups. If age does not influence the spread of IOR, we expect no age differences in coefficients modelling distance-response time, regardless of the absence of placeholders. This would provide further support to claims that the spatial spread IOR remains stable with healthy ageing. If, however, age differences in the spatial spread of inhibition exist, we expect these coefficients to differ significantly. If older adults have a relatively larger coefficient, this would suggest that they have a more focal distribution of inhibition. In contrast, if older adults have a relatively smaller coefficient, this would suggest they adopt a more diffuse spread of inhibition. In turn, such a finding would support the broader literature claiming age differences in attentional distribution, which may potentially be linked to differences in working memory capacity.

4.5.1 Method

Participants

Eighty-three participants from the Australian National University and the general public participated in the study, and provided written informed consent. The ethical aspects of the research were approved by the Australian National University Higher Research Ethics Committee. Persons aged 18 to 30 years were recruited for the younger adult sample, and persons aged 60 years and over were recruited for the older adult sample. The younger adult group comprised of 42 participants, and the older adult group comprised of 41 participants. Participants completed a series of questionnaires designed to capture personality, health, and cognitive traits. These were the 15 item geriatric depression scale (GDS; Yesavage & Sheikh, 1986), the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), and demographic and health questionnaire designed by the research team. This questionnaire asked participants to indicate the presence of any physical (including eye health), cognitive, or psychological illnesses by ticking the appropriate box. A summary of demographic data for the participant groups used in the main analysis is presented in Table 4.1

Table 4.1. *Demographic data of participants included in final analyses of Experiment 1.*

	Younger	Older	p-value
Age	*M* = 20.16 (*SD* = 1.77)	*M* = 70.88 (*SD* = 6.25)	
Total Years Education	*M* =14.84(*SD* =1.93)	*M* =17.41(*SD* = 6.53)	.040
Ethnicity	Western = 13	Western = 31	<.001*
Gender	Female = 20	Female = 22	. 492
GDS	*M* =4.36(*SD* =3.40)	*M* =.75(*SD* = 1.16)	< .001*
MMSE	*M* =29.55 (*SD* =0.83)	*M* =29.44(*SD* =0.95)	.627
Eye Health	N = 0	N = 5	-
Hearing Impairment	N = 0	N = 8	-
Cognitive Health	N = 0	N = 1	-
Psychological Illness	N = 4	N = 3	-
High Blood Pressure	N = 0	N = 8	-
Diabetes	N = 2	N = 1	-
Arthritis	N = 0	N = 19	-

Notes. Ethnicity refers to whether participants identified with an Eastern or Western culture, or both. Eye health refers to participants who reported having cataracts, glaucoma or macular degeneration. Cognitive health refers to participants who reported having Parkinson's disease, dementia, or mild cognitive impairment. To test between group differences, independent t-tests were conducted for continuous variables. Where necessary, these tests were corrected for violations of equal variance. Two participants did not report their specific age, or total years of education. One participant did not report ethnicity.

Stimuli and Apparatus

Stimuli were presented on a LCD monitor, with a refresh rate of 59Hz set to a black background, with a luminance 0.94 cd/m^2. The physical dimensions of the monitor were 520mm by 325mm. To ensure that participants centred their gaze for the duration of each trial, eye movements were recorded using an Eyelink 1000 eye tracker (SR-Research, 2005-2008). Participants were seated comfortably for the duration of the experiment, and the viewing distance of the stimuli was fixed using a forehead and chin rest situated 940mm from the monitor. This ensured that all participants' eyes were fixated on the centre of the monitor, and that eye position was consistent across participants relative to the eye tracker. Participants wore glasses if necessary.

MATLAB, the Psychophysics Toolbox (Brainard, 1997), and the Eyelink Toolbox (Cornelissen, Peters, & Palmer, 2002) were used to generate the stimuli and record eye movements. To determine the location of presented stimuli, an invisible 6 x 6 grid, subtending 9.65° x 9.65° of visual angle was drawn and centred on fixation. As shown in Figure 4.3, the cue, an unfilled green circle, with a luminance of 189.28 cd/m^2, and a diameter subtending approximately 0.5° of visual angle, was presented at one of four possible locations, positioned at the centre of each quadrant of the grid. The target, a filled white circle with a luminance of 273.86 cd/m^2, and diameter subtending 0.5° of visual angle, could appear at either the centre of each quadrant, or at one of the 36 locations where the invisible grid lines intersected. On each trial, the assignment of the cue and target locations was pseudo-random, with the constraint that the cue fell at each of the four potential cued locations equally as often, the cue and the target fell at the same location on 12.5% of trials, and the cue and target appeared at differing locations on remaining trials 87.5% of trials. This meant that on average, on 3.15% trials, the target fell at the same location as the cue, and that the target fell at each one of the

39 target locations on 2.24% of trials. Therefore, even though it was more likely that a target would appear at a location other than the cue, given the large number of potential non-cue locations, on each trial, it was more likely that the target appeared at the cued location rather than any other location.

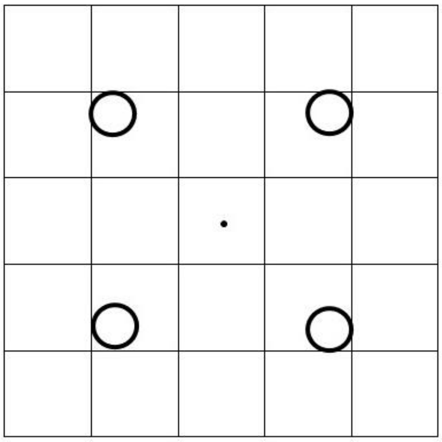

Figure 4.2. Potential target locations used in the current study. Targets could appear at any locations in the visual field where grid lines intersected, or at one of the four cue locations (represented by the unfilled circles, enlarged for illustrative purposes). This led to 40 possible target locations, and 21 possible cue-target distances.

Procedure

The experiment consisted of three blocks: a calibration block, a practice block, and an experimental block. For the calibration block, a standardized 9-point calibration was completed to confirm that the eye tracker was accurately recording the participant's visual gaze. Calibration was repeated until this requirement was met. However, for 14 participants (7 older, 7 younger), after repeated attempts at calibration, eye movements were unable to be accurately tracked. These participants were given the option of completing the study without their eye movements being recorded. As the current study is interested in covert attention, and controlling for eye movements, their data are not reported here. This leaves a total sample of 69 participants (34 older, 35 younger).

Following the calibration block, participants completed a practice block of the IOR task, consisting of approximately 10 to 20 trials. Of the practice (and subsequent experimental) trials, 80% included both the cue and the target trials, and 20% contained only the cue (catch trials). The trial sequence as shown in Figure 4.3 was as follows: Firstly, for the trial to begin, participants were required to focus their gaze on a ring presented at the centre of the screen and press space bar. Participants gaze was required to be within a circular region with a 2 degree radius for a trial to begin. Only when the eye-tracker registered this did a trial begin. Once the trial began, the central fixation ring changed to a fixation point which was shown for 1000ms. The cue was then displayed for 100ms. Following this, on target-present trials, a cue-to-target delay of 1315ms was used to produce the IOR effect. Although it is important to recognise that the gradient of IOR differs with different cue-target delays (e.g. Taylor et al., 2015), here, we chose a single time delay designed to maximise our chance of reliably measuring age differences in attentional distribution. That is, the delay time was chosen based on earlier research indicating that maximal IOR effects with minimal differences in IOR magnitude across the two age groups would be present with this time delay (Castel, Chasteen, Scialfa, & Pratt, 2003). Finally, on target present trials, the target was presented and participants were required to press the space bar on a keyboard as soon as they had detected the target. The target was presented until the participant responded, or 1000ms elapsed. For cue absent trials, the 1315ms delay was presented, as well as a blank screen for 1000ms. In the target absent trials, participants were asked to not respond. In the practice block, corrective feedback was given based on the participant’s response. Together, the calibration and practice block typically took between 10 to 20 minutes.

Once participants understood the task, they completed the experimental block, which consisted of 410 trials. The parameters of the experimental block were identical to the practice block, except that no corrective feedback was given. The independent variables were cue and target location, which determined the spatial distance between cue and target, and the dependent variables were accuracy for target detection, and response time. Self-paced rest breaks were offered to the participant every 10% of trials completed. Further to this, where necessary, eye movements were recalibrated with the eye tracker throughout the study. Overall the experiment took about 1.5 hours to complete.

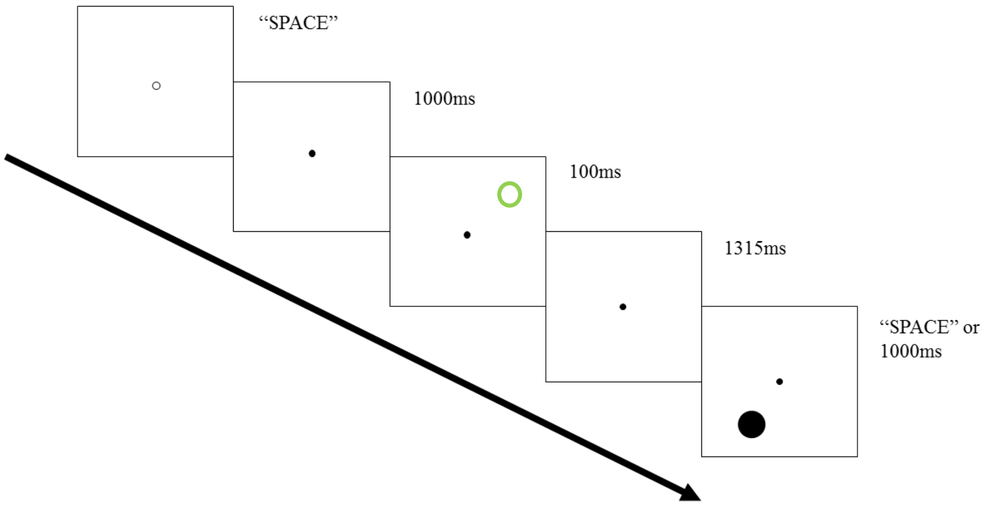

Figure 4.3. The IOR method used in the current study. At the beginning of each trial, participants complete a drift correction with the eye tracker to ensure accurate recordings of eye movements. After this, participants pressed the spacebar on the keyboard to begin a trial. For the duration of the trial, participants are required to maintain fixation. A transient exogenous cue, the green circle, is briefly flashed at one of four possible locations, followed by a blank interval of approximately 1315ms. Following this, the target, a white circle, is presented at one of 40 possible locations, until the participants detects it, via the pressing of the spacebar, or 1000ms has passed.

4.5.2. Results and Discussion

Eye Movement Data

To measure covert attention, for each participant, a trial level analysis of eye movement data was conducted. For each trial, we determined whether a participant maintained fixation on the centre of the screen, or shifted their eye movements away from this location. If participants fixated for more than approximately 75ms outside of a square 2.07$^{\circ 2}$ interest area (IA), drawn around the central fixation point, eye movement data for the trial was scored as a 0. If the participant's gaze remained in the IA, eye movement data for the trial was scored as a 1. To check that we were not inaccurately scoring trials as zero due to eye blinks, or glare from glasses, the fixation time of approximately 75ms outside of the IA was chosen.

It is important to note that we did not recycle trials where participants moved from the IA as we believed that this would be too demanding and risk undue fatigue in participants. That is, since it took approximately one hour and 15 minutes to complete the computer task, we deemed it inappropriate to continue to require participants (especially older participants) to persevere with the task longer than necessary. Likewise, in order to retain the largest amount of data as possible, rather than removing trials where participants failed to maintain fixation in the central IA, instead, we statistically controlled for any eye movements made in our main analysis. This is because using a trial removal approach may have not left enough data to reliably measure IOR effects and attentional spread at the individual level.

Accuracy Data

Next, accuracy data was analysed. Firstly, participants were removed from further analysis if their accuracy in target-present trials fell below 90% (i.e., if they failed to respond on more than 10% of the target-present trial). This was done to maximise the possibility that all participants included in later analysis were actively engaged in the task. One older participant was removed from the data set. Likewise, in the target-absent condition, participants' data were removed from further analysis if their accuracy fell below 90% (in other words, if they failed to withhold responses on more than 10% of the target-absent 'catch' trials). This allowed us to control for anticipatory strategies participants may have adopted while completing the IOR task. A further three participants were removed from the data set for this reason (2 younger, 1 older), leaving a data set of 65 participants (32 older, 33 younger). For the remaining data, an independent *t*-test, with unequal variances corrected for, indicated a marginally significant difference in accuracy between the older and younger adult groups, $t(54.90) = -1.88$, $p = .066$, $d = 0.47$ where older adults were slightly less accurate (M_{older} = 98.74%, SD_{older} = 1.57%, $M_{younger}$ = 99.37%, $SD_{younger}$ = 1.08%). Likewise, an independent samples *t*-test on 'catch' trial accuracy indicated no significant difference in performance between age groups for this task, $t(63) = -0.823$, p = .413, $d = 0.21$, ($M_{errorolder}$ = 1.75%, $SD_{errorolder}$ = 1.91%, $M_{erroryounger}$ = 2.18%, $SD_{erroryounger}$ = 2.26%).

Response Time Data

Following this, response time data was analysed to confirm an overall IOR effect for participants, and to explore whether any potential age differences existed in the magnitude of this IOR effect. Z-scores were calculated for each participant's response times across all cue-target distances. Any Z-scores exceeding +/- 3.29 were excluded from further analysis. For the remaining data sets, overall mean reaction times were calculated. An independent samples *t*-test indicated a difference between older and younger adults, t (63) = 4.61, $p < .001$, $d = 1.14$, where older adults were slower than younger adults, (M_{older} = 484ms, SD_{older} = 78ms, $M_{younger}$ 398ms, $SD_{younger}$ = 72ms). Next, mean response times for cued versus uncued locations were calculated for each participant, and IOR magnitude was compared between age groups. Specifically, to calculate IOR effects, the mean response time at the cued location was obtained, and then compared to the average mean response time from the remaining 20 cue-target distances. A repeated measures ANOVA with cue location and age group indicated that there was a significant IOR effect, $F(1, 63) = 46.78$, $p < .001$, $\eta_p^2 = .426$, where mean response time at the uncued location was faster than at the cued locations (M_{cued} = 457ms, SD_{cued} = 92ms, M_{uncued} = 439ms; SD_{uncued} = 86ms). The interaction between age group and cue location was non-significant, $F(1, 63) = 2.66$, $p = .108$, $\eta_p^2 = .040$ ($M_{\text{cued-uncued older}}$ = 22ms, $SD_{\text{cued-uncued Older}}$ = 23ms, $M_{\text{cued-uncued Younger}}$ = 14ms; $SD_{\text{cued-uncued Younger}}$ = 20ms), suggesting the magnitude of the IOR effect was similar across both age groups.

Age Differences in Attentional Slope

To explore potential age differences in the spatial gradient of inhibition, the relationship between cue-target distance, and response time was analysed, and then compared between age groups. Figure 4.4 depicts mean response times at each cue-target distance for the two age groups. Two hierarchical regressions, quantifying the relationship between cue-target distance, and response time, controlling for eye movements were run for each participant. The first run checked for the presence of any univariate or multivariate outliers in the participants' data. This allowed us to remove any extreme response time data which may have unduly influenced results. Univariate outliers were defined as those with Z-scores exceeding +\- 3.29. Multivariate outliers were defined as those with Mahalonobis distance scores exceeding 5.99. These outliers were removed, and the second run produced the cue-target distance regression coefficients used in later analyses. The eye movement variable was entered into the first block to control for any eye movements made, and the cue-target distance variable into the second block. The distance coefficient represents the unique influence of cue-target distance on response times, indicating the slope of inhibition surrounding the cued location, and thus attentional spread.

It is important to recognise that the mean response time differed between the two age groups, and that overall response times and regression slopes in the IOR paradigm are typically related (Wilson et al., 2016). This difference in mean response time is likely due to generalised slowing with age (Verhaeghen & Salthouse, 1997). Likewise, rather than reflecting age changes in attentional spread, it is possible that changes in visual system with age may have influenced the findings observed in the current experiment.[1] While the majority of participants reported having normal or corrected to normal vision, five older adults reported issues with eye health, such as being diagnosed with macular degeneration, glaucoma, or having cataracts. Furthermore, across the lifespan, contrast sensitivity, as well as the functionality of visual pathways in the brain decline, particularly for fine detail processing (Elliott, Whitaker, & MacVeigh, 1990; Elliott & Werner, 2010; Owsley, 2011). Although the experiment was designed with the intention of controlling for these factors, such as increasing the contrast of the presented stimuli, as well as presenting the stimuli predominantly in para-foveal vision, it is possible that the eye health of some of the older adult participants unduly influenced the observed results.

Consequently, we compared age differences in inhibitory slope, while including mean response times and self-reported eye health issues as covariates. There was a significant influence of response time. F (1, 61) = 4.26, p =.044, η_p^2 = .065, suggesting that age related slowing may account for some of the variance in the inhibitory slopes observed (Verhaeghen & Salthouse, 1997). In contrast, the influence of eye health was non-significant, F (1, 61) = 0.003. p = .953, η_p^2 = 0.00. Finally, and crucially, when mean response time and eye health were controlled for the influence of age group on inhibitory slopes was significant, F (1, 61) = 7.25, p = .009, η_p^2 =.106, (M_{older} = -.122, SD_{older} = .087, $M_{younger}$ = -.077, $SD_{younger}$ = .094). This is strong evidence to suggest that when the appropriate controls are in place, older adults exhibited a strongly, significantly narrower spread of attention relative to younger adults.

We also compared inhibitory slopes when mean RT and eye health were not controlled for. An independent samples *t*-test was conducted to compare the relationship between age group (older vs. younger), and the value of the cue-target distance coefficient. Overall, the difference in regression coefficients between the two groups was marginally significant, t (63) = -1.97, p = .053, d = 0.49, where for older adults the slope value was greater. This provides converging evidence that, even when known age changes are not controlled for, older adults had a narrower spread of attention than younger adults.

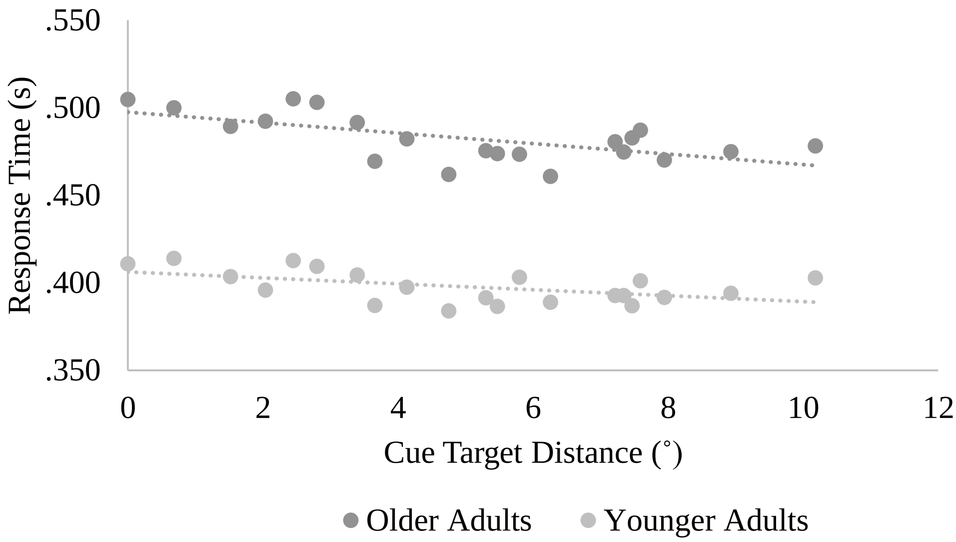

Figure 4.4. Experiment 1: Mean response time as a function of cue-target distance for the younger and older adult groups.

Interestingly, the obtained slopes in the current study differ in magnitude to that of previous work using this method (e.g. Taylor et al. 2015; Wilson et al. 2016). One reason for these differences in slope may have been the time difference between cue and target presentation in the current experiment compared to previous work. That is, while Wilson et al. (2016) utilised a cue-target delay of 800ms, the current experiment cue-target delay was 1315ms. Given that Taylor et al. (2015) demonstrated that the slope of inhibition differs across varying cue-target delays, where inhibitory slope becomes increasingly shallow with increased time delays, this would explain the relatively shallower slope obtained across both age groups.

Finally, to explore whether the control for eye movements influenced the pattern of results obtained, each participant's regression analysis was re-run without the eye movement covariate included. Here, the between subjects factor was age group, and the covariates included were mean response time, and eye health. Under this analysis, the effect of mean response time was non-significant, F (1, 65) = 1.73, p =.193, η_p^2 = 0.028, as was the effect of eye health, F (1, 65) = 0.03, p = .872, η_p^2 = 0.00. However, the effect of age group on inhibitory slopes was marginally significant, F (1, 65) = 3.98, p = .051, η_p^2 = 0.061. This suggests that even when eye movements are not controlled for, there is an age difference in inhibitory slopes, and thus, attentional spread. However, when covariates were removed from the analysis, the age difference was minimal, t (63) = -1.67, p = .100, d = 0.42. This is surprising given empirical work which suggests that the slope of inhibition does not differ for perceptual and motor IOR (Wang, Hilchey, Cao, & Wang, 2014). Nonetheless, here we believe that by controlling for trials where eye movements were made, we were able to get a cleaner measure of covert attention. Thus, it may be that when covert attention is closely measured, there is a higher sensitivity to detect age differences in covert inhibitory spread.

Implicit Learning of Cue-Target Contingencies

In the current paradigm, the cue was predictive of target location above chance level. Therefore, on each trial, it was more likely that the target fell in the previously cued location than any other location. This is important to note, as IOR effects are only typically seen when attention is exogenous (i.e. automatic, and not driven by top down goals; Posner & Cohen, 1984). This probability manipulation may have had an overall effect on the IOR gradient for both groups, where the younger adult group better learnt the implicit probabilities inherent to the task over and above that of the older adult group. For instance, response times for target detection were actually faster, when the cue and target fell at the same location, compared to the other potential cue-target distances. This is turn, may have led to shallower IOR slopes overall. Further, a recent review by Howard and Howard (2013) notes that while many processes of implicit learning are preserved with healthy ageing, other processes, for example, the learning of second order probabilities declines with healthy ageing. Nonetheless, in the current study, it unlikely that the probability manipulation drove age differences in attentional gradient. Specifically, if the younger adults were superior in implicitly learning cue-target probabilities, we would expect their attention to be narrowed in to the cued locations to a greater degree than the older adults. Consequently, this would cause them to display a relatively narrower distribution of attention. However, in contrast to these predictions, we obtained the opposite pattern of results, where older adults showed a narrower distribution of attention compared to younger adults. Therefore, given our obtained results, our data strongly suggests that older adults have a relatively restricted distribution of attention in comparison to younger adults. This conclusion is also supported by Experiment 2 (see below).

Covert and Overt Attention

Compared to previous studies of spatial IOR and ageing, in the current study, eye movements were measured via an analysis of central fixation patterns. Specifically, we asked participants to maintain fixation, while also measuring eye movements and then statistically controlling for any eye movements that were made. Given that there appears to be a difference in attentional and oculomotor inhibition of return (for example, Hunt & Kingstone, 2003), it is possible that the current study was measuring a different form in IOR compared to that of previous work. However, given that recent research indicates that the spatial spread of inhibition shows similar patterns with, and without eye movements (Wang et al., 2014), we believe that this does not render our work and previous work incomparable. Instead, we believe that by controlling for eye movements, we can be more confident that we measured a form of inhibition that more accurately captures the deployment of covert spatial attention, with a higher degree of sensitivity compared to past research.

Furthermore, it is important to recognise recent research which has shown that when covert, perceptual IOR is measured, IOR effects have been found to be minimal when placeholders are removed from the visual display (e.g. Hilchey et al., 2016). This is in contrast to our study, which found substantial IOR effects without placeholder stimuli. One potential reason for this discrepancy is that the current study adopted a more sensitive measure of IOR compared to Hilchey et al. (2016). That is, while Hilchey and colleagues only measured changes in IOR magnitude across three locations, we tested across 40 possible locations, and 21 cue-target distances. Indeed, in Hilchey and colleagues' experiments, participant's attentional resources need only have been spread equally, to the bounds of the three locations, thus minimising potential for IOR magnitude effects to be found. In contrast, our study contained far more locations, making it more likely that subtle attentional differences may emerge. Thus, it appears that using a sensitive measure of attentional gradient across multiple cue-target locations may be able to tap into subtler changes in IOR than previous research.

4.5.3. Summary

Overall, the data from Experiment 1 provides compelling evidence that older and younger adults distribute their attentional resources differently. While younger adults distributed their attention broadly to complete the IOR task, older adults focused their attention narrowly. This is in contrast to previous research that found minimal age differences in attentional spread. The key difference between Experiment 1 and past research was the absence of placeholders to cue attention. Specifically, the use of placeholders to cue attention had the potential to restrict the range over which attention was spread, thus lowering the sensitivity of the method to detect any group level differences. Here, for the first time, we have demonstrated that when placeholders are absent, inhibitory slope differs for younger and older adults, with older adults having steeper slopes. This implies that in comparison to younger adults, older adults show a relatively restricted spread of attention.

Nonetheless, while the presence versus absence of placeholders was the primary methodological difference between the current and previous studies, without a direct comparison of placeholder present versus placeholder absent experimental conditions, it is still possible that other factors are driving the observed age difference in Experiment 1. Given that there are sensory changes with healthy ageing, age differences in vision, rather than attention, may have driven the obtained findings. Specifically, there is typically a reduction in contrast sensitivity with healthy ageing (Owsley, 2011). This may have made stimuli not appear as bright for older compared to younger adults, leading them to have a narrower scope of attention. [2] Therefore, Experiment 2 sought to address this by comparing age differences in attentional slope for both placeholder present, and placeholder absent conditions. For the placeholder present condition, if sensory factors were driving the observed age differences, the stimuli would still appear dimmer to older adults, and thus lead older adults to have a narrower scope of attention. However, if no age difference are observed in the placeholder present condition, it is more likely that potential differences are driven by attentional processes. Thus, if, as we predict, placeholder presence restricts the spread of attention, age differences should only emerge when placeholders are absent from the visual display. In contrast, when placeholders are present, we expect age differences in attentional slope to disappear. This would provide strong converging evidence that placeholders are a key factor driving the distribution of attention, while explaining the previously obtained, null age differences in attentional slope.

4.6. Experiment 2

4.6.1. Method

Participants

Participants were from recruited from the general public and Australian National University, and were offered either course credit, or payment for participation. The ethical aspects of the research were approved by the Australian National University Human Research Ethics Committee. Participants included 30 younger adults, and 30 older adults. A summary of demographic data for the participant groups used in the main analysis is presented in Table 4.2.

Table 4.2. *Demographic data of participants included in final analyses of Experiment 2.*

	Younger	Older	P - value
Mean Age (Years)	*M* = 21.90(*SD* =3.56)	*M* = 69.23(*SD* = 5.84)	-
Total Years Education	*M* = 16.85(*SD* = 3.12)	*M* = 18.30(*SD* =3.22)	.082
Ethnicity	Western = 12	Western = 28	-
Gender	Female = 23, Male = 6, Other = 1	Female = 24, Male =6	-
GDS	*M* = 3.5 (*SD* = 3.35)	*M* = 1.17 *SD* = (1.66)	.001*
MMSE	*M* = 28.67 (*SD* = 1.54)	*M* = 28.97 (*SD* =0.72)	.339*
Eye Health	N = 0	N =11	-
Hearing Impairment	N = 0	N = 7	-
Cognitive Health	N = 0	N = 0	-
Psychological Illness	N = 4	N = 2	-
High Blood Pressure	N = 0	N = 7	-
Diabetes	N = 1	N = 1	-
Arthritis	N= 0	N = 10	-

Notes. Ethnicity refers to whether participants identified with an Eastern or Western culture, or both. Eye health refers to participants who reported having cataracts, glaucoma, macular degeneration, or another uncorrected eye health condition. Cognitive health refers to participants who reported having Parkinson's disease, dementia, or mild cognitive impairment.

To test between group differences, independent t-tests were conducted for continuous variables. Where necessary, these tests were corrected for violations of equal variance.

Stimuli and Apparatus

Stimuli were presented on an Apple Macintosh computer with an LCD monitor of dimensions 475mm by 270mm, and refresh rate of 60Hz. Participants were seated comfortably, 600mm from the monitor, with their head movements stabilised using a chin rest. Stimuli were presented using MATLAB and the psychophysics toolbox (Brainard, 1997) set to a black background with a luminance of 0.36 cd/m^2. The method was largely similar to Experiment 1, however, there were some changes. Firstly, we did not include an eye tracking component. Secondly, fewer cue-target locations were sampled. This allowed us to measure IOR slopes with a high degree of sensitivity, while lowering fatigue effects for participants. Stimuli were presented within a rectangular 5 x 5 grid, with dimensions 10° x 10° of visual angle. The cues were presented at the centre of each quadrant of the grid while targets were presented at each intersection point of the grid. This led to a total of 100 possible cue-target combinations, and 10 possible cue target distances.

At the beginning of each trial a grey, central fixation dot subtending a diameter of 0.10° with a luminance of 77.41 cd/m^2 was presented for 500ms. In the placeholder absent condition, the cue, a green annulus with luminance 257.80 cd/m^2, a diameter of 0.48°, and thickness of 0.05°, was then presented for 100ms. Following this, there was a delay of 1317ms, following which the target, a white circle with luminance 358.98 cd/m^2, and diameter 0.48° was presented until the participant responded, or 1000ms had elapsed. If participants made anticipatory responses (i.e. they reacted during the delay period), a warning message, reminding participants to wait for the white circle, appeared on the screen and remained for 3000ms. In the placeholder present condition, the same stimuli were used, except that now, at the beginning of each trial, placeholder stimuli appeared at each of the possible four cue locations, and remained on screen for the duration of the trial. The placeholder stimuli were green annuli, with diameter 0.48° and thickness 0.048°, and a luminance of 30.73 cd/m^2.

Procedure

The experiment consisted of four blocks, two practice blocks corresponding to two experimental blocks. Placeholder presence and absence were blocked, and order of completion of the two blocks was counterbalanced. Firstly, participants completed a practice block consisting either of 10 placeholder present, or placeholder absent trials (corresponding to which condition they were about to complete). Participants then completed the first experimental block. This consisted of 240 trials containing either placeholders, or no placeholders. Of these, 200 trials were cue-target trials, while 40 trials were cue-only trials. For cue-target trials, it was equally likely for any possible cue target combination to occur. In comparison to Experiment 1, this miminised the chance that any age differences in cue-target contingency learning would influence results. Following this, participants completed the remaining practice block and experimental block. Within experimental blocks, self paced rest breaks were offered to participants every 60 trials completed. Overall, the experiment took approximately 1 hour to complete.

4.6.2. Results and Discussion

Accuracy Data

First, accuracy data for the experiment were analysed[3]. Accuracy across both experimental conditions was high for both age groups. No single participant's accuracy fell below 90% in either the placeholder absent or placeholder present conditions, thus, no data were excluded from further analyses. A mixed ANOVA indicated no differences in accuracy across the placeholder present versus absent conditions, $F(1, 58) = 0.96$, $p = .332.$, $\eta_p^2 = .016$, and a trend level interaction between placeholder and age group, $F(1, 58) = 3.22$, $p = .078$. $\eta_p^2 = .053$. Likewise, participants showed high accuracy for the target absent trials across both age groups and conditions, with no single participant's accuracy falling below 90%. Therefore, no data were excluded from further analyses for this reason. A mixed ANOVA indicated no differences in trial absent accuracy across the placeholder present versus absent conditions, $F(1, 58) = 0.07$, $p = .790$, $\eta_p^2 = .001$, nor an interaction between placeholder and age group, $F(1, 58) = .00$, $p = .703$, $\eta_p^2 = .00$. Accuracy data for Experiment 2 are summarised in Table 4.3.

Table 4.3. *Accuracy data for the placeholder present versus absent conditions in Experiment 2.*

	Younger	Older	p-value
Placeholder Absent Condition: Trial Present	*M* = 99.17(*SD* = .76)	*M* = 99.32(*SD* =0.90)	.487
Placeholder Absent Condition: Trial Absent	*M* = 98.33(*SD* = 1.83)	*M* = 99.17(*SD* = 1.78)	.477
Placeholder Present Condition: Trial Present	*M* = 98.88(*SD* = 1.23)	*M* = 99.40(*SD* = 0.94)	.073
Placeholder Present Condition: Trial Absent	*M* = 98.75(*SD* = 2.05)	*M* = 99.08(*SD* = 2.13)	.539

Notes. Independent samples t-tests were conducted to compare accuracy between age groups across the two placeholder conditions.

Response Time Data

Response time data was analysed to confirm an overall IOR effect for participants, and to explore whether any potential age differences existed in the magnitude of this IOR effect. Z-scores were calculated for response times across all cue-target distances. Any Z-scores exceeding +/- 3.29 were excluded from further analysis. For the remaining data sets, overall mean reaction times were calculated. There was a main effect of placeholders on reaction time, F (1, 58) = 8.37, p = .005, η_p^2 =.126, and age group, F (1, 58) = 39.73, p < .001, η_p^2 =.406. As shown in Table 4.4, overall, older adults had slower mean response times compared to younger adults. The interaction between placeholders and age group was non-significant, F (1, 58) = 0.99, p = .323, η_p^2 =.017.

Table 4.4. *Mean response times (ms) for placeholder absent and present conditions*.

	Younger	Older
Placeholder Absent	*M* = 354(*SD* = 38)	*M* = 440(*SD* = 72)
Placeholder Present	*M* = 363(*SD* = 47)	*M* = 459(*SD* = 70)

Next, IOR magnitude was compared between age groups for placeholder present and absent conditions. As shown in Figure 4.5, for the placeholder present condition, a mixed ANOVA revealed a main IOR effect, F(1, 58) = 104.74, p < .001, η_p^2= .644, and a main effect of age group on response time, F(1,58) = 36.18, p < .001, η_p^2= .384. Critically, the interaction between IOR magnitude and age group was non-significant, F (1, 58) = 1.74, p =.193, η_p^2= .029, suggesting that the IOR effect was similar for both age groups in the presence of placeholders (M_{cued_older} = 511ms, SD_{cued_older} = 89ms, M_{uncued_older} = 459ms, SD_{uncued_older} = 71ms, M_{cued_younger}

= 403ms, SD_{cued_younger} = 56ms, $M_{uncued\_\text{younger}}$ = 362ms, $SD_{uncued\_\text{younger}}$ = 49ms). For the placeholder absent condition, a different pattern of results emerged, where there was a main effect of valid versus invalid trials, $F(1,58) = 11.14$, $p = .001$, $\eta_p^2 = .161$, age group, $F(1, 58) = 37.09$, $p < .001$, $\eta_p^2 = .390$, and, crucially, an interaction between trial type and age group on response times, $F(1, 58) = 6.38$, $p = .014$, $\eta_p^2 = .099$. This suggests that the IOR effect differed between age groups when placeholders were absent. Follow-up paired samples *t*-tests indicated that while there was a significant IOR effect for the older adult group, $t(29) = 3.40$, $p = .002$, $d = 0.64$ (M_{cued_older} = 462ms, SD_{cued_older} = 83ms, M_{uncued_older} = 435ms, SD_{uncued_older} = 73ms), this was not apparent for the younger adult group, $t(29) = 0.804$, $p = .428$, $d = 0.157$ (M_{cued_younger} = 356ms, SD_{cued_younger} = 46ms, $M_{uncued\_\text{younger}}$ = 352ms, $SD_{uncued\_\text{younger}}$ = 38ms).

Nonetheless, visual inspection of Figure 4.6 provides a possible explanation for this null finding. As can be seen, similar to Experiment 1, the younger adult group appeared to respond faster at the cued, compared to uncued locations. This is contradictory to what is expected in a typical IOR paradigm. While in Experiment 1 we speculated that this pattern of results may have resulted from unequal cue-target probabilities, resulting in implicit learning, this factor was ruled in out in Experiment 2. Thus, it is unclear why younger adults showed this pattern of results here. One possible explanation is due to the long-time delay between the cue and the target. While IOR effects are thought to be equivalent for younger and older adults at this cue-target delay, it is possible that here, younger adults' attention reoriented to the originally cued location following the long delay. In turn, this may have minimised the sensitivity of the pooled IOR magnitude measure to detect valid trial versus invalid trial effects. This is because the pooled IOR magnitude measure averaged over all of the possible non target locations which could lower the sensitivity of the measure to detect magnitude differences. Thus, to further explore IOR effects in Experiment 2, two secondary repeated measures analysis for the placeholder absent condition were run, which measured response times changes over all possible cue target distances for older and younger adult groups separately. In both analyses, sphericity assumption was violated, χ^2_{older} (44) = 116.58, p < .001, $\chi^2_{younger}$ (44) = 68.17, *p* = .013, and was corrected for using a Greenhouse-Geisser correction. The analyses revealed that both the younger and older adult groups experienced an IOR effect, F_{old} (9, 29) = 9.57, *p* < .001, η_p^2= .248, F_{young} (9, 19) = 4.67, *p* < .001. η_p^2= .139. Altogether, this means that there was a significant IOR magnitude effect for both groups, whereby participants were generally slower at detecting targets around the cued locations, compared to when targets fell at uncued locations further away. This is important as it confirms IOR occurred for both groups, subserving the main analysis where individual inhibitory slopes, reflecting attentional spread, are compared for the older and younger adults.

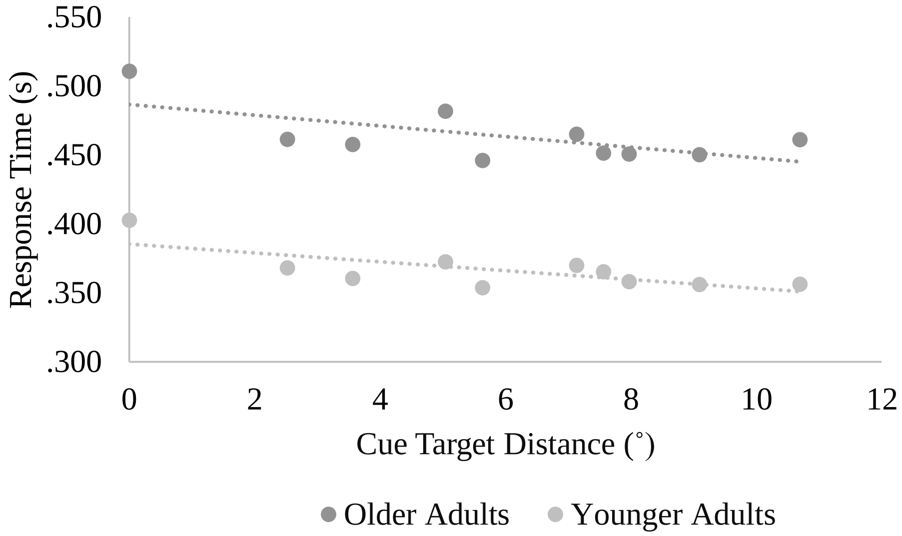

Figure 4.5. Experiment 2: Mean response time as a function of cue-target distance for the younger and older adult groups in the placeholder present condition.

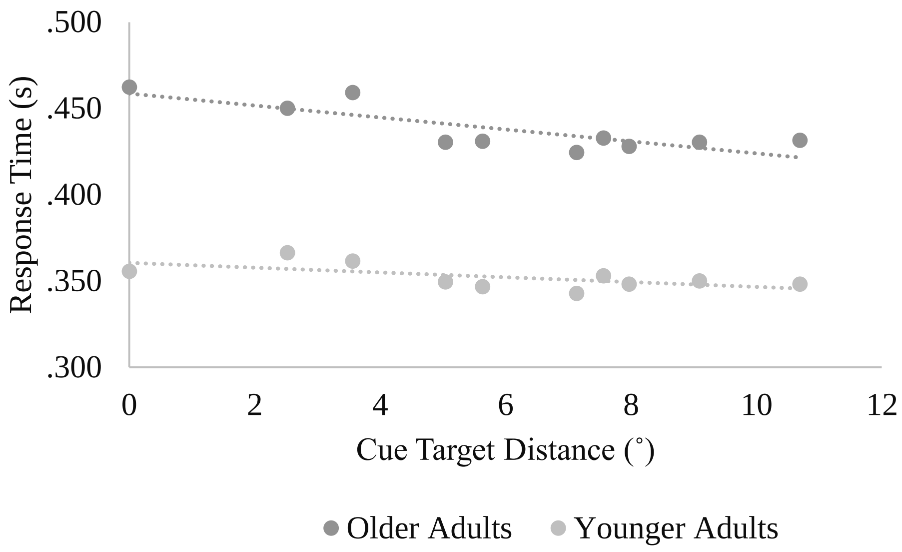

Figure 4.6. Experiment 2: Mean response time as a function of cue-target distance for the younger and older adult groups in the placeholder absent condition.

Age Differences in Attentional Slope

To calculate individual participant inhibitory slopes for both the placeholder present and absent conditions, screened response time data were submitted to a linear regression, where cue-target distance was the independent variable, and response time was the dependent variable. A mixed ANOVA, with placeholders as a within subjects measure, and age group as a between subjects measure was then run to compare inhibitory slopes for the younger and older adults across the two experimental conditions. Overall, there was no main effect of placeholder presence versus absence, $F(1, 58) = 0.60$, $p = .443$, $\eta_p^2 = .010$, age group, $F(1,58) = 2.56$, $p = .138$, $\eta_p^2 = .037$, or interaction between placeholders and age group, $F(1, 58) = 2.50$, $p = .119$, $\eta_p^2 = .041$ on IOR slopes. However, given the relatively small sample size of the current study, it is possible that the reason for these null findings is a lack of statistical power. Furthermore, eye health, and mean response times in the placeholder absent and present conditions were not included as covariates here. This is because mean response times differed significantly as a function of both placeholder conditions, making it inappropriate to calculate a combined response time measure to include in the analysis. Consequently, it is possible that the omnibus ANOVA, comparing slopes across placeholder conditions and age groups had a lowered sensitivity to detect potential age differences.

To address this, we conducted analyses separately for the placeholder present, and placeholder absent conditions, while controlling for age differences in mean response time and eye health. For the placeholder present condition, neither mean response time, F (1, 56) = 1.09, p = .302, η_p^2= .019, eye health, F (1, 56) = 0.37, p = .570, η_p^2= .006, nor age group, F (1, 56) = 0.59, p = .446, η_p^2= .010, significantly influenced inhibitory slopes (M_{older} = -.09, SD_{older}= .07, $M_{younger}$ = -.10; $SD_{younger}$ = .07). This supports Langley et al. (2011), and Hartley and Kiely (1995), who found that when placeholders are present in the visual display, age differences in inhibitory slope are not observed.

Crucially, when placeholders were absent from the display, there was a main effect of age group on inhibitory slopes, F (1, 56) = 5.60, p = .021, η_p^2= .091, where older adults had steeper slopes compared to younger adults (M_{older} = -.13, SD_{old}= .10, $M_{younger}$ = -.08; $SD_{younger}$ = .08). This provides strong, converging evidence with Experiment 1, that when placeholders are removed from the visual display, age differences in attentional spread emerge. The effects of mean response time, F (1, 56) = 0.76, p = .388. η_p^2= .013, and eye health, F (1, 56) = 0.87, p = .356, η_p^2= .015, were non-significant,

When eye health and mean response time were not controlled for, there were no age differences in inhibitory slopes for the placeholder present condition, t(58) = 0.104, p = .917, d = 0.03. Critically however, similar to Experiment 1, in the placeholder absent condition, there was a marginally significant influence of age group on inhibitory slopes, t (58) = -1.920, p = .060, d = 0.50, where older adults had a steeper slope compared to younger adults This indicates that when placeholders were absent from the visual display, older adults had a restricted attentional spread compared to younger adults. Thus, taken together, this is consistent with the results in Experiment 1, and provides converging evidence that placeholder presence versus absence influences the relationship between ageing and the slope of inhibition.

Finally, we combined the data from Experiment 1 and Experiment 2 placeholder absent conditions and reran our main analyses comparing inhibitory slopes for the younger and older participant groups[4]. To equate the experiments as much as possible, for Experiment 1, we used the inhibitory slopes which were calculated when eye movements were not controlled for. The model included age group and Experiment as between subject's effects, and mean response time and eye health as covariates. This allowed us to have higher statistical power to detect any potential age effects on attentional spread. Overall, this analysis revealed a main effect of age group on inhibitory slope, F (1, 119) = 9.88, p = .002, η_p^2 = .077. No other effects in the model were significant. As a whole, this provides convincing evidence that age group significantly influences inhibitory slopes, and thus, the spread of attention.

4.7. General Discussion

The aim of the current study was to better understand potential age differences in the spread of IOR, so to explore the relationship between healthy ageing and attentional distribution more generally. Previous studies have shown that the spatial spread of inhibition is largely preserved in healthy ageing. However, these studies employed placeholder stimuli to cue attention. This may have restricted attentional spread, and lowered the sensitivity of the paradigm to detect age differences. To address this, Experiment 1 compared age differences in inhibitory spread when placeholders were absent from the display. Experiment 2 then directly compared the influence of placeholder presence versus placeholder absence on inhibitory spread for both younger and older adults. Across both studies, our data indicates that when placeholders were absent from the visual display, inhibitory spread differs between younger and older adults, whereby attention is restricted for the older adult group. Further, Experiment 2 allowed us to control for age related sensory changes, thus allowing us to conclude that the observed age differences in the current data are likely to be driven by differences in attentional processing.

That older and younger adults show differences in inhibitory spread is consistent with a range of studies using different methods to compare age differences in attentional distribution (Gottlob & Madden, 1999; Greenwood & Parasuraman, 1999, 2004; Hüttermann et al., 2012; Kosslyn et al., 1999; Pesce, et al., 2005). These studies typically require participants to process stimuli in disparate locations of the visual field simultaneously. For example, Hüttermann and colleagues recently developed a breadth of attention test to measure differences in older and younger adult populations (Hüttermann et al., 2012). Following two instantaneous circular cues, participants were asked to identify the presence of target shapes in two spatially offset locations, equidistant from a central fixation cross. The maximum limit of attentional distribution was defined as the spatial distance between the two cued arrays where participants could identify the correct number of targets at an accuracy greater than 75%. Nonetheless, by presenting targets at large spatial displacements in chorus, it was possible in this study, that rather than spreading attention, participants were shifting, or splitting their attentional resources between the two locations. Further, given that to measure the upper limits of attentional distribution, stimuli had to be presented at increasingly larger retinal eccentricities, it is not clear whether the observed age differences were a factor of visual declines, attention, or both. Given these uncertainties, the current study adds a unique piece of information to the literature, as it clearly demonstrates that neither peripheral stimuli, nor simultaneous location processing are necessary to observe age differences in attentional distribution.

The finding that younger adult versus the older adult group have different attentional distributions, where the younger adult resources encompass a broader range of the visual field, is likely to be based on declines in working memory with ageing (McDowd & Shaw, 2000; Zanto & Gazzaley, 2014). Indeed, Kreitz et al. (2015) have demonstrated a sizable positive correlation between performance in attentional spread tasks, and working memory tasks, where low working memory capacity predicted narrower attentional spread. Likewise, working memory capacity and attentional control have been related in a variety of tasks which indirectly involve a flexible allocation of attentional distribution (e.g. Bleckley et al., 2003; Heitz & Engle, 2007; Redick & Engle, 2006; Rolle, et al., 2017). One recently-identified means of testing the relationship between working memory capacity and attention spread is to develop training programs that aim to improve working memory capacity, and subsequently, attentional flexibility (Rolle et al., 2017). That is, if working memory capacity improves with training, one would also expect to see a subsequent improvement on measures of attentional distribution. Indeed, by training both younger and older adults on a “distributed attention task”, Rolle et al. (2017) found marked improvement in both the capacity to focus and spread attention, as well as improvement in the performance of a spatial working memory task, after generalised slowing was accounted for. This strongly suggests that the processing of working memory and attention are tightly linked, and can explain the pattern of results observed in the current study. However, as we did not directly measure working memory capacity, nor did we measure and manipulate attention in a similar manner to Rolle et al. (2017), this conclusion can only be made tentatively. Future work exploring the relationship between working memory capacity, working memory load, and the distribution of inhibition in perceptual tasks is necessary to understand these potentially subtle relationships.

In the current study, a relatively broader distribution of attention would be most beneficial for efficient performance in the primary task (i.e. detecting the white circle). This is because the target could appear over a relatively large area of the central visual field, therefore, by distributing cognitive resources broadly, an individual would be more likely to detect the target on any given trial. Correspondingly, there is an obvious disadvantage to restricting the distribution of attention. This would require the participant to spend more time covertly scanning the visual field in order to detect a target. Therefore, the younger adult group's broader spread of attention may reflect an efficient way to complete the task.

In comparison, the older adults' use of a restricted attentional spread may have reflected an adaptation to physiological changes in the visual system. For instance, due to decreased peripheral acuity, older adults may have narrowed their attentional spread, thus experiencing attention akin to "tunnel vision" (Owsley, 2011). However, for the older adult population, there is a potentially positive role that a narrower distribution of attention would have: the relative increase in perceptual sensitivity that focused attention offers. Specifically, the zoom lens model predicts that compared to a broad attentional spread, a narrow spread of attention will increase the visual systems capacity to resolve spatial detail (Eriksen & James, 1986). Numerous behavioural and imaging studies support these claims (Balz & Hock, 1997; Goodhew et al., 2017, 2016; Hock, Balz, & Smollon, 1998; Müller et al., 2003). Consistent with this notion of compensation, it is well known that the visual system declines with ageing, for both the physical optics of the eye and atrophy of occipital regions in the brain (Owsley, 2011). For example, older adults show decreased spatial contrast sensitivity with ageing, and more internal perceptual noise (Elliott et al., 1990; Kline, Schieber, Abusamra, & Coyne, 1983; Owsley, Sekuler, & Siemsen, 1983; Sekuler & Owsley, 1982; Tulunay-Keesey, Ver Hoeve, & Terkla-McGrane, 1988), as cited in Owsley, 2011). If focused attention increases perceptual sensitivity, via processes such as contrast gain, it is therefore possible that a relatively narrow spread of attention may be more beneficial for the ageing brain, regardless of task, via a compensation of the declining visual system. This potential benefit of a smaller spread of attention is broadly consistent with compensatory models of ageing. Reuter-Lorenz and Cappell (2008) have developed a model of healthy ageing which posits that potential deficits of the ageing brain may be compensated for by the brain "working harder", recruiting more neural resources to complete behavioural tasks to a satisfactory standard (Compensation-related utilization of neural circuits hypothesis, or CRUNCH). It is postulated that increases in neural activity would help to reduce the increased levels of internal perceptual noise that older adults encounter (Reuter-Lorenz & Cappell, 2008). For instance, Grady et al. (1994) compared levels of neural activation for younger and older adults in perceptual processing of spatial locations and faces. They found older and younger adults to have equivalent behavioural performance, but differential neural activation, where in comparison to younger adults, older adults exhibited more activation of the frontal areas of the brain. Here, we suggest that a focused spread of attention may be related to such compensatory activity.

To conclude, our study provides strong evidence that ageing influences the capacity to distribute attentional resources in an IOR task. This relationship holds, when both placeholders are removed from the visual display, and when eye movements are controlled for. Two potential reasons for these age differences may be differences in working memory capacity, and the resolving power of the visual system. Future work should more closely explore the link between working memory capacity and inhibitory spread, as well as the viability of training programs to enhance attentional flexibility.

4.8. Notes

1. We thank an anonymous reviewer for these insights
2. We thank an anonymous reviewer for this suggestion
3. Two participants were erroneously run on only 50% of placeholder absent trials. However, given that the participants still completed 120 trials, we included their data in analyses. Further, one participant completed a slightly modified version of the experiment. For this participant, in both the placeholder present and absent conditions, two of the possible 100 cue-target combinations were not completed. These trials were replaced with a random selection of the remaining 98 cue-target combinations.
4. When adding the data from Experiment 1 and Experiment 2 for combined analyses, we note that a small number of participants completed both Experiment 1 and Experiment 2.

Chapter 5: Does Cultural Background Predict the Spatial Distribution of Attention?

5.1. Foreword

Chapter 4 of the thesis tested whether healthy ageing influenced attentional scale. Across two experiments healthy ageing reliably affected attention spread, where older adults had a narrower scale of attention compared to younger adults. In particular, it was demonstrated that the IOR task was a highly sensitive measure of individual differences in attention distribution when placeholders were removed from the visual display. In Chapter 5, the thesis aimed to test the effect of cultural background on attention distribution. Those from East Asian cultures tend to process the world holistically, attending to the associations between elements in the environment. In contrast, those from Western cultural backgrounds are more likely to process the world analytically, focusing on individual details (Nisbett, Peng, Choi, & Norenzayan, 2001). These different thought styles might influence how individuals distribute spatial attention, and interact with the visual world (Boduroglu et al., 2009). Therefore, exploring potential differences in attentional distribution will reveal if, and how cultural experience might shape cognitive mechanisms. Therefore, in Chapter 5, the IOR task was used to measure the spatial distribution of attention for East Asian and Western participants.

Australian National University

Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

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M. EDWARDS		01/03/2019
Jolene Cox		01/03/2019
Rebecca Lawrence		01/03/2019

Endorsed

Print Name	Signature	Date
Stephanie Goodhew (Primary Supervisor)		01/03/2019
MARK EDWARDS (Delegated Authority)		01/03/2019

5.2. Abstract

The current study aimed to explore cultural differences in the covert spatial distribution of attention. In particular, we tested whether those born in an East Asian country adopted a different distribution of attention compared to individuals born in a Western country. Previous work suggests that Western individuals tend to distribute attention narrowly and that East Asian individuals distribute attention broadly. However, these studies have used indirect methods to infer spatial attention scale. In particular, they have not measured changes in attention across space. Furthermore, recent studies have failed to replicate previously observed cultural differences in visual cognition, calling into question the validity of these original effects. To address this, in the current study, we used an inhibition of return (IOR) paradigm which directly measured changes in attention across space, while controlling for eye movements. The use of the IOR task was a significant advancement, as it allowed for a highly sensitive measure of attention distribution compared to past research. Critically, using this new measure, we failed to observe a cultural difference in attention distribution. Instead, individuals from East Asian countries and Western countries adopted a similar attention spread. However, we did observe a cultural difference in response speed, whereby Western participants were relatively faster to detect targets in the IOR task. This relationship persisted, even after controlling for individual variation in attention slope, indicating that factors other than attention distribution might account for cultural differences in response speed. Therefore, this study provides robust, converging evidence that group differences in attentional processing do not drive cultural variation in response speed.

Key words: visual attention; spatial attention; space-based attention; attentional breadth; inhibition of return

5.3. Introduction

Humans use spatial attention to filter visual information, triaging certain stimuli for enhanced processing at the expense of others (Carrasco, 2011; Desimone & Duncan, 1995; Posner, 1980; Posner & Cohen, 1984). Here, we are interested in individual differences in the *covert* distribution of spatial attention (e.g. Lawrence et al., 2018). For example, attention can be narrowed to focus on a small region of the visual field. Alternatively, it could be expanded to cover more of the visual field. This is an important function, as narrow attention improves performance on tasks requiring the processing of fine spatial detail (e.g. Balz & Hock, 1997; Eriksen & James, 1986; Eriksen & Yeh, 1985; Goodhew et al., 2017, 2016; Mounts & Edwards, 2017), while broad attention improves our ability to process ensemble statistics, and detect changes in the environment (e.g. Chong & Treisman, 2005; Pringle et al., 2001). Although objects of different sizes can play a critical role in changing the spatial distribution of attention, attentional scaling is not purely a form of object-based attention since the effects generalise beyond the object of induction to others within a given spatial extent (Goodhew & Edwards, 2017). Therefore, we conceptualise it as a form of spatial attention.

Broadly, research on attentional scaling has focused on understanding the influence of scaling on visual perception (e.g. Goodhew et al., 2017, 2016), measuring the flexibility of attentional scaling, or understanding individual differences in how attention is distributed (i.e. narrowly or broadly). Flexibility refers to the capacity to expand and contract attentional resources across the visual field relative to task demands. It is typically indexed by measuring the efficiency of individuals to change their scale of attention from narrow to broad, or broad to narrow (Jefferies & Di Lollo, 2009; Jefferies, Enns, & Di Lollo, 2014; Shulman & Wilson, 1987). Cultural differences in attention flexibility have been shown between British and Himba observers (a group from remote Namibia), where compared to British observers, Himba observers showed a greater ability to attend to global and local information in the presence of distraction (Caparos, Linnell, Bremmer, de Fockert & Davidoff, 2013). In contrast, spatial attention scaling is a measure of whether an observer distributes attention narrowly or broadly across a region when minimal task demands are imposed (e.g. Bennett & Pratt, 2001; LaBerge, 1983; Lawrence et al., 2018).

Measuring group and individual differences in attentional distribution can give useful insight regarding how experience, cognition and vision interact. For example, Wilson et al. (2016) found that stable individual differences in personality predicted spatial attentional distribution. Participants who scored highly on trait Conscientiousness tended to adopt a narrow spread of attention. In contrast, those who scored highly on an Openness to Experience scale tended to adopt a broad spread of attention. Furthermore, Lawrence et al. (2018) recently demonstrated that a reliable age difference in attentional spread exists, where older adults distributed attention narrowly compared to younger adults. In the current study, we were interested in understanding how another relatively stable factor, cultural background, influences attentional distribution. In particular, we tested whether those born in countries with a predominantly East Asian culture versus those born in countries of predominantly Western culture differed in their spatial attentional distribution.

Over the past two decades, an accumulating body of research suggests that there are cultural differences in cognition (e.g. Boduroglu & Shah, 2017; Goh et al., 2007; Ketay, Aron, & Hedden, 2009; Masuda & Nisbett, 2006). For example, Nisbett et al. (2001) identified that those from East Asian and Western cultural backgrounds might show differences in thinking styles. Specifically, those from East Asian cultural backgrounds were proposed to value role relations, and thus would show a holistic cognitive style, processing relational and contextual elements of the world. In contrast, those of a Western cultural background were more likely to process the world analytically, focusing on individual objects and their details. Cultural differences in attention have been shown in the framed line task (Kitayama, Duffy, Kawamura, & Larsen, 2003), the processing of foreground and background objects (Goh et al., 2007), and even the way in which children construct pictures (Senzaki, Masuda, & Nand, 2014).

Boduroglu et al. (2009) proposed that these differences in cognitive styles may be due to underlying cultural differences in attentional processing and working memory. Due to their holistic thinking style, East Asian individuals would tend to adopt a broad spread of attention, while Western individuals with a more analytical thought process would tend to adopt a narrow spread of attention. The authors tested this idea by using a change detection task. (Figure 5.1). Here, participants were shown four coloured blocks arranged cardinally around fixation across two time-intervals. In the second time interval, one of the blocks could change colour, and participants were required to detect this change. Critically, to measure the distribution of attention adopted by the two culture groups, between the two time intervals, the spatial area over which coloured blocks appeared was also manipulated. That is, the blocks either expanded out to encompass a wider spatial location (broad attention, Experiment 1), contracted to cover a smaller spatial location (narrow attention, Experiment 2), were displaced randomly, or remained in the same location (control conditions). Further to this, occasionally, a probe task was included in between trials, to measure response times to detect a centrally presented target. When the colour blocks expanded, East Asian participants outperformed American participants. In contrast, when the colour blocks contracted, American participants outperformed the East Asian participants. Finally, in the probe task, East Asians had slower response times to detect the central target. Taken together, this suggests that the two cultural groups utilised different distributions of spatial attention to complete the change detection task, where East Asians utilised a broad spread of attention, and Americans adopted a narrow spread of attention.

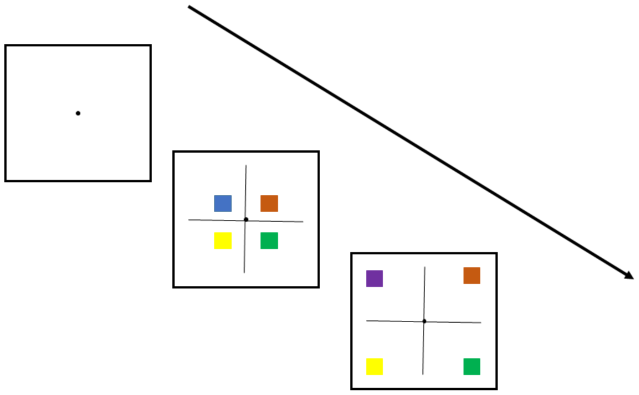

Figure 5.1. Example of the stimuli used in Boduroglu et al. (2009). The condition above is a change trial, where the location of the colour blocks expands (i.e. broad attention).

Although the study by Boduroglu et al. (2009) provided a valuable framework for understanding cultural differences in attention distribution, a later study conducted by the same research group failed to replicate this finding (Boduroglu & Shah, 2017). Again, the authors used the change detection task with an East Asian and a Western cultural group. However, instead of finding East Asians to outperform Western participants in the "Expand" condition, performance in the Expand and Contract conditions did not vary across cultural groups. Although the authors suggest this may be due to lower overall performance in the task by both cultural groups, the lack of interaction between culture and performance on the different conditions of the change detection task suggests that this particular task may not be a reliable measure of differences in the spatial distribution of attention. Furthermore, a recent pre-registration study conducted by Hakim et al. (2017) only partially replicated Boduroglu et al. (2009). Indeed, in some instances, using Bayes analysis, the authors found evidence against the originally predicted cultural differences. Finally, across all studies using this paradigm, eye movements were not controlled for (i.e. participants were able to use overt attention). This is an important issue to consider, as some research has shown cultural differences in East Asian and Western participants' eye movements when viewing a scene (e.g. Chua et al., 2005; Kelly, Miellet, & Caldara, 2010; Rayner, Li, Williams, Cave, & Well, 2007, although see Rayner, Castelhano, & Yang, 2009; Evans, Rotello, Li & Rayner, 2009 who found culture to have minimal influence on eye movement patterns). For example, Chua et al. (2005) found that while Chinese participants tended to fixate more on background objects in complex scenes, American participants moved their eyes more towards central objects. Therefore, based on this research, it is possible that in Boduroglu et al. (2009) differences in change detection performance may be due to the use of different eye movement strategies, rather than differences in covert spatial attention spread per se.

Given that the change detection task described above is not a typical method used to measure attentional distribution, and that the results using this paradigm have been conflicting, the implications of those results for cultural differences in attentional distribution remains unclear. A far more common stimulus type used to investigate attentional breadth are Navon letter stimuli (Navon, 1977, 2003). Navon letters are compound stimuli, where a larger letter is made up of smaller local letters (Figure 5.2). In a divided attention version of the task, participants respond to the presence of a target letter (which is presented at the global or local level). The assumption is that when responding to the global level, an individual's attentional distribution is larger, and when responding to the local level, attentional spread is narrow. An individual's attention spread is inferred by measuring response times to both global and local letter targets, and consequently, measuring whether they had a preference for processing stimuli at the global or the local level (i.e., a global preference is calculated by taking the local level response times minus global level response times. A positive number indicates a global preference).

McKone et al. (2010) used Navon letters to measure global and local processing preferences for those of Eastern and Western backgrounds. Note that the authors did not specifically intend to measure spatial attention; instead, they measured global and local preferences for Navon processing. Overall, the authors found East Asian participants to have a stronger global preference compared to Western participants. This suggests that East Asian participants spread their spatial attention across a relatively broader area, to the global level, while Western participants may have adopted a narrower spread of attention. Converging evidence for this conclusion came from another study in which participants were primed to think interdependently versus independently, and differences in Navon letter processing emerged. In particular, interdependent thinking styles predicted a global preference, and independent thinking styles predicted a local preference (Lin & Han, 2009). This distinction is important, as East Asian cultures are typically associated with an interdependent thinking style, and Western cultures with an independent thinking style (Gardner, Gabriel, & Lee, 1999; Markus & Kitayama, 1991).

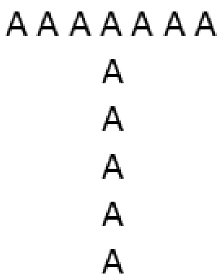

Figure 5.2. Example Navon Stimulus. The local level letters (As) are arranged to compose a global level letter (T).

Again, however, although these studies indicate that culture might shape spatial attention distribution, Navon figures may not be an optimal stimulus for directly inferring the spread of attention. The attentional mechanisms underlying Navon processing are diverse, and likely involve more than solely spatial attentional scaling (Flevaris, Bentin, & Robertson, 2011; Navon, 2003; Poirel, Pineau, & Mellet, 2008; Robertson et al., 1993). Indeed, early work by Robertson et al. (1993) suggests that while attentional scale can influence which level of Navon letters are attended, categorical attention may also play a role. That is, while one could attend to different spatial regions that global and local elements encompass, for a Navon stimulus, one could also categorically attend to either the global, low spatial frequency elements of the stimulus, or the local, high spatial frequency elements, regardless of the distribution of attention (Shulman & Wilson, 1987). This is akin to selectively attending to features *within* an attended spatial region. Importantly, Robertson and colleagues showed that both categorical and spatial attention could influence the processing of Navon letters. Therefore, in McKone et al. (2010), as participants were allowed to view Navon stimuli freely, it is unclear whether the two groups used only spatial attention, categorical attention, or a combination of the two. Furthermore, similar to the change detection task, recent research has failed to replicate a cultural difference in Navon letter processing (Hakim et al., 2017). As such, the Navon task may not be the most appropriate tool to use when measuring cultural differences in spatial attention.

Finally, one recent paradigm which has been used to claim cultural differences in attention distribution is the functional field of view task. Here, Boduroglu and Shah (2017) demonstrated cultural differences in performance on a functional field of view task, which the authors conceptualised as a measure of attention spread and spatial resolution. Participants were required to identify the location of targets which were shown for short periods across a broad range of eccentricities, demarcated by 24 placeholder stimuli. Lower accuracy scores and longer response times were interpreted as participants adopting a broader spread of attention. This assumption is based on the zoom lens model. This model predicts that a larger attentional distribution leads to lower processing efficiency within the attended region (Eriksen & James, 1986). Therefore, worse performance in the functional field of view task was assumed to reflect a broader attention scale. Overall, Boduroglu and Shah (2017) found that across all eccentricities, East Asian participants were less accurate, and slower to respond than Western participants. These accuracy and response time differences were interpreted as East Asian participants adopting a broader attentional spread. Furthermore, the authors analysed the types of location identification errors participants made, finding that when Western participants made location errors, on average, the misidentified location was close to the actual target location. In contrast, when East Asian participants made location errors, the errors were more randomly distributed throughout the 24 placeholder locations. The authors took this as further evidence that East Asian participants adopted a broad spread of attention.

Nonetheless, this interpretation assumes that all targets within a task fall within the *attended region*. Although targets will be detected relatively efficiently within a narrow compared to broad attention distribution, targets falling outside of this region should also be detected relatively slowly and inaccurately. Therefore, an equally plausible argument in this paradigm is that East Asians were slower/less accurate to respond because they had a *narrow* distribution of attention which they randomly shifted across the visual field. In the functional field of view task, many targets may have fallen outside of the distribution of attention, leading to overall slower response times as participants shifted their attentional resources across the visual field. This distribution of attention could also lead to a higher proportion of random errors.

Furthermore, the utility of the functional field of view as a measure of attentional distribution has recently been questioned, with research suggesting that the task measures the speed of information processing and attentional control processing more generally rather than the spatial distribution of attention (Cosman, Lees, Lee, Rizzo, & Vecera, 2012; Lunsman et al., 2008; Matas, Nettelbeck, & Burns, 2014). Finally, a number of studies report stable differences in response time generally, which may not be linked to differences in spatial attention (e.g. Brebner & Cooper, 1974; Deary, Der, & Ford, 2001; Der & Deary, 2006; Edman, Schalling, & Levander, 1983; Goodhew & Edwards, 2019; Lahtela, Niemi, & Kuusela, 1985; Schmitz, Daly, & Murphy, 2007; Sheppard & Vernon, 2008). Therefore, while

Boduroglu and Shah (2017) provide promising evidence of a cultural difference in attentional distribution, whereby East Asian participants adopt a broader spread of attention, a more nuanced method of measuring spatial attention is required for cleaner conclusions.

Taken together, the above literature review highlights the need for further examination of the potential role of culture in predicting spatial attentional spread. While Boduroglu et al.'s (2009) change detection task initially showed cultural differences in attentional distribution, two replications of this study produced conflicting findings, bringing into question the reliability of the measure as a method to infer differences in attention. Divided attention Navon tasks have also been used to tap into attentional processing (McKone et al., 2010), however, it is unclear whether differences in Navon letter processing relate to changes in spatial attention, feature-based attention, or both. Furthermore, a recent pre-registered study attempting to replicate the Navon letter effect failed to observe a cultural difference. The functional field of view task used by Boduroglu and Shah (2017) provides promising evidence that cultural differences in spatial attention and resolution exist, however, given that the functional field of view only measures overall response time and accuracy, a more direct measure of attention spread will allow for more definitive conclusions to be made regarding the distribution of attention across space. Finally, given that there potential cultural differences in eye movement patterns (Chua et al., 2005), as the studies described above did not control for eye movements, it is unclear whether culture influences overt attention, covert attention or both.

As an alternative to the tasks described above, a powerful method used to tap into group differences in attentional processes is the Posner cueing paradigm (Posner & Cohen, 1984; Posner et al., 1985). The Posner paradigm was initially developed to measure the processes of attentional facilitation and inhibition following a spatial *shift* of visual attention. The method is summarised in Figure 5.3. Participants are first required to fixate at the centre of the screen. An uninformative peripheral cue then briefly appears, which automatically attracts attention to the location of the cue. Finally, a target to be detected appears, either at the cued location or at an opposing location (uncued location). Target detection response times are calculated for cued, and uncued trials to measure the dynamics of spatial attention facilitation and inhibition. The key variable of interest is the time between the cue and target presentation. When the cue and target appear quickly after one another (less than 300ms), participants are quicker at detecting the target at the cued location. However, when there is a relatively long gap in time between the cue and target (greater than 300ms), response times at the cued location are slower compared to uncued location suggesting attentional inhibition.

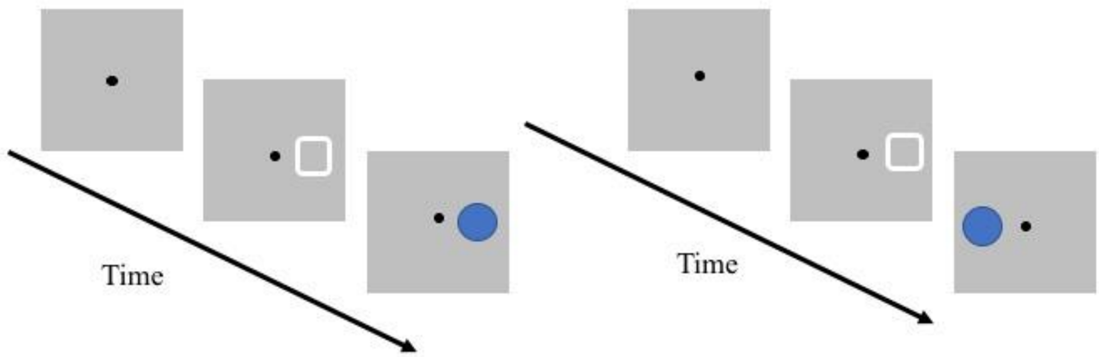

Figure 5.3. Example of the Posner Cueing Paradigm. Attention is attracted to the white square (the cue). A blue circle (the target) appears at either the cued (left) or uncued (right) location. Differences in response time for the two locations reflect attentional facilitation and inhibition.

While the Posner paradigm was designed to measure the influence of *shifts* of attention, it has since been adapted to measure group differences in attentional *spread* (e.g. Wilson, Lowe, Ruppel, Pratt, & Ferber, 2016; Lawrence et al., 2018). In order to do so, the spread of attentional inhibition around a cued location is mapped by measuring response times for targets appearing at varying distances from the cue (Figure 5.4). For example, when measuring attentional inhibition, response times are slowest at the cued location. However, as the distance between the cue and target increases, response times become gradually faster (e.g. Bennett & Pratt, 2001; Downing, 1988; Klein, Christie, & Morris, 2005; LaBerge, 1983; Taylor, Chan, Bennett, & Pratt, 2015). This release from inhibition across space can be used to infer the distribution of attention by exploring the rate of change in response times for different cue-target distances (i.e. the attentional slope). When response times decrease sharply across cue-target distance, an individual's attention resources are assumed to be distributed over a relatively small spatial region, suggesting they have adopted a narrow focus of attention. In contrast, when response times decrease relatively shallowly across cue-target distance, it is thought that an individual has distributed attention across a larger region of the visual field (Wilson et al., 2016). Previous research has used inhibition paradigms to measure attentional distribution, as the paradigm allows for a higher degree of sensitivity in measuring individual differences, giving enough time for somewhat sluggish attentional processes to develop (Lawrence et al., 2018; Wilson et al., 2016). This is particularly important for the current study, as previous work has observed cultural differences in attention flexibility, as well as response speeds in visual attention tasks (e.g. Borudoglu et al., 2009; Caparos et al., 2013).

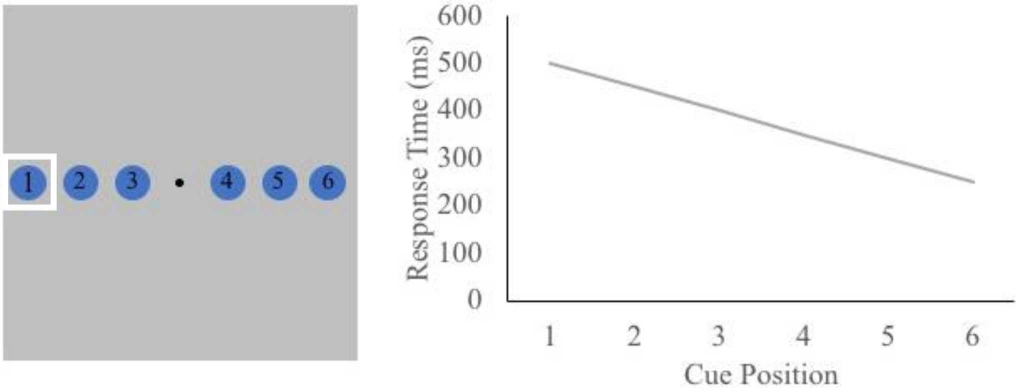

Figure 5.4. Relationship between distance and target detection speeds when measuring attentional inhibition. Left: experimental paradigm. The white square represents the cue. The blue circles represent differing distances the target may appear at. Right: Hypothetical results. As the distance between the cue and target increases, target detection speeds gradually decrease. The slope of this decrease is assumed to reflect attentional distribution.

A recent study conducted by Lawrence et al. (2018) used the attentional inhibition paradigm to test whether healthy ageing influenced spatial attention spread. Here, attention was directed to one of four potential locations, using a bright, briefly presented (100ms) ring. After 1315ms, a target appeared at varying distances from the cue. Participants responded to the target as quickly as possible by pressing the spacebar. Regression coefficients were calculated for each participant, which measured the change in response time across increasing cue-target distances. These coefficients were compared for the two age groups. Overall, it was found that older adults had a steeper slope of inhibition, suggesting that the older adult group adopted a relatively narrow focus of attention. This finding was replicated in a second experiment, suggesting that the paradigm is an appropriate tool for measuring individual differences in attentional distribution across different times and samples.

Given the robust nature of the attentional inhibition method to measure group differences in spatial attentional distribution, the current study aimed to measure the influence of cultural background on attentional inhibition, and thus, infer potential group differences in covert attentional spread. The attentional inhibition task was mostly similar to that used by Lawrence and colleagues (2018). During the task, participants were instructed to fixate their gaze on the centre of the screen. Further, their eye movements were monitored. This instruction allowed us to ensure that the participants were only using covert attention to complete the task. In line with similar research exploring differences in attentional inhibition with a younger sample, a cue-target interval of 803ms was adopted (Taylor et al., 2015; Wilson et al., 2016).

On each trial, there were four cue locations and 20 possible target locations. Response times for target detection were recorded across ten possible cue-target distances, and individual regression slopes were calculated for each participant, which reflected attentional distribution. Following completion of the attentional inhibition task, participants completed a demographic survey, and autism-like traits scale (Allison, Auyeung, & Baron-Cohen, 2012). This scale was included as those scoring higher in autistic-like traits tend to adopt a narrower distribution of attention (Mann & Walker, 2003).

Given that East Asian participants are thought to process information more holistically, we predicted that those who identify as such would have a relatively broad attention spread. In contrast, Western participants who are more likely to process information analytically, are predicted to adopt a relatively narrow attention spread (Boduroglu et al., 2009). Therefore, compared to Western participants, East Asian participants are likely to have relatively a shallower slope of attentional inhibition across increasing cue-target distances (Figure 5.5).

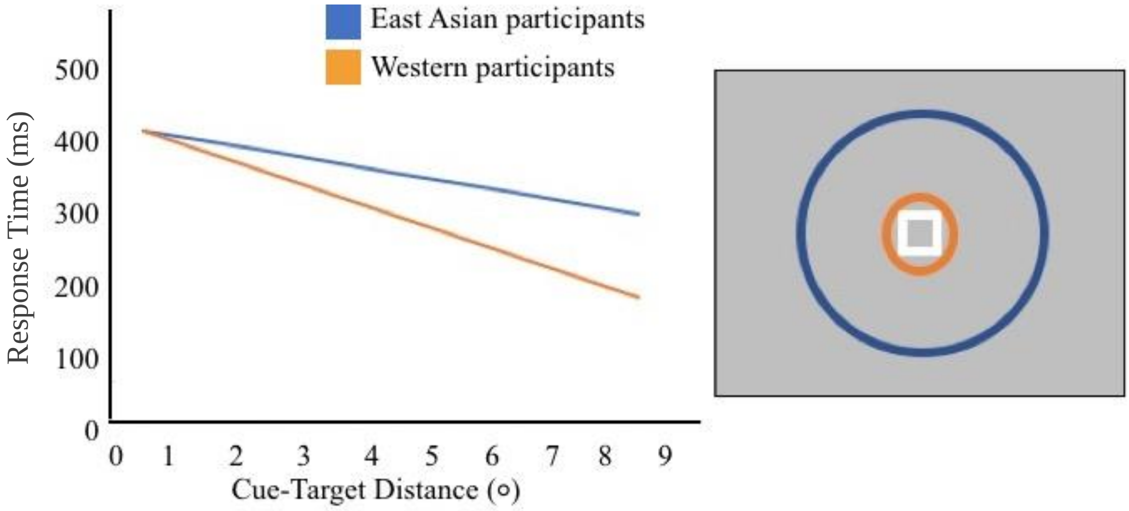

Figure 5.5. Predicted pattern of attentional inhibition (left), and thus, attentional spread around a cued location depicted by the white square (right), for East Asian versus Western participants. The distance between the cue and target is shown on the X axis, and response time is shown on the Y axis. A steeper attentional slope is assumed to infer a narrower distribution of attention (orange circle), while a shallower slope is assumed to infer a broader distribution of attention (blue circle).

5.4. Method

Participants

One hundred and twenty-eight individuals aged between 18-40 years participated in the current study. This sample size was deemed adequate to compare cultural differences in cognition, with past research typically using approximately 30 participants in each group (e.g. Boduroglu et al., 2009). All participants provided written informed consent, and had normal or corrected to normal vision. Participants were recruited on the basis that they self-identified as East Asian or Western. However, in the primary analyses, country of birth was used as the grouping variable for cultural background[1]. One participant did not provide demographic data following participation and was excluded from further analysis. A further six participants did not report their birth county. However, based on responses to other questions in the demographic survey (i.e. which countries have you lived in, and how for how long?), birth country was inferred as being of East Asian or Western origin, and these participants were included in our primary analysis. Finally, six participants were excluded due to experimenter and technical errors during the computer task (e.g., eye-tracker not calibrating). Following exclusions, this left a total sample of 121 participants.

Our culture variable, birth country, was categorised by determining whether a participant's birth country was predominantly of East Asian or Western culture. Participants who were born in Australia (82.7%), England (9.6%), the Netherlands (3.8%), New Zealand (1.9%), or the United States of America (1.9%) were classified as being from a predominately Western cultural background. Participants who were born in China (84.8%), Korea (13.6%) and Japan (1.7%) were classified as being from a predominantly East Asian cultural background. Eight participants who were born in South Asian, or South East Asian countries were not included in final analyses, nor was one participant who was born in South Africa, and one participant born in Morocco. Overall there was a final sample of 111 participants (52 Western, 59 East Asian). Demographic details of these participants are summarised in Table 5.1.

Table 5.1. *Demographic details of the participant sample of the current study.*

	East Asian	Western	p-value
Gender	Female = 41, Male =16	Female = 42, Male= 10	.279
Age (years)	*M* = 21.05(*SD* =1.85)	*M* = 20.21(*SD* = 2.07)	.030
Handedness	RH = 53, LH =,1 A =3	RH = 47, LH =,4 A =1	. 230
Vision	Corrected = 37	Corrected = 12	<.001
Total Years Education	*M* = 16.47(*SD* = 2.64)	*M* = 14.90(*SD* = 1.80)	.001
Self-Identified Culture	East Asian = 56, Caucasian = 1, Other = 2	East Asian = 6, Caucasian = 46, Other = 0	<.001
Strength of Cultural Identity	*M* = 3.69(*SD* = 1.15)	*M* = 3.08(*SD* = 1.05)	.004
Multicultural Identity	N = 21	N = 11	.094
Number of languages Spoken	*M* = 2.27(*SD* =.61)	*M* = 1.35(*SD* =.65)	<.001
Time Spent Living in Australia (years)	*M* = 2.51 (*SD* = 2.90)	*M* = 18.11(*SD* = 5.31)	<.001
Autism Quotient -10	*M* = 3.59(*SD* = 1.60)	*M* = 2.58(*SD* = 1.82)	.002

Notes.

1. LH = left handed, RH = right handed, A = Ambidextrous.

2. Self-identified culture reflected the group that the participant most strongly associated with throughout the survey. Strength of cultural identity and multicultural identity was measured using a five-point Likert scale adapted from the Mutual Intercultural Relations in Plural Societies (MIRIPS) questionnaire which captures levels of acculturation (Berry, 2014). The questionnaire asks participants to rate how much they see themselves as part of the cultural group they identify with (1 = Not at all, 5 = Very Much), and indicate if (and how strongly they felt) they belonged to a different cultural group to the one they identified as their primary culture (alternate cultural groups identified by the participants are not reported here).

3. The published cut-off score for AQ-10 is a score of 6 or higher (Allison et al., 2012).
4. Group differences in continuous variables were analysed using paired samples t-tests, and categorical variables were compared using Pearson Chi-square tests.[2]

Stimuli and Apparatus

The study was conducted with stimuli presented on an LCD monitor with dimensions 530mm by 300mm, and resolution 1920 by 1080 pixels. Participants were seated 850mm from the computer screen, and head movements were stabilised using a chin rest. The experiment was programmed using MATLAB, the psychophysics toolbox, and the Eyelink toolbox (Brainard, 1997; Cornelissen, Peters, & Palmer, 2002). Throughout the study, to ensure the participants were using covert, and not overt attention to complete the task, participant's eye movements were tracked using an Eyelink 2000 eye tracker, with a sample rate of 1000Hz (SR-Research, 2005-2008).

Stimuli were shown on a grey background of luminance of 43 cd/m^2. There were four possible cue locations and 25 possible target locations. The possible cue and target locations were determined by creating an invisible 5 x 5 grid subtending approximately 10° x 10° of visual angle. Grid lines were evenly spaced, 2.5° apart, and cues and targets appeared where grid lines intersected. Therefore, there were ten possible cue-target distances to be sampled, ranging in distances from 0° to 10.6°. For the duration of a trial, a black fixation dot, subtending .01°, was presented at the centre of the screen. Participants were required to maintain their gaze on this fixation region. The cue was a white unfilled circle with a luminance of 253 cd/m^2, and the target was a filled, off-grey circle with a luminance of 28 cd/m^2. Both circles had a radius of .25°. Participants completed 240 trials, where 200 trials contained both cues and targets, and 40 trials contained only cues (catch trials). The cue was uninformative of the target location. Therefore, each cue-target combination was presented an equal amount of times.

Procedure

The overall procedure is shown in Figure 5.6. Firstly, participant's eye movements were initially calibrated using a standard nine-point calibration procedure. Following calibration, participants were given the attentional inhibition task instructions and completed ten practice trials. At the beginning of a trial, participants completed a drift-correct using the Eyelink drift-correction function to ensure an accurate recording of gaze. Here, participants were required to fixate on a central fixation ring and to press space bar to begin the trial. The trial would only commence following successful drift correction. Participants were told to maintain their gaze on the central fixation dot. This instruction was given to ensure we measured covert, and not overt attention processes.

After the participant commenced the trial, a blank screen was shown for approximately 1000ms. Next, the fixation dot appeared alone for 501ms. The cue would then briefly appear for 100ms, followed by a blank interval of 801ms. In the target-present trials, following this blank interval, the target would appear for 1002ms, or until a participant had made a detection response. In the target-absent trials, no target appeared and was instead replaced by a longer blank interval, lasting 1803ms. Corrective feedback was given, where a message showing "CORRECT" appeared for one second if participants responded appropriately. If participants responded early, or during a catch trial, a warning message appeared for three seconds. After the practice trials, participants completed the experimental trials. This experimental block was similar to the practice block, except the "CORRECT" message did not appear if participants responded correctly. Participants were given a rest break every 40 trials. Throughout the experiment, recalibration of the eye tracker was conducted where necessary. Following completion of the computer task, participants completed a brief demographic questionnaire, a cultural identity scale (Berry, 2014), and the AQ-10, a self-report measure of autism-like traits (Allison et al., 2012).

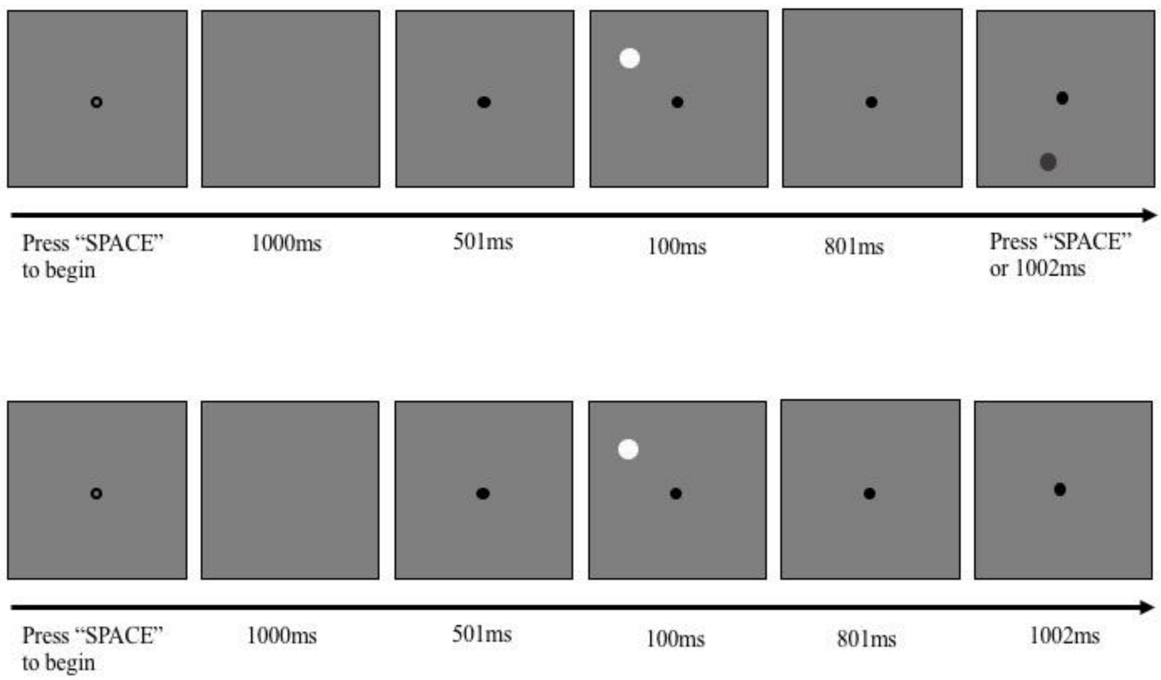

Figure 5.6. IOR task used in the current study. An example of a target present trial is shown above, and a target absent trial is shown below. On each trial, following a cue (the white circle), participants were asked to detect the presence of an off grey circle as quickly as possible.

5.5. Results and Discussion

Accuracy Data

First, we examined accuracy data to ensure that participants in both groups were actively engaged in the attentional inhibition task. Participants who scored below 90% accuracy for either the target present or target absent (catch trial) conditions were removed from further analyses. Three participants were removed for this reason.

Eye Movement Data

Next, eye movement data was analysed to check whether participants shifted their gaze from the central fixation region during each trial. The aim here was to only include trials in our final analyses where participants used covert, and not overt attention to complete the IOR task. We were primarily interested in the spatial distribution of covert attention. Thus, trials were excluded from further analyses if participants made an eye movement outside of the central fixation region. This region was defined as a 3.8 x 3.8° rectangular region centred on the fixation dot. A larger fixation region was chosen, as initial pilot testing suggested that with a smaller region of fixation trials were incorrectly being excluded from further analysis (e.g. glare from glasses, eye blinks). In particular, we wanted to be certain that any eye movements made by participants were genuine, rather than due to changes in fixation drift on a trial-by-trial basis. Further, if participants made a saccade outside of the central interest area on more than 30% of trials, the entire participant's data was removed from further analyses[3]. We chose this number because we wanted to ensure that we only included participants who were actively using covert attention to complete the task. Seven participants were removed from further analyses for this reason. Overall, this left a total sample of 101 participants (50 East Asian participants, 51 Western participants). For the remaining participants, overall accuracy, catch trial accuracy, and eye movement accuracy was high (Table 5.2). Interestingly, there was a significant difference in eye movement accuracy for the two cultural groups. In particular, East Asian participants shifted their gaze from the central fixation region more often than Western participants. This is consistent with work suggesting cultural differences in overt attentional processes (e.g. Chua et al., 2005).Nonetheless, as both groups maintained a high level of eye movement accuracy (greater than 90%), it appears that all participants were able to accurately engage with the task, and use covert attentional processes.

Table 5.2. *Mean accuracy data (and standard deviations) for East Asian and Western participants in the IOR task.*

	East Asian	Western	p-value
Accuracy	98.37% (1.32%)	98.31% (1.49%)	.841
Catch Trial Accuracy	98.39% (2.18%)	98.43% (2.06%)	.922
Eye Movement Accuracy	91.51% (7.64%)	95.10 % (5.00%)	.006

Notes. Significance values were obtained by computing independent samples t-tests for each of the variables. The accuracy of eye movements reflects a participant's ability to maintain their gaze in the central fixation region of the screen during an experimental trial.

Response Time Data

Before analysing the influence of cue-target distance on response time, participant's raw response time data were examined for outliers. For each participant group, at each cue-target distance, outliers were defined as those response times with a Z-score exceeding +/-3.29. Following outlier exclusion, mean response times for each distance were recorded. Next, response time outliers at the group level were then identified as any response times at each distance which had a Z-score that exceeded +/- 3.29 for each cultural group. Participant's data violating this criterion were excluded from further analysis. One Western participant was removed for this reason, leaving a total sample of 50 East Asian, and 50 Western participants. Cue-target distance and birth country were then entered into a mixed ANOVA to check that both groups experienced IOR. This analysis was important, as differences in attentional slopes would only be meaningful if the main experimental manipulation actually influenced attention. Mauchly's test of sphericity was violated, χ^2 (44) = 190.78, p < .001, so a Greenhouse-Geisser correction was used ($\varepsilon = .683$). Overall, there was a main effect of cue-target distance on response time, F (6.15, 602.34) = 28.53, $p < .001$, $\eta_p^2 = .23$, suggesting that participants experienced inhibition around the cued location. As shown in Figure 5.7, responses were slower at closer cue-target distances compared to larger cue-target distances. There was also a main effect of birth country on response time, F (1, 98) = 9.09, p =.003, η_p^2 =.09, where compared to Western participants, East Asian participants had slower response times, regardless of cue-target distance (Figure 5.7). Finally, there was no interaction between cultural group and cue-target distance, F (6.15, 602.34) = 1.06, p = .385, $\eta_p^2 = .01$, suggesting that the magnitude of the cueing effect was similar for both participant groups.

Cultural differences in attentional slope

Next, we compared the influence of cultural group on participants' attentional slopes. Each participant's attentional slope was calculated by running a linear regression with cue-target distance as a predictor, and response time as the outcome variable. A greater magnitude attentional slope reflects a narrower distribution of attention (Figure 5.5). The slopes were then compared using an independent samples t-test. No outliers were detected, and the assumptions of normality and equality of variance were met. The effect of birth country on attentional slopes was non-significant, t (98) = 1.82, p = .072, d = .36 ($M_{\text{East Asian}} = -.11$, $SD_{\text{East Asian}} = .12$, $M_{\text{Western,}} = -.15$, $SD_{\text{Western}} = .10$). Overall, this suggests that in the current study, cultural differences in attention inhibition, and thus attention spread were minimal. This null finding is consistent with a growing body of work suggesting that there are none, or only minimal cultural differences in visual attention processing (e.g. Hakim et al., 2017).[4]

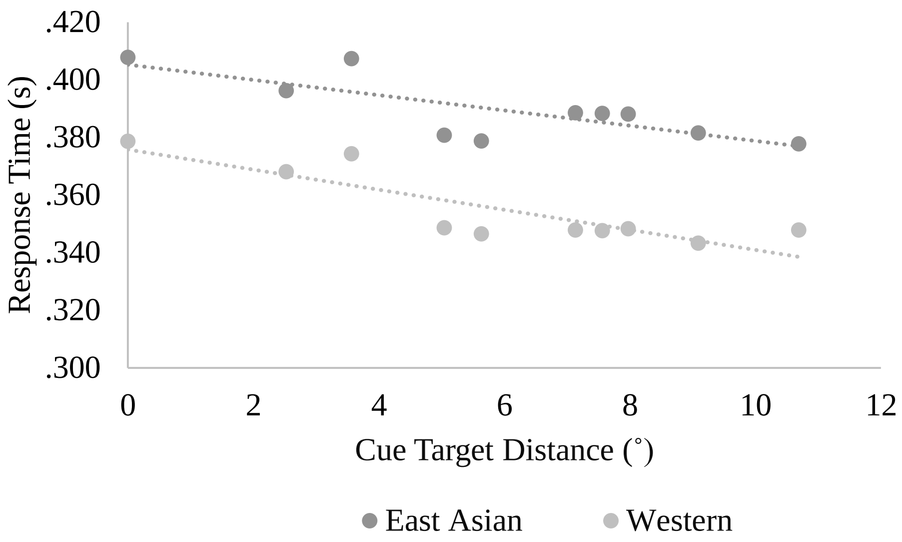

Figure 5.7. Averaged group data for East Asian and Western participants in the attentional inhibition task. The distance between the cue and target is shown on the X-axis, and average response time for target detection is shown on the Y-axis. The rate of change in response time (i.e. the attention slope) indicates the distribution of attention Overall, East Asian participants had a shallower attentional slope, suggesting that during the task, they adopted a broader attentional distribution.

Exploring the relationship between cultural background, attention slope, and mean response time

Of particular importance, in the current study, East Asian and Western participants had different average response times. This response time difference is consistent with previous research, which has found that on average, East Asian participants are slower to respond than Western participants (e.g. Boduroglu & Shah, 2017). Nonetheless, past research has shown that controlling for overall differences in mean response time can help clarify individual differences in attentional slope for the IOR task (Lawrence et al., 2018). Therefore, we ran a multiple regression analysis, where cultural differences in mean response time were accounted for when testing the influence of cultural background on attentional slope.

For the multiple regression analysis, mean response time scores (i.e. mean response time across all cue-target distances), were screened for univariate outliers using Z scores exceeding +/-3.29 as a cut-off, and multivariate outliers were determined by checking participant cases where Mahalonobis distance values exceeded 13.82 with birth country and mean response times as predictors. No outliers were identified. The assumptions of multiple regression were then checked. Here, it is important to note that even though cultural background predicts mean response time, the variance inflation factor for the model was low (*VIF* = 1.10), suggesting that potential multicollinearity between the variables had minimal influence in the model. Overall, the regression model was significant, $R^2 = .17$, $F(2, 97) = 7.60$, $p = .001$. Further, there was a relationship between mean response time and slope, $b = .34$, $t(97) = 3.40$, $p = .001$, where slower response times were associated with a shallower slope of attention. However, cultural group alone did not show a relationship with attentional slope, $b = .08$ $t(97) = .77$, $p = .412$. Overall, this provides converging evidence that there are minimal cultural differences in attention spread.

Although mean response time predicted slope and cultural group did not, it is important to note that the multiple regression should not necessarily be interpreted as differences in mean response time *causing* differences in attentional slope. Instead, it is equally plausible that differences in attentional slope predict slower response times overall. Indeed, a secondary multiple regression shows that both attentional slope, $b = .32$, $t(97) = 3.40$, $p = .001$, and cultural group, $b = .24$, t $(97) = 2.56$, $p = .012$, predict mean response time. Critically, this demonstrates that proposed cultural differences in attention distribution cannot solely account for cultural variation in response time. Even though we found no evidence in favour of a cultural difference in spatial attention distribution, group differences in response time were still observed (where East Asian participants were slower to respond compared to Western participants), even after variation in attention slope was accounted for. This is crucial, as past research has often interpreted cultural differences in response time as reflecting variation in attention distribution (e.g. Boduroglu et al., 2009; Boduroglu & Shah, 2017). Therefore, the current study adds an important clarification to the literature, showing that cultural differences in response speed may be explained better by factors other than attention.

Do other factors related to culture predict attention spread?

Finally, although our study suggests that birth country is not related to attentional slope, it is important to note that our sample also differed on a number of relevant demographic factors, such as age, number of languages spoken, self-identified culture, vision, multiculturalism, time spent living in Australia, and total years of education. It is therefore still unclear if, and what, other factors related to culture might be related to group differences in attention spread. To address this, we conducted a series of exploratory analyses, measuring whether any factors which significantly differed between the two cultural groups predicted attentional spread, regardless of the participant's cultural group. However, no factors predicted attention slope. Therefore, it appears that there is minimal evidence for a relationship between culture and the spatial spread of attention, as measured by the IOR task.

Although our analysis suggested that factors other than time spent in Australia (e.g. language), may not be necessary for defining cultural differences in attention, in the current study, all of these variables were measured via self-report. For example, for the variable: "number of languages spoken" participants were asked to state how many languages they were fluent in speaking. As participants may differ in their judgement of what constitutes fluency, a better measure of multilingualism would be more appropriate to measure whether language predicts attentional spread. Furthermore, our multiculturalism variable was determined by asking participants which ethnic groups they identified with (i.e. East Asian or Western), as well as how strongly they saw themselves as a part of these groups. However, during data collection it became apparent that different participants interpreted this question in various ways. For example, when participants reported other ethnic groups they identified with, some appeared to consider Australia as a separate ethnic group, whereas others did not. Likewise, some participants reported high levels of identification with sub cultures within the broader ethnic group they identified (e.g. people who speak a specific language). This made the coding of the multiculturalism variable challenging, and required a degree of interpretation from the research group. Thus, future research should endeavour to more directly measure which factors predict cultural differences in attention, be it language, multiculturalism, or another factor often coinciding with culture in these studies.

Furthermore, even though time spent living in Australia did not predict attention slope, within our East Asian participant sample, many individuals had lived in Australia for an extensive period (e.g. up to 21 years). This length of time differs markedly from other research exploring cultural differences in cognition, where participants are sometimes recruited on the basis of having lived in Australia for less than five years (e.g. Boduroglu et al., 2009). Therefore, it is possible that in the current study, the inclusion of East Asian participants who had lived in Australia for a substantial amount of time may have potentially weakened the measured relationship between culture and the spatial distribution of attention. In turn, this could have led to the null result observed. Specifically, in the current study, acculturation processes may have led these participants to adopt a different cognitive style to that typically associated with those of an East Asian cultural background. For example, work conducted by Cheung, Chudek and Heine (2011) has shown that both age and the amount of time spent residing a new country of residence is related to the degree to which an individual identifies with that country. In particular, the younger an individual is when they moved to Australia, as well as how long an individual has been living in Australia, may influence the strength with which they identify with Australian culture, and consequently adopt attentional strategies similar to those prevalent in Western cultures (i.e. analytic processing styles, and a narrower slope of attention). To address this, we ran a secondary analysis comparing attention for East Asian and Western participants, which only included East Asian participants who had lived in Australia for less than five years. The value of five years was chosen as it allowed us to include enough participants from our East Asian sample for meaningful statistical analysis, while also following the recruitment methods of relevant previous studies exploring cultural differences in attention breadth (i.e. Boduroglu et al., 2009 who measured cultural differences in change detection of East Asian participants who had lived in America for less than five years). This left a total sample of 94 participants (44 East Asian, 50 Western).

When defining culture by both birth country, and time spent in Australia, a similar pattern of results emerged to our original analysis. For the repeated measures ANOVA comparing the influence of distance and birth country on response time, again, Mauchly's test of sphericity was violated, χ^2 (44) = 194.88, $p < .001$, and a Greenhouse-Geisser correction was used (**ε** = .666). Overall, there was main effect of distance, F (5.99, 551.34) = 28.49, $p < .001$, $\eta_p^2 = .24$, and a main effect of birth country, F (1, 92) = 11.93, $p = .001$, $\eta_p^2 = .12$. There was no interaction between birth country and distance, F (5.99, 551.34) = .89, $p = .499$, $\eta_p^2 = .01$. Again, this suggests that East Asian participants were slower to detect targets, regardless of cue-target distance. Finally, an independent samples t-test revealed a non-significant relationship between birth country and attention slope, where East Asian participants had a slightly shallower attention slope compared to Western participants, t (92) = 1.85, $p = .068$, g =.33 ($M_{\text{East Asian}}$ = -.11, $SD_{\text{East Asian}}$ = .12, $M_{\text{Western,}}$ = -.15, SD_{Western} = .10). Furthermore, a Bayesian analysis provided anecdotal evidence in favour of the null hypothesis, BF_{10} = .965 (Wagenmakers et al., 2018). Taken together, these analyses therefore suggest that even after accounting for group differences in acculturation processes, and using a more sensitive measure of culture, there appears to be no reliable relationship between cultural background and attention slope.

5.6. General Discussion

The current study aimed to explicitly test whether cultural group predicted spatial attention distribution using an IOR task. Compared to previous research exploring cultural differences in spatial attention, the attentional inhibition task has notable strength because it allows for differences in attentional slope to be directly measured across space. Further, we were able to control for cultural differences in eye movement patterns, which some research suggests might differ between East Asian and Western participants in scene viewing tasks (Chua et al., 2005). Overall, when using a more direct measure of spatial attention, we found no evidence of a reliable relationship between culture and attention distribution. This null effect is consistent with recent work claiming minimal cultural differences in visual attention more generally (Hakim et al., 2017). Critically, however, a reliable cultural difference in response time was observed. In particular, East Asian participants were slower to respond to targets across all cue-target distances in the IOR task. As such, it appears that group differences in response time may be driven by factors other than attention processing.

Culture and Attention Spread

In contrast to earlier research, we found no reliable evidence that cultural group predicted attention slope. This is inconsistent with theoretical models stating that East Asian individuals have a more holistic thought processing style compared to Western participants (Nisbett et al., 2001), which would lead to differences in attention distribution (Boduroglu et al., 2009), as well with previous studies measuring cultural differences in visual attention processing more generally (e.g. Boland, Chua, & Nisbett, 2008; Chua et al, 2005; Senzaki et al, 2014). Instead, the results of the current study are similar to an accumulating body of work suggesting minimal cultural differences in attention processing (e.g. Boduroglu & Shah, 2017; Evans et al., 2009; Hakim et al., 2017; Rayner et al., 2009). For example, in a scene perception and memory task, Evans et al. (2009) found no evidence of a cultural difference in eye movement patterns. This null finding is in contrast to Chua et al. (2005) who found that on average, East Asian participants tended to fixate on background objects, and Western participants to fixate on focal, foreground objects. Furthermore, a large scale replication study conducted by Hakim and colleagues recently found little to no evidence favouring a cultural difference in attention processing as measured by the Boduroglu et al. (2009) change detection task, the McKone et al. (2010) Navon letter task, and the Kitayama et al. (2003) framed line task. Hakim et al. (2017) noted that one potential reason for this might be that previously reported effects of cultural differences have been quite small and based on small sample sizes. These small sample sizes can often lead to false positive findings (Ioannidis, 2005). Therefore, the current study demonstrates that even when using a highly sensitive measure of spatial attention distribution, with a relatively large sample size, cultural differences in attention distribution are either minimal or non-existent.

Culture and Response Time

Interestingly, the current study found a significant cultural difference in overall response speed, where Westerners were relatively faster to detect targets compared to East Asian participants. That group differences in response time were observed is consistent with previous research showing that on average, East Asian participants are slower to respond during target detection tasks (Boduroglu & Shah, 2017; Boduroglu et al., 2009). Although slower responding has previously been interpreted as reflecting cultural differences in attention distribution (Boduroglu & Shah, 2017), given the results of the current study, we believe that this is unlikely. In particular, even after controlling for variation in attention slope, group differences in response time remained.

One possible reason for cultural differences in response speeds are group differences in response biases. For example, East Asian participants may have used a more conservative response criterion compared to Western participants. In turn, this may have led East Asian participants to have slower overall responding, as participants may have waited for more perceptual evidence to accumulate before responding to the target. Indeed, recent research suggests that in perceptual tasks, participants from an East Asian cultural background may have a more conservative response bias compared to Western individuals (Hakim et al., 2017). Specifically, Hakim et al. (2017) compared cultural differences in participants' performance of the Boduroglu et al. (2009) change detection task (Figure 5.1). Critically, in both the ‘expand’ and ‘contract’ conditions of the task, Chinese participants were more likely to report “no change” compared to American participants, indicating that they adopted a more conservative response style (however, this difference was not observed when comparing Asian International student participants versus American student participants).

Furthermore, cultural differences in motivation and self-regulation may have influenced response styles, and subsequently overall target detection response times in the IOR task. In particular, East Asian individuals are thought to be motivated to avoid adverse outcomes, while Western individuals show stronger motivation to approach positive outcomes (e.g. Hamamura, Meijer, Heine, Kamaya & Hori, 2009; Heine et al., 2001). For example, Heine et al. (2001) found that persons from Japan and North American responded differently to feedback indicating success, versus feedback indicating failure. In particular, when given negative feedback regarding performance on a task, Japanese participants continued with the task for a longer amount of time compared to Western, participants, indicating they were more motivated by this form of feedback. In the current study, during the experimental block, participants were provided with corrective feedback if they performed the IOR task incorrectly (i.e. responded before the target appeared, or during a catch trial). Specifically, a warning message appeared in red text for 3 seconds which asked participants to wait for the target stimulus. Given that there are known cultural differences in motivation following negative feedback, the warning message presented in the current study may have had a different impact on motivation, and subsequently, completion of the IOR task. East Asian participants may have been more motivated by the ‘failure message' to avoid further errors, and thus responded more conservatively when searching for the target. Nonetheless, it is important to note that cultural background did not predict the number of ‘catch trial' errors made by participants. If East Asian participants were more conservative in responding, their catch trial accuracy should be higher compared to Western participants due to Western participants potentially responding more liberally. Nonetheless, given that catch trial accuracy was very high for both cultural groups, this might not be a sensitive enough measure of response bias.

Finally, a growing body of research suggests that stable differences in response time exist. For example, age, impulsivity and sex have been found to predict response time (e.g. Sheppard & Vernon, 2008; Der & Deary, 2006). However, similar to Boduroglu and Shah (2017), it is important to emphasise that the response time difference obtained in the current study does not reflect group differences in overall ability to complete the attentional inhibition task. The reasons for this are twofold. Firstly, overall accuracy scores for both groups were high, and the difference between the groups was not significant. Secondly, our participants were drawn from the same, highly educated, university sample. Taken together, this would suggest that the two groups were of equal ability.

Conclusion

In conclusion, the current study provides converging evidence that there are no or minimal cultural differences in spatial attention distribution. Despite this, however, a reliable difference in target detection response time was observed, where East Asian participants were slower compared to Western participants. This difference in response time is not solely attributable to differences in attention, and as such, future work should explore whether differences in response criterion or motivation might cause this effect.

5.7. Notes

1. Initially, we intended to create our East Asian and Western participant groups for analysis based on self-identified cultural background. To do so, in the demographic survey, we asked participants which ethnic group they most strongly identified with (Caucasian, East Asian, South Asian, Indigenous, or Other). We also asked participants if they identified with any other cultural groups and the strength of their identification with these groups. Inspection of responses to this question suggested that the question was a poor measure of culture, with some participants providing unclear responses to the questionnaire. For example, some participants answered that they most strongly identified as being from an East Asian ethnic group, however, when prompted if they identified with another ethnic group later in the survey, they responded that they more strongly identified as Caucasian than East Asian. Furthermore, some participants self-identified equally as having many ethnic associations, making individual's responses hard to categorise into clear cultural groups. Therefore, we chose to use birth country as the main grouping variable for analysis, as it allowed for a cleaner demarcation of cultural groups compared to self-identified culture. This is consistent with previous research, which has used birth country as the grouping variable for cultural background (e.g. Boduroglu et al., 2009).
2. A subset of participants did not to respond to some demographic questions. This resulted in smaller participant numbers for the variables age, self-identified culture, and total years of education. Further, apart from the data reported in Table 5.1, the demographic survey also measured a) which countries a participant had lived in, as well as for how long they lived in those countries, b) countries in which the participant completed primary and secondary education, as well as the language spoken at those schools, c) the degree to which they saw themselves as Australian, compared to their self-reported cultural group (using a 5 point Likert scale; Berry, 2014) and d) birth country of both of their parents . Variation in responses to these questions were highly variable, and often misinterpreted, and were thus, not included in our final analysis. Furthermore, our original survey asked participants their a) first language, b) what languages they were fluent in, and c) the main language they used now. However, for clarity, we condensed this into one variable, labelled “number of

languages spoken" and recorded the number of separate languages participants reported speaking across these three questions.

3. We originally intended to exclude participant data if eye movements were made on more than 20% of target present trials. However, this meant that a high number of data sets were excluded. Therefore, to include as much data as possible, we lowered our accuracy cut off score to 70% (i.e. participants were excluded if they moved their eyes on more than 30% of trials). Nonetheless, both exclusion criteria led to a similar overall pattern of results.
4. In earlier version of this manuscript, we collected 82 useable data sets for final analyses (32 East Asian, 50 Western). The original analysis included in this manuscript found that the effect of birth country on attention slope was non-significant, t (80) = 1.92, p = .058, d = .42. Further, in the original version of the manuscript, when East Asian participants who had been living in Australia for greater than 5 years were excluded from analyses, the effect of birth country on attention slope was significant, t (75) = 2.14, p = .035, d =.49. However, upon the request of an anonymous reviewer, we collected a further 19 useable data sets, so that there were 50 East Asian, and 50 Western participants in our final sample, and revised manuscript.

Chapter 6: A Critical Review of the Cognitive and Perceptual factors Influencing Attentional Scaling and Visual Processing

6.1. Foreword

Having determined that ageing influences spatial attention distribution while culture does not, the second half of this thesis aimed to understand what impact different attentional distributions have on behaviour, and in particular, vision. Past research argued that narrow attention typically improves visual processing in tasks requiring fine detail processing (Eriksen & James, 1986). However, recent work has shown that attentional scaling can have various effects on different types of vision, as mediated via the major visual pathways of the brain (Goodhew et al., 2017; Mounts & Edwards, 2017). The following chapter addresses this, by critically analysing the various methods testing the relationship between attentional scaling and visual perception.

Australian National University

Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

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Name	Signature	Date
M. Edwards		01/03/2019
Louisa Talipski		01/03/2019
Stephanie Goodhew		01/03/2019
Rebecca Lawrence		01/03/2019
Candidate – Print Name	Signature	Date

Endorsed

Stephanie Goodhew		01/03/2019
Primary Supervisor – Print Name	Signature	Date
M. Edwards		01/03/2019
Delegated Authority – Print Name	Signature	Date

6.2. Abstract

An important mechanism used to selectively process relevant information in the environment is spatial attention. One fundamental way in which spatial attention is deployed is attentional scaling: the process of focusing attentional resources either narrowly or broadly across the visual field. Although early empirical work suggested that narrowing attention improves all aspects of visual processing, recent studies have demonstrated that narrowing attention can also have no effect or even a detrimental impact when it comes to vision mediated via the magnocellular mediated pathway of the visual system. Here, for the first time, we synthesise empirical evidence measuring the behavioural effects of attentional scaling on tasks gauging the contribution of the major neural pathways of the visual system, with the purpose of determining the potential factors driving these contradictory empirical findings. This analysis revealed that attentional scaling could be best understood by considering the unique methodologies used in the research literature to date. The implications of this analysis for theoretical frameworks of attentional scaling are discussed, and methodological improvements for future research are proposed.

6.3. Introduction

On a moment to moment basis, our brains are inundated with vast streams of visual information. Spatial attention is one way that the brain selects key pieces of information for enhanced processing. Numerous studies over the past four decades have demonstrated that spatial attention is highly dynamic. Firstly, attention can be *shifted* across the visual field (Carrasco, 2011; Posner, 1980; Posner & Cohen, 1984). Second, it can be *split* into discontinuous locations in space (Castiello & Umiltà, 1992; Muller et al., 2003; however see Jans et al., 2010). Finally, attention can be *scaled* to varying sizes (Eriksen & James, 1986; Eriksen & Yeh, 1985; Greenwood & Parasuraman, 1999, 2004; Müller et al., 2003). When attention is focused to a constrained area of visual space, it is said that an individual has adopted a *narrow attention scale*. When spatial attention is spread over a relatively diffuse region, the individual has adopted a *broad attention scale* (Figure 6.1). Here, we are interested in this third facet of spatial attention: *attention scaling.*

Figure 6.1. Examples of attentional scaling. While attentional shifting involves the movement of spatial attentional resources across the visual field to varying locations of interest, attentional scaling involves both the narrowing and broadening of attentional resources according to task demands. The left figure shows a broad scale of attention, while the right figure shows a narrow scale of attention.

Elucidating the relationship between scaling and vision has far-reaching implications in a number of clinical and research domains. Attentional scaling is known to influence performance in everyday activities such as reading, driving, and visual search (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ball & Sekuler, 1986; Facoetti et al., 2003; Greenwood & Parasuraman, 1999). Furthermore, there are demonstrated deficits in attentional scaling for conditions including Dyslexia, Schizophrenia, and Alzheimer's disease (Elahipanah et al., 2011; Facoetti & Molteni, 2001; Greenwood et al., 1997; Vidyasagar, 1999). Finally, recent work has demonstrated that training programs may be effective at improving the flexibility of attentional scaling processes (Fang et al., 2017; Rolle et al., 2017), highlighting the potential for improving everyday functioning for individuals with attentional-perceptual deficits. Taken together, this is why understanding the effect of attentional scaling on visual perception has become the focus of a recent line of research.

To the best of our knowledge, currently, no literature reviews exploring attentional scaling and visual perception exist. This is problematic, as a survey of the literature exploring attention scaling and vision could understandably leave one confused, with studies often arriving at contradictory conclusions. Although an early theory of attentional scaling assumed that narrowing attention unequivocally improved visual processing, recent work has shown this is not necessarily the case, wherein some instances, narrow attention has even impaired visual processing (Chong & Treisman, 2005; Goodhew et al., 2017, 2016; Mounts & Edwards, 2017; Shulman & Wilson, 1987). To address these inconsistencies, three more recent accounts of attentional scaling and vision have been proposed: the selective spatial enhancement account (Goodhew et al., 2016) , the spatiotemporal trade-off account (Goodhew et al., 2016; Shulman & Wilson, 1987), and the attentional attraction field account as applied to attentional scaling (Baruch & Yeshurun, 2013; Mounts & Edwards, 2017). However, empirical evidence supporting each theory is not only limited but conflicting. This is particularly true for studies measuring the effect of scaling on processes thought to be mediated by the magnocellular channel of visual processing, such as temporal resolution and low spatial frequency perception (Goodhew et al., 2017, 2016; Goto et al., 2001; Mounts & Edwards, 2017; Poggel, Treutwein, Calmanti, & Strasburger, 2006).

Therefore, the purpose of this review is to synthesise the evidence from studies exploring scaling and visual perception, in order to determine potential reasons for inconsistencies across the literature. Firstly, we summarise the major theoretical accounts of attentional scaling and vision, and present key evidence favouring each theory. Following this, we examine how these key pieces of experimental evidence supporting each theory differ in their methodology. Factors covered in this analysis include the roles of endogenous versus exogenous attention, the use of stimuli which encourage an annular distribution of attention rather than attention scaling, the complex influences of perceptual and cognitive load, as well as the influence of varying stimulus eccentricity to manipulate and measure magnocellular visual processing. By evaluating how each methodology used may lead to particular effects of spatial attention on vision, we hope to clarify the scope of each attentional scaling theory.

6.4. Theoretical Accounts of attentional scaling and vision

6.4.1. Zoom Lens Account

The zoom lens account is by far the most pervasive account of attentional scaling and vision in the literature (Eriksen & James, 1986; Eriksen & Yeh, 1985). This account proposes that the primary function of attentional scaling is to enhance visual processing relative to task demands. While broad attention allows for the processing of a large region of visual space, narrowing attention allows one to concentrate their cognitive resources for enhanced processing within a smaller visual region. In other words, the zoom lens account espouses a trade-off between narrow versus broad attention scale and improved visual processing. Thus, this account assumes that narrow attention unequivocally improves visual processing relative to broad attention.

Indeed, early research demonstrated that this was the case for commonly used perceptual tasks such as target detection, whereby narrow attention improved response times compared to broad attention (Barriopedro & Botella, 1998; Eriksen & James, 1986; Eriksen & Yeh, 1985; Greenwood & Parasuraman, 1999). For example, Eriksen and James (1986) measured the influence of attentional scaling for target detection. In this study, the participants' task was to determine the location of a target letter under varying scales of attention. Specifically, the participants' attentional scale was set using a cueing procedure, where the number of cued areas was manipulated to alter the spatial scale of attention. It was assumed that when the cued number of letters was small, attention was narrowed and that with increasing letter positions cued, attention was broadened. In line with the zoom lens account, target detection times were faster under narrow, compared to broad attention. This suggests that a narrow scale of attention improves visual processing.

Following the initial study of the zoom lens model, a series of studies conducted by Umiltà and colleagues attempted to determine the extent over which attentional resources could be deployed using a modified Posner cueing procedure (Benso et al., 1998; Castiello & Umiltà, 1990; Posner, 1980; Turatto et al., 2000; Umiltà, 1998). For example, to measure the effects of attention scaling on visual perception, while ruling out the role of attentional shifting, Turatto and colleagues (2000) measured how response times for target detection changed following the appearance of either small (2.5° radius) or large (7.5° radius) circular pre-cues which indicated the precise location of a target to be detected. Similar to past work, it was found that target detection speeds were faster for smaller attentional cues compared to larger attentional cues.

Nonetheless, it is critical to emphasise that these early studies of attentional scaling and visual perception inferred visual processing capacity by comparing *response times* (Castiello & Umiltà, 1990; Eriksen & Yeh, 1985; Turatto et al., 2000). In contrast, relatively less work has explored the influence of broad and narrow attention on *visual sensitivity*, using accuracy measures, for tasks targeting specific areas of the visual system. The distinction between response time and accuracy is crucial, as it is possible that response time measures do not reflect the same visual cognitive processes as do accuracy measures. Indeed, Prinzmetal, McCool and Park (2005) suggest that accuracy and response time measures reflect different attentional processes, dependent upon whether automatic or involuntary attention is being studied.

Specifically, through a series of experiments testing voluntary and involuntary attention using variants of the Posner paradigm, Prinzmetal et al. (2005) found that voluntary attentional shifting influenced both accuracy and response time, while involuntary attentional shifting appeared to only influence response time. The authors suggested that voluntary manipulations of attention influence the ‘perceptual representation’ of stimuli, thus enhancing their signal for processing in the visual system. This may be best captured via measures of accuracy. In contrast, when attention is manipulated involuntarily, the authors argue that ‘decision processes’ are the most important contributors to overall performance, which are best reflected via response time measures. Therefore, early studies supporting the zoom lens account using response time measures, particularly those manipulating attention scaling exogenously, may not be measuring how attention influences visual perception. Instead, the differences in response times measured might reflect decisional criteria. As such, studies which use accuracy tasks to measure performance will be the focus of the remainder of the review paper.

In contrast to studies measuring response time differences, there have been a small series of studies that have shown attention scaling influences visual processing performance using both accuracy measures and neuroimaging measures. For example, the influence of scaling on spatial acuity has been studied using a Vernier acuity task (Balz & Hock, 1997). Participants were shown nine dots presented along the horizontal meridian (0.5° x 0.5° in size, spanning 9.8° of visual angle). Attention scale was varied by asking participants to detect changes in the brightness of the different dots. The change could occur in one of the dots presented at fixation (small scale of attention), or in one of the dots presented at wider eccentricities (large scale of attention). The participants then decided whether two lines presented above and below the luminance dots were aligned. Overall, it was found that participants showed higher levels of acuity when attention was narrow, suggesting that a small spatial scope of attention improves the quality of visual perceptual processing at the attended region.

Likewise, Poggel et al. (2006) found narrow attention to improve temporal processing. Here, a visual search task was used to endogenously manipulate attention scale. Double pulse temporal resolution at different spatial scales was then measured. On each trial, eight white light stimuli were presented concentrically around a white light shown in the middle of the display. Eight of the lights were shown continuously for the entire display duration, and one of the lights was flashed twice. Following each presentation, participants indicated the location of the double pulse, so it was assumed that all nine positions were simultaneously monitored. Critically, the spatial layout of the lights was varied between each block, where within a block, the circle of lights was either narrowed into smaller eccentricities (i.e. narrow attention), or widened to cover larger areas of the visual field (i.e. broad attention). The range of stimulus eccentricities was from 2.5° through to 20° from fixation. A threshold for temporal resolution was calculated, so that for each condition, the minimum temporal gap in the double pulse presentation was determined. Overall, it was found that for the centrally presented light, thresholds to detect the double pulse decreased, suggesting that temporal resolution increased under narrow attention. Thus Poggel et al. (2006) demonstrated that endogenous narrowing of attention can improve temporal resolution, providing further support for the zoom lens account.

Finally, there is neuroimaging evidence which shows that attention scaling can influence visual processing mediated by the visual cortex (Müller, Bartelt, Donner, Villringer, & Brandt, 2003; Sasaki et al., 2001). Müller et al. (2003) found that under narrow attention, activation in the primary visual cortex was modulated, such that there was increased magnitude activation over a smaller region of the visual cortex for narrow attention, relative to the broad condition in which a larger region was activated, but to a lesser extent. This is broadly consistent with the zoom lens account.

6.4.2. Selective Spatial Enhancement

Although there are many studies suggesting that a small scale of attention enhances all aspects of visual perception, some research has found that narrowing attention does not improve all types visual processing (Chong & Treisman, 2005; Goodhew et al., 2017, 2016; Mounts & Edwards, 2017; Pringle, Irwin, Kramer, & Atchley, 2001; Yeshurun & Carrasco, 2008). To explain these contrasting effects, Goodhew et al. (2017, 2016) suggested that attentional scaling effects on visual perception may be largely reliant on the extent to which the stimulus is processed by the magnocellular or the parvocellular visual pathways (Goodhew et al., 2017, 2016).

Decades of physiological and behavioural data have demonstrated that the human brain processes visual information via parallel pathways and that the cells in these pathways are specialised for processing different types of visual information. (Derrington & Lennie, 1984; Livingstone & Hubel, 1988; Nassi & Callaway, 2009; Nassi, Lyon, & Callaway, 2006; Schiller et al., 1990). Two of the predominant visual channels are the parvocellular and magnocellular channels (named after cells in the lateral geniculate nucleus). Table 6.1 summarises their key properties. Although there is not a complete demarcation, at the limits of perceptual processing, parvocellular and magnocellular neurons differ in the visual information they are most sensitive to. Parvocellular neurons are better versed to process rapid spatial luminance changes (high spatial frequencies), and less able to process rapid temporal changes. In contrast, magnocellular neurons are better able to process the coarse spatial details of a scene (low spatial frequencies), and fast luminance changes over time, having higher temporal resolution (Butler & Javitt, 2005; Butler et al., 2006; Denison et al., 2014; Derrington & Lennie, 1984; Goodhew et al., 2017; Livingstone & Hubel, 1988; Öğmen et al., 2008; Schulte-Körne, Remschmidt, Scheuerpflug, & Warnke, 2004).

To infer changes in parvocellular and magnocellular sensitivity, a large host of behavioural studies have utilised tasks specifically designed to tap into visual processing mediated by the two pathways. For instance, in acuity tasks, participants are required to detect small spatial gaps in stimuli, or temporal discontinuities in brief stimulus presentations (Figure 6.2). Changes in gap detection accuracy are assumed to reflect changes in perceptual sensitivity, where higher accuracy scores are thought to correspond to enhanced activation along a visual pathway. Changes in spatial acuity are interpreted to reflect changes in parvocellular sensitivity, while changes in temporal acuity are interpreted to reflect changes in magnocellular sensitivity. Likewise, changes in spatial frequency sensitivity are measured by comparing performance on orientation discrimination tasks for high and low spatial frequency stimuli (Figure 6.3). Although some authors have suggested that parvocellular and magnocellular sensitivity cannot be reliably measured using behavioural methods (e.g. Skottun, 2013; Skottun & Skoyles, 2011), a large host of empirical studies exploring both attention, motor processing and clinical deficits refute this (see Goodhew et al., 2017 for a brief review of this issue).

The relative input of parvocellular and magnocellular neurons to visual processing was originally thought to be purely stimulus driven. However, a growing body of behavioural research demonstrates that cognitive factors can also influence these processes(Carrasco, 2006, 2011; Goodhew, Fogel, & Pratt, 2014; Hein, Rolke, & Ulrich, 2006; Thomas, 2015; Yeshurun & Levy, 2003). For example, Yeshurun and Levy (2003) demonstrated that *attentional shifting* can have differential effects on performance of spatial and temporal acuity measures. Here, spatial attention was found to improve spatial acuity, while impair temporal acuity. This was interpreted as spatial attentional shifting enhancing parvocellular, and impairing magnocellular sensitivity. Likewise, (Gozli, West, & Pratt, 2012) found that hand positioning can alter performance in spatial and temporal acuity tasks. When participants' hands were positioned close to the computer screen, performance on the temporal acuity task was enhanced, and decreased on the spatial acuity task, contrasted the hands being placed further away from the computer screen. Similarly, the perception of low spatial frequencies is enhanced and high spatial frequencies impaired near the hands under conditions of low perceptual load (Abrams & Weidler, 2014). Taken together, this suggests that cognitive factors can alter the relative input of parvocellular and magnocellular neurons to visual processing.

Table 6.1. *Defining Characteristics of Magnocellular and Parvocellular neurons.*

Parvocellular	Magnocellular
Smaller receptive fields	Larger receptive fields
Demonstrates colour opponency	Relatively colour blind
Lower temporal resolution	Higher temporal resolution
Higher spatial resolution	Lower spatial resolution
High spatial frequency sensitivity	Low spatial frequency sensitivity
Greater sensitivity to higher contrasts	Greater sensitivity to lower contrasts

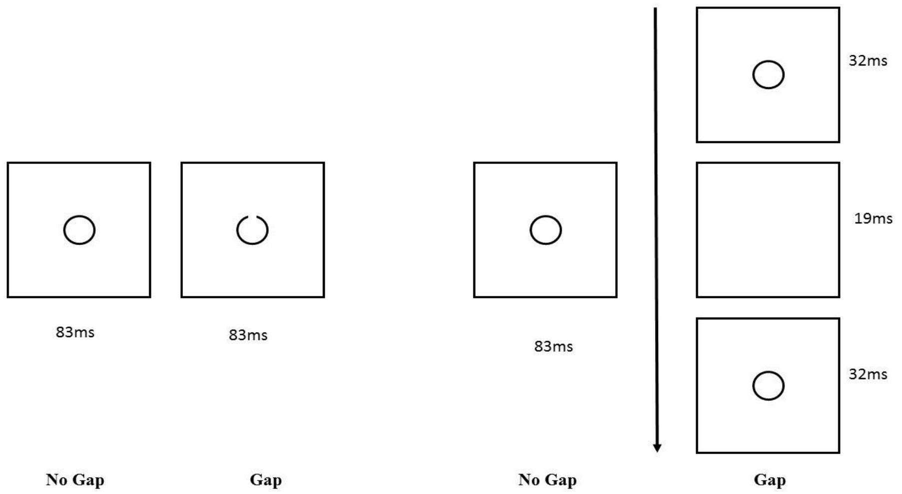

Figure 6.2. Spatial (left) and temporal (right) acuity tasks. Participants are shown brief presentations of circles and are required to determine whether the presented circle contained either a small spatial or temporal gap.

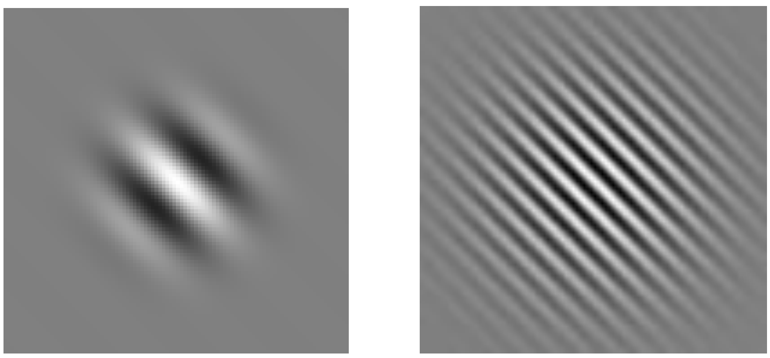

Figure 6.3. Low (left) and High (right) spatial frequency Gabors. Parvocellular neurons are better versed to process local information (high spatial frequencies). Magnocellular neurons are better versed to process global information (low spatial frequencies).

Based on the differential properties of the visual system, Goodhew and colleagues suggested that attention scaling has different effects on parvocellular and magnocellular mediated processing. Specifically, the selective spatial enhancement (SSE) account argues that changes in the spatial scale of attention influence parvocellular mediated processing, while having no influence on magnocellular mediated processing. To test this theory, Goodhew et al. (2016) initially explored the effect of scaling on parvocellular related spatial acuity versus magnocellular related temporal acuity. To manipulate spatial attention scale, Goodhew et al. (2016) used a shape inducer task. Specifically, participants determined the identity of briefly presented circle and ovals that were either small (approximately .5° radius), hence inducing a small scale of attention, or large (approximately 20° radius), inducing a large scale of attention. The effect of attentional scaling on parvocellular and magnocellular sensitivity was then tested using spatial and temporal acuity tasks respectively. That were presented at fixation. Goodhew et al., (2016) found that attentional scaling influenced only parvocellular mediated vision, such that spatial acuity improved with narrow attention, whereas temporal perception was not impacted by attentional scale.

Furthermore, using a similar shape inducer task to manipulate attention scale, Goodhew and colleagues (2017) demonstrated that performance on a temporal order judgement, and an orientation discrimination task using low spatial frequency stimuli – both magnocellular-mediated aspects of visual perception – were not influenced by attentional scale. This occurred under conditions in which performance on fine detailed spatial tasks (parvocellular mediated) was enhanced by inducing the smaller attentional scale. Further, unlike their original experiment, Goodhew et al. (2017) also varied the eccentricity of the magnocellular related stimuli, so that they appeared either 2° to the left or right of fixation. Critically, presenting targets either to the left or right of fixation introduced a level of uncertainty regarding target location. This is likely to have encouraged participants to adopt the attentional scale consistent with the intended experimental manipulation. That is, it would be less likely that participants might attend to just the periphery of the inducer shapes and the centre of the visual field simultaneously. Using this updated methodology, spatial acuity was improved for narrow attention, while no effect was found for temporal acuity.

It is also important to recognise that earlier studies testing attention scaling and perception provide some evidence largely consistent with the predictions of the SSE account. For example, Goto et al. (2001) used a dual task paradigm to measure attentional scaling and contrast sensitivity thresholds for high and low spatial frequency Gabors. The primary task, which manipulated attention scale, required participants to detect changes in patterns which appeared in different sized concentric rings presented around fixation (2.5° vs. 5° in radius). To measure the effects of attention on spatial frequency perception, while completing the primary luminance detection task, participants were also required to report if they noticed a Gabor patch appear at fixation during the task. On trials where the Gabor patch was present, the contrast of the stimulus gradually increased until the participant detected it. Thus, differences in contrast sensitivity for Gabor patches of varying spatial frequency could be measured. The authors found that contrast sensitivity for lower spatial frequency Gabors (i.e. <2 cycles per degree) differed minimally under narrow versus broad attention scales, while compared to broad attention, a small scale of attention improved contrast sensitivity for Gabors of high spatial frequency content. While this provides evidence largely consistent with SSE, it is important to note that in this study, the lower spatial frequencies are perhaps too high to tap magnocellular processing (e.g. see Skottun & Skoyles, 2011). Therefore, future work using stimuli which more cleanly taps into magnocellular mediated, low spatial frequency perception is needed.

Finally, by testing the effect of attention scaling on global motion perception, there has been some indirect evidence favouring the selective SSE account (Burnett, d'Avossa, & Sapir, 2013). Global motion processing is measured behaviourally using Random Dot Kinematograms (RDKs). RDKs are constructed by presenting an array of moving dots, where a subset of dots move coherently, and others move randomly (Edwards & Badcock, 1994; Newsome & Pare, 1988). To perceive motion, the dorsal visual system is engaged to pool the motion signal. This is important, as some research suggests that there are neuronal pathways projecting from magnocellular neurons through to global motion processing areas of the brain (e.g. the dorsal visual pathway and motion processing area MT; Denison et al., 2014; Derrington & Lennie, 1984; Goodale & Milner, 1992; Livingstone & Hubel, 1988; Maunsell & van Essen, 1983; Mishkin, Ungerleider, & Macko, 1983; however see Nassi & Callaway, 2009). Therefore, it is possible that the effects of attentional scaling on motion processing may be linked to influence of attention on the magnocellular visual pathway.

Recently, Burnett and colleagues (2013) measured the effect of attention scaling on global motion perception. In Burnett et al.'s study, attention could be oriented using a peripheral, non-informative exogenous cue to one of four possible locations. These four locations contained RDKs, which either consisted of noise dots (3 locations), or a coherent motion signal (1 location). Participants decided the direction of coherent motion. Furthermore, on 50% of trials, a red dot probe appeared at one of the four locations (not necessarily the same location as the motion stimulus). Where relevant, participants indicated in which location the dot probe appeared. Across trials, cue size changed, such that the cue matched the size of the RDK (11° in diameter), or was smaller, and fit inside of the RDK (4° in diameter). Consistent with the SSE account, small and large exogenous cues produced equivalent validity effects for RDK task, though only the small cue produced validity effects for the dot probe task. This indicates that the size of the cue had little to no effect on global motion processing, and suggest that attentional scaling has minimal influence on visual processing related to global motion perception. If one accepts that magnocellular perception may contribute to global motion processing, this provides further converging evidence favouring the SSE account.

6.4.3. Spatiotemporal Trade-off Account

Although Goodhew and colleagues found that attentional scaling has minimal effects on magnocellular related visual processing, there are still other studies have found narrow attention to impair magnocellular mediated perception. For example, Mounts and Edwards (2017) used a peripheral cueing task to manipulate attention scale. Here, either an arc of a circle (30° to 120° segments of circles), or a parallel line (length of 1.25° to 6.25°) of differing sizes was briefly flashed to alert the participant to the particular location of an upcoming target. When the cued region was small, it was assumed attention narrowed, and when the region was large, attention broadened. Immediately following the cue, either spatial or temporal stimuli were presented. The spatial and temporal stimuli used were similar to those used by Goodhew et al. (2016), which can be inferred to tap parvocellular and magnocellular processing. Critically, unlike Goodhew et al. (2016), Mounts and Edwards found that although narrow attention improved spatial acuity relative to broad attention, it impaired temporal acuity. This suggested that in some cases, rather than having no effect, narrow attention could impair magnocellular mediated perception.

Furthermore, earlier research conducted by Shulman and Wilson (1987) suggests that broadly scaled attention may improve low spatial frequency detection. Here, Navon letters were used to manipulate attention as has been done previously (Borst & Kosslyn, 2010; Navon, 1977, 2003). Navon letters are constructed by combining smaller letters to make the shape of one larger letter. Therefore, one can attend to the local level (i.e. the small letters) and determine their identity, or attend to the global level to determine the larger letters identity. When attending to the local letters, it can be assumed that attention is narrowed. In contrast, when attending to the global letters, attention is broadly spread. In Experiment 1 of Shulman and Wilson (1987), on a trial by trial basis, participants attended to, and discriminated local elements (.2° x .2° in size) or global elements (2° x 2° in size) of Navon letters. Alongside this, on 50% of trials either a high spatial frequency or low spatial frequency Gabor was presented with the Navon figure. At the end of the trial, participants were required to state whether the Gabor was present or absent, as well as what spatial frequency content was presented. Critically, when participants attending to the local elements (i.e. narrow attention), contrast sensitivity for the high spatial frequency Gabors improved. However, when attending to the global elements (i.e. broad attention), contrast sensitivity for the low spatial frequency Gabors improved. This implies that while narrow attention improved parvocellular mediated perception, broad attention enhanced magnocellular mediated perception.

However, changes in spatial frequency sensitivity observed here may be largely due to changes in categorical/feature-based attention, rather than spatial attention per se (Robertson et al., 1993). That is, rather than altering spatial attention to be broad (encompassing the entire Navon figure), or narrow (encompassing only a single letter), it is possible that observers were able to tune their cognitive resources to either the global, low spatial frequency aspects of the Navon letter, or the high spatial frequency local components, while keeping their spatial attentional scale consistent. Although research suggests that spatial attention, object-based attention and feature-based attention interact on a day to day basis (e.g. see Kravitz & Behrmann, 2011), future research is needed to in order to disentangle exactly if (and how) feature-based attention versus spatial attention differently influence parvocellular and magnocellular mediated visual perception.

That narrow attention could impair performance in low-spatial-frequency and temporal-gap-acuity tasks is also physiologically plausible when considering the constraints of the visual system. Indeed, as an alternative to the SSE account, Goodhew et al. (2016) also proposed the Spatiotemporal Trade-off Account (STA). This account suggests that differences in attentional scale may map onto the different receptive field sizes of parvocellular and magnocellular neurons, consequently having varying effects on perception. Indeed, while parvocellular neurons have small receptive fields, magnocellular neurons have relatively larger receptive fields. Narrow attention may preferentially require the smaller receptive fields of parvocellular neurons, enhancing spatial acuity, and impairing temporal acuity, while broad attention would map onto the larger receptive fields, calling on magnocellular input to enhance low spatial frequency perception and temporal acuity, while impairing high spatial frequency perception and spatial acuity.

6.4.4. Attentional Attraction Field Account

Finally, an alternate explanation for the findings of Mounts and Edwards (2017) is Baruch and Yeshurun (2013) attentional attraction field (AAF) account. The AAF was originally developed to explain the functioning of attentional shifts. The primary assumption of this account is that under attentional focus, the receptive fields of cells at different levels of the visual hierarchy converge, and subsequently, overlap one another. This contraction of receptive fields to a single location allows for both increased spatial and decreased temporal resolution. Increases in spatial resolution occur as the overlapping of receptive fields allows for a higher sampling rate of the attended area, and thus, increased ability to perceive fine detail. In contrast, decreases in temporal resolution occur due to this increased population response of cells converging at the attended location, thereby diffusing a precise temporal signal. Specifically, the increased activation increases the strength and variability of cellular responses at the attended location, causing a prolonged population response. This makes it more likely that two temporal events in close proximity are perceived as a single event, thus lowering temporal resolution. Therefore, Mounts and Edwards (2017) proposed that instead of differentially influencing parvocellular and magnocellular neurons, in their study, the varied effects of attentional scaling on spatial and temporal resolution may have been due to increased convergence of visual cell receptive fields under narrow, compared to broad attention. That is, narrow attention would attract receptive fields to a smaller, overlapping spatial region, thus increasing spatial acuity, and decreasing temporal acuity. As both the STA and the AAF account both predict the same behavioural outcome via different physiological mechanisms, currently, behavioural evidence is unable to distinguish between the two accounts.

6.4.5. Interim Summary

The zoom lens, SSE, STA, and AAF accounts each outline how attentional scaling might influence visual processing. All four accounts of attentional scaling propose that narrowing attention improves performance on parvocellular mediated behavioural tasks, such as spatial gap acuity and letter discrimination. However, the predictions of the accounts diverge when elucidating the role of narrowing attention on performance for magnocellular mediated behavioural tasks (Figure 6.4 While the Zoom Lens Account argues that narrowing attention improves all aspects of visual processing, more recently developed accounts propose that the effects of attentional scaling on magnocellular mediated perception differ, where narrow attention either has none, or a negative impact on low spatial frequency perception and temporal resolution. Complicating this, each theory has unique pieces of supporting evidence, all of which demonstrate complex and varied effects of attention and perception. Here, we believe that to fully understand how attention scaling influences vision, the differences in these studies, and their outcomes must be critically analysed. Specifically, the varied effects found in the literature may be largely due to the distinct methods that each of the studies have used to alter attentional scale. Therefore, in the following section, we focus on evaluating the methodological differences present in key papers supporting each theoretical model, so to provide much needed clarity to the literature.

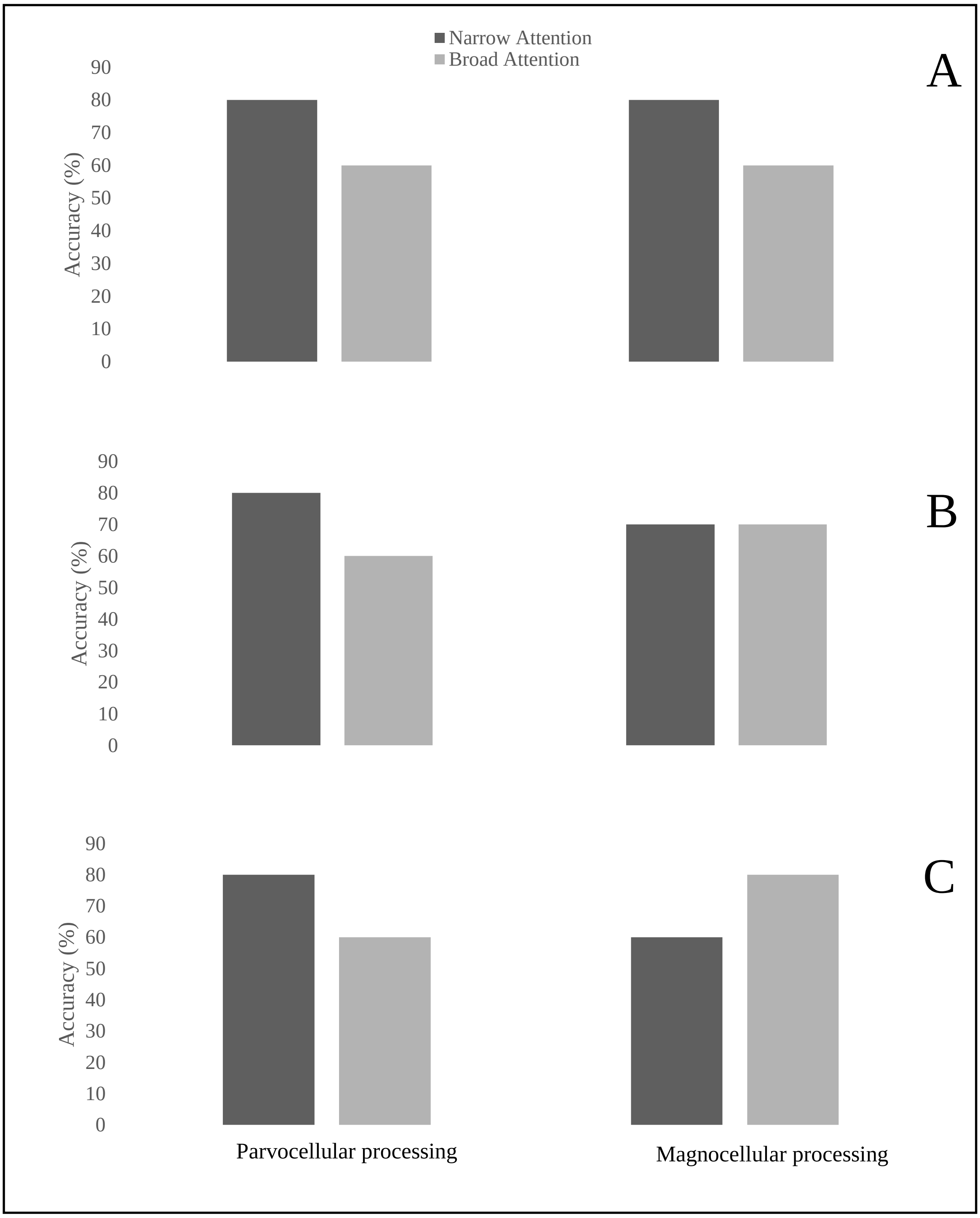

Figure 6.4. The effects of attentional scaling on visual processing as predicted by the Zoom lens account (A), the SSE Account (B), and the STA and AAF Accounts (C). Each account declares differing effects of narrowed attention on temporal acuity.

6.5. Methods of Attentional Manipulation

6.5.1. Endogenous and Exogenous Attention

As evident from the above review, the methods used to manipulate and measure the effects of attention scaling on vision are widely varied, and in turn, may contribute to the discrepant effects scaling appears to have on magnocellular mediated visual perception. For instance, all four accounts of attentional scaling and vision are agnostic as to how endogenous versus exogenous scaling might influence vision. This is surprising, as unpacking exactly how endogenous and exogenous scaling might influence perception may provide much-needed clarity to the literature (Mounts & Edwards, 2017).

Broadly, endogenous, or ‘top-down' attention is typically thought of as internally, goal driven attention and exogenous, ‘bottom-up' attention is thought of as externally driven, goal irrelevant attention (Awh et al., 2012; Carrasco, 2011; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). Attentional scaling has been manipulated exogenously using both central and peripheral cueing paradigms, where the size of a briefly presented luminance change is altered to capture and set attention (Greenwood & Parasuraman, 1999, 2004; Greenwood et al., 1997; Jefferies & Di Lollo, 2017; Mizuno, Umiltà, & Sartori, 1998; Mounts & Edwards, 2017; Turatto et al., 2000; Umiltà, 1998). In contrast, endogenous attention is thought to have a slower time course, be sensitive to manipulations of cognitive load. For example, endogenous attention has been manipulated using central cueing procedures, which indicate the spatial region over which attentional resources should be deployed for upcoming target detection (Balz & Hock, 1997; Goto et al., 2001; Müller et al., 2003; Poggel et al., 2006; Shiffrin, McKay, & Shaffer, 1976).

Although the dichotomization of attention into endogenous and exogenous factors has proved useful for understanding the dynamics and flexibility of attentional scaling using response time measures (e.g. Benso et al., 1998; Turatto et al., 2000; Umilta, 1998), it is important to note that there has recently been substantial debate in regards to the utility of this distinction. (Benso et al., 1998; Turatto et al., 2000; Umiltà, 1998). In particular, Theeuwes and colleagues have argued that rather than considering spatial attention components comprising a dichotomy, instead, they can be considered as a trichotomy: endogenous factors; exogenous factors; and selection history (Awh et al., 2012; Failing & Theeuwes, 2017). Selection history is conceptualised as the enduring influence of attention across time, regardless of top-down and bottom-up attentional forces (Awh et al., 2012; Failing & Theeuwes, 2017; Theeuwes, 2018). For instance, Fuggetta, Lanfranchi, and Campana (2009) used visual search arrays of varying sizes to manipulate the spatial scale of attention via selection history. A search array, of a particular size, was repeated over a series of trials. This repetition led to faster processing times in the visual search task when the size of the search array remained consistent. In contrast, when the size of the search array changed, response times for visual search were substantially slower. Likewise, global versus local attention has been reliably manipulated via trial repetition of Navon letters (e.g. Hubner, 2000). Nonetheless, while Theeuwes and colleagues suggest this is a distinct process to endogenous attention, we believe that selection history can suitably be categorised as an element of top-down attention scaling. That is, selection history can be conceptualised as the carryover or hysteresis of an endogenous effect which takes some time to instantiate (e.g. effects may increase over first few trials in a block) and does not decay immediately after a goal is removed (Egeth, 2018). Indeed, Egeth argues that rather than separating attentional effects into three separate categories, endogenous and exogenous attention can be broadly considered to be ‘cognitive’ and ‘perceptual’ phenomena, which both have different subclasses, and sometimes differing effects on behavioural outcomes. While changes in the environment may trigger perceptual adjusting of attention, trial repetition, or volitional goals are cognitive mechanisms of attentional adjustment.

Understanding the separate roles of endogenous and exogenous scaling on visual perception is important as a parallel literature suggests that when attention is *shifted*, endogenous versus exogenous attention have qualitatively different effects on parvocellular and magnocellular mediated processing (Hein et al., 2006; although see Prinzmetal et al. 2005). That is, while exogenous shifts of attention improve parvocellular mediated spatial acuity and impair magnocellular mediated temporal acuity (Yeshurun & Levy, 2003), endogenous attentional shifting enhances both spatial and temporal acuity (Hein et al., 2006). Mounts and Edwards (2017) noted that since this exogenous/endogenous distinction is so critical for shifts of attention, there is a distinct possibility that it might also be equally important for attentional scaling. Therefore, understanding how endogenous versus exogenous attentional scaling influences visual perception will help disentangle the circumstances under which narrowing attention scale either improves, has no influence on, or impairs magnocellular mediated processing (Mounts & Edwards, 2017).

Indeed, Mounts and Edwards (2017) recently suggested that endogenous versus exogenous attentional scaling may explain the difference in empirical findings of Goodhew et al. (2017, 2016) and their own studies. This may provide clarity as to the explanatory power of the SSE and STA accounts of scaling. As shown in Figure 6.5, Goodhew and colleagues used a shape inducer paradigm to manipulate attention scale. Although the authors did not specify whether their shape inducer paradigm utilised endogenous or exogenous attention, the task may be considered more endogenous than exogenous (Mounts & Edwards, 2017). This is because on each trial, participants were required to voluntarily interpret form information at different spatial scales (sizes). When inducer shapes were small, to complete the task correctly, an observer needed to internally adjust the region over which their attention was spread to a small spatial area. In contrast, when the shapes are large, they must have voluntarily widened their region of attention to perceive form differences. Furthermore, the inducer task is completed via a trial repetition. For the manipulation to work, participants must learn to not only adjust, but maintain their scale of attention across time, which requires effortful, goal directed cognitive resources (i.e. sustained attentional component to maintain the region over which cognitive resources are deployed). Indeed, early research exploring attention flexibility suggest that while exogenous attention can initially set the size of the attention scale, sustained cognitive effort is required to maintain a particular attended region size (Turatto et al., 2000).

In contrast, Mounts and Edwards' (2017) peripheral cueing paradigm can be seen as a more exogenous manipulation of attention (Figure 6.6). On each trial, a participant's attention is captured by an external luminance change. It is thus assumed that participants automatically scale their attention to the size of the cued region, regardless of their goal of target detection, which requires relatively less cognitive effort. Further, the time interval between the cue and target is relatively short (i.e. 90ms), thus necessitating the use of faster attentional mechanisms. Therefore, it is possible that when attention is scaled endogenously in Goodhew and colleagues studies, there is no impact on magnocellular mediated perception, whereas when attention is scaled exogenously, broadening attention can improve magnocellular related processing.

Nonetheless, it is important to recognise that Mounts and Edwards manipulation may not be a purely exogenous manipulation. In particular, in the study, the cue itself was predictive of the region in which the target would appear in on 100% of trials (although not 100% predictive of the exact target location). Given that exogenous attention is, by definition, goal irrelevant, this level of cue-target predictability may have caused the perceptual effect of attention scaling on vision, rather than the more exogenous elements of the overall procedure. Recall that in Prinzmetal et al. (2005), the authors found automatic shifts of attention to only influence response time, and not accuracy. Therefore, it is possible that the inclusion of a slightly endogenous element to Mounts and Edwards (2017) was crucial in obtaining differences in perceptual sensitivity for parvocellular and magnocellular perception. As such, it would be fruitful for future research to systematically test purely endogenous, versus purely exogenous attention scaling on all aspects of visual perception. In line with Prinzmetal et al. (2005), it may be the case that purely exogenous scaling has no influence on perceptual sensitivity, instead solely influencing response time and decisional criteria.

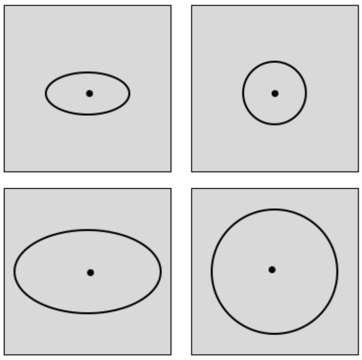

Figure 6.5. Shape Inducer Task used by Goodhew and colleagues (inducer sizes not to scale). The participant’s task is to determine the shape presented on a trial by trial basis at either a small (top) or large (bottom) spatial scale. Inducer size was blocked so that participants would adopt either a narrow or broad focus of attention across a series of trials.

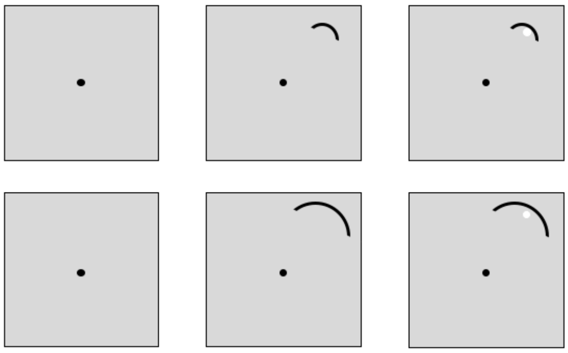

Figure 6.6. The peripheral cueing task used by Mounts and Edwards (2017). Each trial, participant's attention was cued to either a small or broad region of the visual field via a brief luminance change (cue), which varied in size. Following the cue, the target, either a spatial or temporal acuity target appeared.

Finally, it is important to note that the distinction between endogenous and exogenous attention scaling as provided by Mounts and Edwards (2017) is unable to account for all attentional scaling effects on vision. While endogenous attention scaling had no influence on magnocellular mediated perception in Goodhew et al. (2017, 2016), there are cases where either endogenous narrowing, or broadening of attention scale has altered magnocellular mediated processing. For example in contrast to Goodhew and colleagues, Poggel et al. (2006) found narrow attention to improve temporal resolution. Recall that in this study, participants were conducting an endogenous visual search for a double pulse target in an array of nine lights. The authors found broad attention impaired temporal sensitivity. Similarly, Shulman and Wilson's (1987) Navon letter study found that broad attention can improve magnocellular perception. In this study, participants had to both complete a Navon letter task, while also monitoring for either high spatial frequency, or low spatial frequency Gabor probes. Here, broad attention improved performance for low spatial frequency stimuli target detection, while narrow attention improved target detection for high spatial frequency stimuli. Thus, this task can be seen as largely endogenous, as participants voluntarily attended to either the global or local level of the primary task. As such, rather than concluding that all scaling effects can be accounted for via the endogenous/exogenous distinction, it is important to consider other methodological factors which may mediate this relationship.

6.5.2. Stimuli Used to Manipulate Attention Scale

Apart from endogenous and exogenous attention, the particular stimuli used to manipulate attention scale has also varied across studies, and could in turn, explain the discrepant results for magnocellular mediated perception in the literature. For instance, many studies use procedures employing different sized unfilled shapes and shape segments to alter the region over which cognitive resources are spread. Across these studies, the effects of scaling on magnocellular mediated perception have been negligible. For example, recall that in Goodhew et al. (2017, 2016), unfilled shapes differing in size were shown over a series of trials, which were intended to alter attention scale. These authors found that narrowing attention had no impact on magnocellular mediated temporal acuity, or low spatial frequency perception. Similarly Burnett et al. (2013) used different sized unfilled cues to orient attention to the potential locations of global motion targets. Again, the effects of scaling on the magnocellular related process appeared to be minimal. Finally, Goto et al. (2001) used ring stimuli to alter attention, finding scaling to have no effect on contrast sensitivity for low spatial frequency stimuli.

As such, it appears likely that previous null findings of attentional scaling and magnocellular mediated visual processing in the literature might be in part due to the use of unfilled shapes to manipulate attention scale. One possibility as to why different sized unfilled shapes have no effect on magnocellular mediated perception is that they encourage observers to deploy an annulus of attention. When structure is present in a scene (such as via an unfilled shape), research has found that individuals may distribute attention as an annulus, focusing resources on the edges of the stimuli (Egly & Homa, 1984; Jefferies & Di Lollo, 2015; Lawrence et al., 2018; Taylor et al., 2015). Therefore, for studies attempting to manipulate attention using unfilled shapes, it is possible that the different type of attentional deployment used by participants (i.e. an annulus distribution of attention), may not influence magnocellular mediated visual processing in the same manner that attention scaling does.

In contrast, studies finding attention scaling to influence magnocellular mediated processing use tasks which do not entail an annulus distribution of attention. Instead, these tasks require attention to be spread evenly across the visual field. For example, Shulman and Wilson (1987) used Navon letters which require an individual to attend to both the global structure of the shape and smaller local elements simultaneously. Thus, the task requires a somewhat even distribution of attention across the stimulus range. Likewise, Poggel et al. (2006) requires participants to attend to peripheral and central target locations simultaneously to detect a luminance change in an array of 9 lights. Although the luminance dots were arranged as an annulus, they do not provide as clear edges as unfilled shapes do. Critically, both of these studies found attention scaling to have an effect on magnocellular mediated perception, without using unfilled shape stimuli to manipulate attention (although the direction of this effect was varied). As such, future research should aim to use methods of attention scale manipulation, which directly encourage an even spread of attention across the entire stimulus region.

6.5.3. Task Complexity

Although the particular type of stimulus used to manipulate attention scale is able to account for a large majority of null findings in the literature, it is still evident that studies which do not adopt unfilled shape stimuli still have somewhat conflicting findings. In particular, while Shulman and Wilson's (1987) research indicates that narrowing attention scale impairs magnocellular mediated visual processing, Poggel et al. (2006) found evidence that narrowing attention can improve magnocellular mediated perception. Both of these studies used a method of attentional manipulation which would encourage an even distribution of attention, rather than an annulus distribution. Therefore, in the following section, we discuss one possible way to explain these discrepant findings: task complexity.

The difficulty of an experimental task may influence how attention is scaled, and therefore, the effect of attention on different channels of visual perception (Caparos & Linnell, 2010; Lavie, 1995, 2005; Lavie, Hirst, De Fockert, & Viding, 2004; Linnell & Caparos, 2011, 2013; Parks, Beck, & Kramer, 2013). Specifically, task complexity can be operationalized via differences in the overall amount of perceptual and cognitive load placed on a participant while completing a task, where higher amounts of perceptual and cognitive load lead to greater task complexity. Perceptual load refers to the complexity of visual stimuli and information to be processed in a scene (Lavie, 1995; Linnell & Caparos, 2013) . For example, a visual search where distractors show little similarity to the target may be considered a low perceptual load task, and a search where distractors are heterogeneous and similar to the target may be considered a high perceptual load task (Roper, Cosman, & Vecera, 2013). In contrast, cognitive load can be thought of as the amount of cognitive/intellectual resources required to complete a task. For example, a high cognitive load task may require participants to complete a complex mathematical equation, and a low cognitive load task may require participants to complete a simple equation (Lavie et al., 2004).

Changes in both perceptual and cognitive load have differing effects on attentional scaling. High levels of perceptual load cause attention to narrow. For example, Figure 6.7 demonstrates a perceptual load manipulation used in a seminal study by Lavie (1995). Typically, the participant's task is to identify the central letter in the display, while peripheral distractors that are either the same or different to the target are in displayed in the periphery. Under levels of low perceptual load, the distractor letter interferes with the processing of the target letter, where target discrimination response times are slower. In contrast, under high perceptual load, the distractor letter has minimal influence on central letter processing. This suggests that while low perceptual load leads to a broader scale of attention, higher perceptual load leads to attentional narrowing. This is because a narrower scale of attention should reduce distractor processing, and thus result in faster processing speeds.

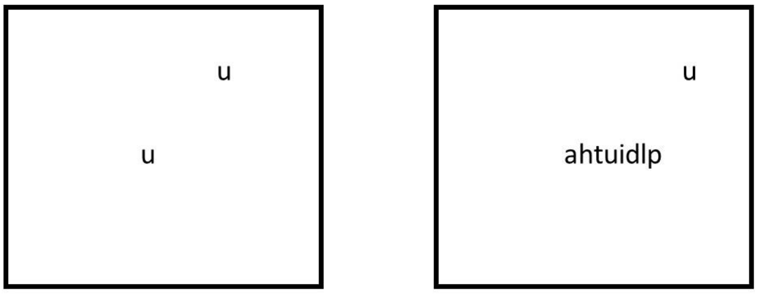

Figure 6.7. Example of a low (left) and high (right) perceptual load display adapted from the original studies of perceptual load theory (Lavie, 1995). Participants' would be asked to identify the presence or absence of the target letter (u) shown at the middle of the display.

Changes in cognitive load have the opposite effect on attentional scaling. For example, while completing a flanker task similar to that shown in Figure 6.7 (left), changes in working memory load can alter the level of distractor processing. Here, before completing the flanker task, participants were required to remember either 1, or 6 digits. After the flanker task, participants were shown another number, and were asked to indicate if they were previously shown that number. Critically, it was found higher levels of cognitive load broadened attention compared to lower levels of cognitive load, whereby flanker letters interfered with central target processing to a greater degree in the high cognitive load condition (Lavie, Hirst, De Fockert, & Viding, 2004). Finally, more recent research has demonstrated that when both cognitive and perceptual load are varied within a single paradigm, perceptual load influences attentional scaling, but only under low cognitive load (Linnell & Caparos, 2011)

Taken together, the empirical evidence to date strongly indicates that either increasing perceptual or cognitive complexity can unintentionally alter the spatial scale of attention. Therefore, the differing effects of scaling on magnocellular mediated processing in attentional scaling studies might be at least partly due differences in cognitive and perceptual load. For example, a study conducted by Carmel, Saker, Rees, and Lavie (2007) exploring attentional resource availability and temporal resolution provides indirect evidence that broadening attention, via changes in perceptual load, may improve magnocellular mediated perception. This is consistent with the STA of attention scaling. In this study, over a series of experiments, participants completed low and high load visual search tasks. As the results of all experiments in the paper suggest a similar pattern of findings, here we describe the methodology from Experiment 1. The visual search task consisted of a circular arrangement of letters centred around fixation at an eccentricity of 2.9°. In the low load conditions, which was likely to broaden attention, participants discriminated between letters X and N, among a set of homogenous distractors (i.e. placeholder shapes) allowing the target letter to ‘pop’ out. In the high load task, which was likely to narrow attention, the distractors were other non-target letters, requiring the participant to deploy more attentional resources to discriminate. During the presentation of the visual search task, a central light was presented, which either flickered, or was presented continuously. Following stimulus presentation, participants were required to report whether an X or N was presented, as well as whether the light was presented continuously, or if it flickered. Compared to the low load condition, under high load, temporal resolution worsened (i.e. lower ability to detect the flicker).

Carmel et al. (2007) explained their results in relation to perceptual load theory (Lavie, 1995). Specifically, it was suggested that high load tasks require a lot of attentional resources. Thus, when processing temporal flicker, there are less resources available, leading to degraded temporal resolution in central vision. In contrast, when perceptual load is low, there is a relatively higher amount of perceptual resources available to process temporal flicker, leading to improved performance. However, if we accept that perceptual load changes the spatial scale of attention, it is likely that the narrow attention decreased temporal resolution in this study. That is, higher perceptual load can cause a broadening of attention.

Interestingly, Carmel et al. (2007) suggest that by considering perceptual load, their findings are directly reconcilable with Poggel and colleagues (2006). Recall that in Poggel et al. (2006) attention scale was directly manipulated, where participants searched for a double pulse light target that appeared at one of nine possible locations. The spatial layout of the lights was altered to manipulate scale (i.e. the lights were presented in rings around fixation with radii of 2.5° to 20°). Overall, temporal resolution was improved for the narrow attention condition. To explain this finding, Carmel et al. (2006) suggest that the narrow attention condition constituted low perceptual load, whereas the broader attention condition constituted high perceptual load. This was because they assumed the broad attention condition was of higher task complexity, and thus, more perceptually difficult. As such, in Poggel et al. (2006) low perceptual load in the narrow attention condition was able to improve temporal resolution.

The discrepancy between Carmel et al. (2006) explanation of their findings and our interpretation of the data points to a broader issue in using the basic perceptual load models, without considering attention scale, when trying to explain the relationship between perception and cognition (for a detailed discussion on this issue, see Chen & Cave, 2013, 2014, 2016). Although from the above discussion, it is not clear exactly how differences in perceptual and cognitive load would produce the precise pattern of results found to differ across studies showing varying effects of scaling on magnocellular mediated perception, it is certain that differences in perceptual and cognitive demands utilised across different attentional scaling paradigms would add to the complexity of data obtained. In turn, this extra noise makes it difficult to assess which theory of attentional scaling and vision might best explain the empirical results to date. As such, future work should closely examine how varying levels of cognitive and perceptual load act to alter attention, and subsequently differing aspects of visual perception. This will help clarify exactly how different accounts of attentional scaling and vision might apply to different types of attentional processing.

6.5.4. Stimulus Eccentricity

Finally, apart from differences in task complexity, the use of central versus peripheral stimulus presentation can unduly influence the dynamics of attentional scaling and vision, and may account for a large degree of inconsistency in the literature regarding magnocellular mediated processing. Indeed, the use of central versus peripheral stimuli has several implications for attention scaling and vision. Firstly, compared to central stimulus displays, presenting stimuli in the periphery requires an attentional *shift*, as well as a change in attentional scale (e.g. Mounts & Edwards, 2017). The conflation of attentional shifting and scaling is particularly problematic, as attentional scaling and shifting are independent mechanisms, showing different time courses, as well as having unique effects on visual perception (Benso et al., 1998; Castiello & Umiltà, 1990; Hein et al., 2006; Turatto et al., 2000; Yeshurun & Levy, 2003). For example, recent work shows that focusing versus shifting attention differentially influences the perception of crowding in central versus peripheral visual field (e.g. Albonico, Malaspina, Bricolo, Martelli, & Daini, 2016).

Secondly, apart from conflating attentional scaling and shifting, studies using peripheral cueing procedures typically manipulate target uncertainty (for example, Mounts & Edwards, 2017 peripheral cueing procedure). While it is possible that target uncertainty may encourage attention scaling, it is possible that by presenting stimuli peripherally, rather than observers adjusting their scale of attention to the size of a cued region, an observer may adopt a smaller sized attention scale to the area cued, and shift their attention within the cued region to find a target. This would mean that instead of measuring the impact of attention scaling on perception, the influence of search array size becomes the variable of interest. Indeed, the null findings of scaling on temporal acuity observed in Goodhew et al. (2017), when target location uncertainty was manipulated, suggests that location uncertainty is not necessary for attention scaling. Thus, an experimental manipulation which lowers the variance of target uncertainty by presenting stimuli centrally allows for a cleaner measurement of attentional scaling effects. This is because it minimizes the chance that each participant uses a different strategy to complete the task.

Finally, it is important to note that comparing the data between attentional scaling studies which present stimuli either centrally or peripherally may be inappropriate, as peripheral stimulus presentation is more likely to engender a larger proportion of eye movements, compared to central stimulus presentation. This is particularly problematic for studies measuring attentional scaling effects on magnocellular related tasks that do not control or record saccades. When eye movements occur, there is a reduction in the visual systems sensitivity to visual input, particular for magnocellular mediated stimulus processing. This is labelled saccadic suppression (e.g. Krekelberg, 2010). Given that high frequency temporal resolution requires a large amount of magnocellular input, eye movements should be minimised, or controlled for in attentional scaling studies. Doing so will allow for cleaner conclusions regarding attention and visual processing more generally.

6.6. Summary

The above analysis illustrates that although attentional scaling effects on parvocellular related processing (e.g. spatial acuity) are somewhat consistent, whereby narrow attention improves visual processing, the effects of scaling on magnocellular related processing (e.g. temporal acuity) are more complex. Critically, current accounts of attentional scaling; The Zoom Lens, SSE, AAF and STA accounts all make differing predictions as to how magnocellular vision is affected, and different studies have provided support for each of the accounts. Here, we have demonstrated that much discrepancy in the literature can be explained by considering the use of unfilled shapes to manipulate attention, the roles of endogenous and exogenous attention, as well as the potential roles of task complexity and stimulus eccentricity on the specific effect scaling has on magnocellular improvement (or impairment). While it cannot yet be claimed that changes in task complexity and eccentricity cause either magnocellular impairment or enhancement, we believe that a systematic exploration of these factors will provide a full understanding of exactly how scaling influences all aspects of visual perception.

Finally, it is noteworthy that attentional scaling can be altered via a number of individual factors. A substantive body of research has found that working memory capacity, age, mood, personality, culture, and sports expertise can all influence preferred attention scale (e.g. Boduroglu & Shah, 2017; Boduroglu, Shah, & Nisbett, 2009; Hüttermann & Memmert, 2015; Hüttermann, Memmert, & Simons, 2014; Kosslyn, Brown, & Dror, 1999; Kreitz, Furley, Memmert, & Simons, 2015; Lawrence, Edwards, & Goodhew, 2018; Wilson, Lowe, Ruppel, Pratt, & Ferber, 2016). Therefore, future research should explore whether the relationship between scaling and perception is consistent for these different groups. For example, a very recent study conducted by Boduroglu and Shah (2017) explored whether cultural background influences attentional scaling and spatial resolution. Chinese and American participants completed a function field of view task, where response times to detect targets at differing eccentricities were measured. It was found that American's were better able to localise targets, suggesting they adopted a narrow distribution of attention for enhanced resolution.

Attentional scaling is a fundamental cognitive process, allowing us to narrow our cognitive resources to relevant locations in the visual field, while filtering out sensory noise. Early accounts of attentional scaling assumed that narrowing attention unequivocally improves visual processing, however, accumulating evidence indicates the relationship between spatial attention and visual perception has far more complexity. Here, we argued that to fully understand attention scaling, the neural pathways involved in visual processing; endogenous versus exogenous attention; the particular stimuli used to manipulate attention, task complexity; and stimulus eccentricity all must be considered conjointly. This is because these factors combine to create unique influences of attentional scaling on vision. Based on these complexities, future research should aim to carefully demarcate the roles of these factors in scaling and vision.

Chapter 7: The impact of scaling rather than shaping attention: Changes in the scale of attention using global motion and Glass inducers influence both spatial and temporal acuity

7.1. Foreword

Having reviewed the major models describing the relationship between attentional scaling and vision, in Chapter 7, the aim was to further explore two specific models of attentional scaling and visual perception: the zoom lens model, and the selective spatial enhancement model. While the zoom lens model argues that narrowing attention improves all aspects of visual processing, the selective spatial enhancement model states that changes in attentional scale influence vision mediated by the parvocellular, and not the magnocellular channel of vision. However, the selective spatial enhancement model has only been tested using one specific method of attentional induction, which used different sized shapes to alter the distribution of attention. This shape inducer method may not have manipulated attentional scaling, rather, it may have caused attention to be deployed as an annulus. Therefore, a new method of attention induction was developed which requires attentional scaling.

Australian National University

Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

Title: The impact of scaling rather than shaping attention: Changes in the scale of att. using global motion & Glass inducers influence both spatial and temporal acuity.

Authors: Rebecca K. Lawrence, Mark Edwards & Stephanie C. Goodhew

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M. Edwards

Rebecca Lawrence		9/4/2019
Candidate – Print Name	Signature	Date

Endorsed

Stephanie Goodhew		9/4/2019
Primary Supervisor – Print Name	Signature	Date
M. Edwards		9/04/2019
Delegated Authority – Print Name	Signature	Date

7.2. Abstract

Originally, the zoom lens model of attention scaling proposed that narrowing attention to a small area of the visual field improves visual perception (Eriksen & James, 1986). This model is supported by a large body of empirical evidence, showing that narrow attention enhances performance in spatial acuity tasks. Despite this, the zoom lens model does not explicitly consider how attention scaling influences different elements of vision, for example, temporal processing. More recent models of attention scaling suggest that scaling has different effects on spatial and temporal acuity (Goodhew et al., 2017, 2016; Mounts & Edwards, 2017). However, the evidence to date supporting these models has had one major pitfall: different sized *unfilled* shapes are presented in attempt to focus attention in, or spread it out broadly. This is problematic because participants may not spread their attention across the entire region defined by unfilled shapes, instead, attending to only the annulus region of the shape inducer. To address this, we developed a new method to manipulate attention, one which requires perception of information across the entire stimulus, not just around the outer border. We then tested the influence of attention scaling on perception using spatial and temporal gap tasks, thought to be processed by the parvocellular and magnocellular visual channels. Across two experiments, we found that narrowing attention scale improved both spatial and temporal acuity. This challenges recent research suggesting that attention scaling has differential impacts on parvocellular and magnocellular processing, instead supporting the zoom lens model, proposed over 30 years ago.

Keywords: Visual Attention, Spatial Attention, Vision, Zoom Lens Model

7.3. Introduction

Humans use spatial attention to filter visual information, triaging certain stimuli for enhanced processing while suppressing others (Desimone & Duncan, 1995; Posner, 1980). Here we were interested in understanding how changing the *scale* of attention influences perception; that is, the narrowing or broadening of spatial attentional resources across the visual field (Eriksen & James, 1986; Eriksen & Yeh, 1985; Greenwood & Parasuraman, 1999, 2004). Note that attentional *scaling* is a distinct form of attentional regulation to *shifting* the centre of the attended location (covert shifts of attention, Carrasco, 2011) or *splitting* attention to multiple regions simultaneously (Castiello & Umiltà, 1992).

Eriksen and James' zoom lens model proposed that narrowing attention enhances all aspects of perceptual processing (Eriksen & James, 1986). Specifically, the model does not specify whether attention scaling has different effects on different types of visual perception, and therefore, it can be inferred that the model predicts that the benefit of narrowing attention applies to all aspects of visual perception. There is a large body of behavioural and neuroimaging evidence supporting the zoom-lens model, where narrow attention has been found to improve target detection response times and spatial resolution (e.g. Balz & Hock, 1997; Castiello & Umiltà, 1990; Eriksen & James, 1986; Eriksen & Yeh, 1985). Furthermore, Müller et al. (2003) have found narrowing attention to increase the intensity of the BOLD response in the primary visual cortex compared to broad attention.

Nontheless, most of the studies that have obtained evidence in support of the model have used visual stimuli that require the processing of fine-grained spatial information. While the ability to resolve rapid changes in luminance across space is an important aspect of perception, perception involves more than just this fine spatial acuity. For example, temporal acuity is another important aspect of perception – that is, the ability to resolve rapid changes in luminance across time. Critically, although only a handful of studies have explored the influence of attentional scaling on temporal processing, they have found conflicting results (e.g. Goodhew et al., 2017, 2016; Mounts & Edwards, 2017; Poggel et al., 2006).

The distinction between spatial and temporal acuity is important for two reasons. Firstly, spatial and temporal detail are processed by two somewhat separable visual channels: the parvocellular and magnocellular channels respectively. Compared to magnocellular neurons, parvocellular neurons have small receptive fields, and increased responsivity to colour and fine spatial detail, but reduced sensitivity to high temporal frequencies. Parvocellular neurons predominantly project to ventral visual areas, which are important in colour and form processing. In contrast, magnocellular neurons have large receptive fields, and are more responsive to low spatial frequency, coarse information, as well as higher temporal frequencies. Magnocellular neurons predominantly project to the dorsal visual pathway, which is involved in motion processing and object localisation (Denison et al., 2014; Derrington & Lennie, 1984; Livingstone & Hubel, 1988; Maunsell & van Essen, 1983; Mishkin, Ungerleider, & Macko, 1983; Nassi & Callaway, 2009). While in daily living, the two visual streams must interact to produce a coherent percept of the outside world, parvocellular neurons underlie our sensitivity to perceive fine-spatial information and magnocellular neurons underlie our perception of fine-temporal information. That is, they mediate spatial and temporal acuity, respectively. Thus, it appears that most research exploring attention scaling and perception have examined the effect of attention scaling on parvocellular related spatial acuity and not magnocellular related temporal acuity processing. Although there is some conjecture regarding whether parvocellular and magnocellular processing is completely separable using behavioural tasks (e.g. Skottun, 2013), there is a wealth of empirical evidence refuting these claims (see Goodhew et al., 2017 for a review). Specifically, when tested at the extremes, temporal acuity processes are best subserved by the magnocellular channel and spatial acuity processes by the parvocellular channel. It is therefore unclear whether the effect of scaling would be similar for both visual pathways.

Secondly, other types of spatial attention deployment, such as *shifts* of attention across the visual field are known to have differential effects on spatial and temporal acuity. Specifically, these studies have found endogenous attention shifting to improve both spatial and temporal acuity, while exogenous attention improves spatial, but impairs temporal acuity (Yeshurun & Levy, 2003; Hein et al., 2006; Yeshurun, 2004; Yeshurun & Hein, 2011). Inspired by this work, recent theoretical developments have proposed differential impacts of attentional *scale* on spatial versus temporal acuity. That is, it has been proposed that changes in attentional scale differentially influence the parvocellular and magnocellular visual channels, in turn, leading to varying effects of attentional scale on spatial versus temporal perception (Goodhew et al., 2016, 2017). An initial study conducted by Goodhew and colleagues used a shape inducer paradigm to measure the influence of scaling on both spatial and temporal perception. On the majority of trials, a primary shape inducer task was used to alter attentional scale, whereby participants discriminated between circles and ovals that were either small, intended to induce a narrow attention scale, or large, intended to induce a broad attention window. On the minority of trials intermixed amongst the majority trials, a secondary spatial or temporal-acuity task then probed the subsequent effect of attentional scaling on parvocellular or magnocellular processing respectively (Figure 7.1).

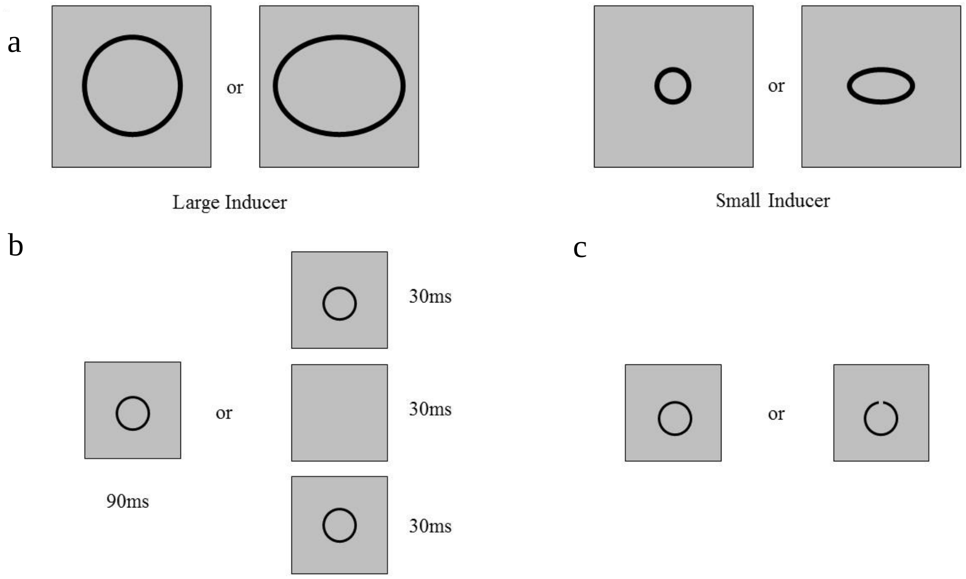


Figure 7.1. Schematic of the attentional inducer task (a), the temporal gap task (b), and the spatial gap task (c), used in Goodhew et al. (2016). For the inducer task, on each trial, participants are required to determine whether a circle or oval are presented, where small shapes engender narrow attention and large shapes engender broad attention. Interleaved with the shape inducer task, are the critical spatial and temporal gap tasks designed to tap parvocellular and magnocellular processing.

Goodhew et al. (2016) found that when a small shape inducer was used, performance was enhanced for the spatial gap task relative to when a large shape inducer was used, while performance on the temporal gap task remained unaffected. When considered in relation to the properties of parvocellular and magnocellular neurons, this suggests that attentional scaling only influences performance on tasks mediated by parvocellular neurons. To account for these findings, Goodhew and colleagues proposed a new model: selective spatial enhancement. According to this model, the primary role of attentional scaling is to increase the spatial resolving power of the visual system, and thus, attentional scaling only acts on the visual channel primarily responsible for this capacity, i.e. parvocellular neurons (Goodhew et al., 2017, 2016).

In contrast, a recent study conducted by Mount and Edwards (2017) suggested that attention scaling might have divergent effects on spatial and temporal resolution. Here, the authors intended to manipulate attention scale using an exogenous cueing task. At the beginning of a trial, a participant's attention was cued using different sized shape segments presented peripherally. It was assumed that smaller shape segments would cause attention narrowing, while larger shape segments would cause attention broadening. Following the cue, the participant completed spatial and temporal acuity tasks similar to those used by Goodhew et al. (2016). Although the small cued condition led to improved spatial acuity compared to the large cued condition, the opposite pattern of results was obtained for temporal acuity. That is, temporal acuity was improved for the large cue condition compared to the small cue condition. This suggest that broadening attention might enhance magnocellular mediated processing (Bush & Vecera 2012; Goodhew et al., 2016; 2017)

The use of unfilled shape cues, or segments of shapes to manipulate spatial attention is very common (e.g. Burnett, et al., 2013; Greenwood & Parasuraman, 1999, 2004; Mizuno et al., 1998; Turatto et al., 2000; Yeshurun & Carrasco, 2008). However, there is a possibility that shape inducer tasks used in past research do not directly manipulate attentional scale in the assumed manner. For example, as shown in Figure 7.1, in Goodhew et al. (2016), the shape inducer task requires participants to attend to the boundaries of the objects presented. However, it does not necessarily require them to attend to the spatial region encompassed by the inducer. Rather, participants might attend to the annulus that the inducer shape provides, while also attending centrally, to where the acuity targets would appear. Indeed, there is mounting behavioural and neuroimaging evidence that dependent upon task demands, participants are able to split their attentional resources to multiple locations simultaneously, as well as in an annulus shape (Castiello & Umiltà, 1992; Egly & Homa, 1984; Jefferies & Di Lollo, 2015; Jefferies, Enns, & Di Lollo, 2014; Lawrence, Edwards, Goodhew, 2018; however see Jans, et al., 2010). As such, it is critically important to use an experimental procedure that we can be more confident results in a change in attentional scale without any other attentional changes, such as shaping attention as an annulus.

Therefore, in the current study, to manipulate attention scale, we used an inducer that required pooling of information over its entire area. Specifically, we used we used a global-motion inducer stimulus (Hutchinson, Ledgeway, & Allen, 2014). Global-motion processing involves the pooling of local-motion to perceive coherent global motion. Unlike the form information in the shape inducer, these signals are located across the entire inducer (Figure 7.2). They are created using a field of dots, where a subgroup of dots travels in a global movement pattern, while the other dots move randomly. Further, the same dots do not carry the signal across the entire stimulus presentation. Instead, the signal dots are varied across frames of stimulus presentation to ensure that the participant cannot track a single dot and must pool the local motion information (Edwards & Badcock, 1994; Newsome & Pare, 1988). Therefore, a participant cannot deploy attention as an annulus in this task; rather, they must spread their attention across the entire stimulus to perceive the motion. In the current study, the size of the motion inducer was varied to alter the spatial scale of attention. The majority of trials in a block were motion inducer trials set to a particular size. The minority of trials (randomly intermixed amongst the majority trials) were spatial and temporal gap tasks similar to those used by Goodhew et al. (2016). This allowed us to assess the effects of attentional scaling on both parvocellular and magnocellular processing. If the shape inducer task is an effective manipulation of attentional scaling, then we would expect a similar effect of changing the size of the motion inducer on spatial and temporal acuity. That is, we would expect a pattern of selective spatial enhancement, where the small motion inducer improves spatial acuity, but has no impact on temporal acuity. However, if the shape inducer is not an effective way to manipulate attentional scaling, then we might get a different pattern of results.

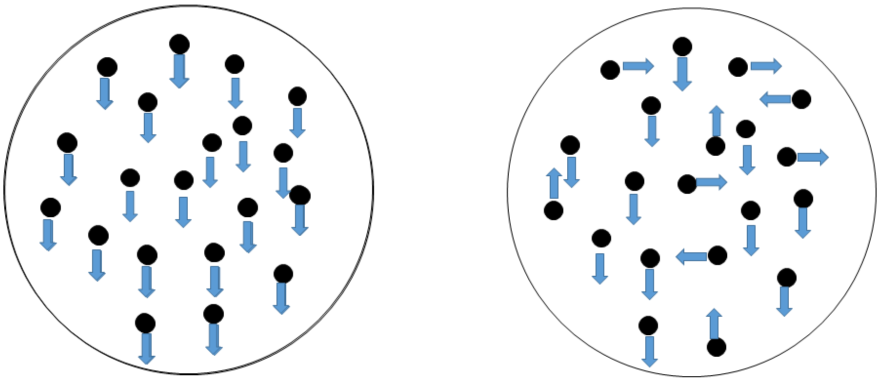


Figure 7.2. Example of Global Motion Stimuli. In a global motion stimulus, the dots all move in the same direction (100% coherence, left), or only a subset of dots will move in the same direction (50% coherence, right). To perceive motion for a low coherence stimulus, participants must pool information across the spatial area, thus having to spread attention.

7.4. Experiment 1

The aim of Experiment 1 was to test the selective spatial enhancement model of attention scaling using a global motion inducer stimulus of varying sizes to manipulate attention scale. Spatial and temporal acuity tasks were used to test the effect of attentional scaling on different aspects of visual perception.

7.4.1. Method

Participants

Thirty-six (9 male) individuals participated in the study (M = 24.39 years, SD = 4.07 years). Sample size was determined using Anderson, Kelley and Maxwell (2017) sample size planner for within subjects ANOVA. The sample size chosen gave us power = .8, and assurance = .25, to detect an interaction effect similar to that observed in Goodhew et al. (2016). Participants provided written informed consent and received a payment of $5 for participating.

All participants reported normal or corrected to normal vision[1]. Thirty-four participants were right handed, and two left handed.

Stimuli and Apparatus

Stimuli were presented on an LCD monitor with dimensions 475mm by 270mm. Participants were seated, and had their head kept stable using a chin rest positioned approximately 600mm away from the monitor. MATLAB, the psychophysics toolbox (Brainard, 1997), and the palamedes toolbox (Prins & Kingdon, 2009) were used to program the experiment. A black fixation dot subtending .10° of visual angle in diameter was presented at the centre of a grey background. The motion stimuli were presented in two different sized circular apertures to induce small, and large attention scales respectively. For each inducer presentation, participants decided whether the signal dots moved in an anticlockwise or clockwise direction by pressing ‘<’ or ‘>’ respectively on a keyboard The small motion stimulus was designed to narrow attention, and had an outer radius of 1.5° of visual angle. The large motion stimulus was designed to broaden attention, and had an outer radius of 10° of visual angle. Both had inner radii of .024° of visual angle. The small inducer contained 26 white dots, and the large inducer contained 834 white dots, both with dot densities of approximately 3.68 dots/degree^2. The spatial step was .19°, with a dot speed of 5.76°/sec. Motion stimuli were presented for approximately 134ms, and consisted of 4 distinct motion images presented for 33ms each. For each stimulus presentation, participants decided whether the signal dots moved in an anticlockwise or clockwise direction by pressing ‘<’ or ‘>’ respectively on a keyboard. On each trial, the signal dot direction was determined randomly.

The signal intensity of the motion inducers was determined on a trial by trial basis, where after each participant response, the signal intensity was updated so to calculate a motion threshold using the PSI method in the palemedes toolbox (Prins & Kingdon, 2009). In turn, this allowed us to estimate a psychometric function for each observer for each experimental block in the study, which quantified performance as a function of stimulus intensity (i.e. the number of signal dots present in the motion inducer). Our task was a two-alternative forced choice task (are the dots rotating anticlockwise or clockwise); thus the motion threshold calculated in each block estimated the number of signal dots required for an observer to determine dot direction with 75% level accuracy. This ensured that the difficulty of the inducer task was equivalent across different inducer sizes, as well as participants in the experiment.

For the acuity tasks, small white unfilled circles were used. These circles had a radius of 0.19° of visual angle, and were centred on the fixation point. For the spatial gap task, on each trial, participants had to decide whether the presented circle contained a small .0002° gap at the top. The circles were presented for 83.5ms. For the temporal gap stimuli, participants had to determine whether one or two circles were presented successively. If one circle was presented, it was shown for 83.3ms. If two circles were presented, the two circles were presented for 33.3ms each, with a gap of 16.7ms inbetween. If a gap was present in the stimuli, participants pressed '<' on the keyboard. If no gap was present, they pressed '>' on the keyboard. Once a response had been recorded for either the gap task, or the motion task, there was an intertrial interval period of approximately 1000ms[2].

Design and Procedure

The experiment was a 2 (small inducer vs. large inducer) x 2 (spatial vs. temporal) repeated measures design. There were four experimental blocks consisting of 140 trials each and four practice blocks. Before completing a task for the first time (e.g. spatial acuity task), participants undertook small practice blocks of 10 practice trials. These practice blocks were interspersed throughout the experiment, and were repeated as necessary until participants were familiar with a task (e.g. a participant might complete 20 practice trials for a given task). For the experimental blocks, participants completed one of four possible block order combinations, which were counterbalanced across participants (Table 7.1). Each of the four experimental blocks consisted of 140 trials. In a block, 80% of trials contained global motion stimuli fixed to be either small or large, and 20% of the trials contained gap tasks, fixed to be either spatial or temporal. Inducer and gap trials were randomly intermixed within a block; however, two gap tasks could not occur consecutively, and the first 5 trials of each experimental block contained inducer trials designed to set the spatial scale of attention. Participants were offered rest breaks every 70 experimental trials. The experiment took approximately 35 minutes to complete.

Table 7.1. *Block order combinations used in Experiment 1.*

	Block Order
1	LS, SS, LT, ST
2	SS, LS, ST, LT
3	LT, ST, LS, SS
4	ST, LT, SS, LS

Notes. Block order was counterbalanced among participants. LS = Large Inducer, Spatial Gap Task. SS = Small Inducer, Spatial Gap Task. LT = Large Inducer, Temporal Gap Task. ST = Small Inducer, Temporal Gap Task.

7.4.2. Results

Exclusion

One participant was excluded as they did not complete all four experimental blocks of the study. Further, participants' data were excluded if their accuracy in either the spatial or temporal acuity tasks fell below 60% across both the small and large inducer blocks. Four participants were removed for this reason, leaving a final sample of 31 participants[3].

Motion Thresholds

First, thresholds for the global motion task in the four experimental blocks were calculated (Table 7.2). A repeated measures ANOVA on motion thresholds indicated that thresholds were higher in the small motion compared to large motion inducer conditions, F (1, 30) = 16.06, p <.001, η_p^2 = .349. This difference indicates that a greater number of signal dots were required for coherent motion perception in the small inducer condition compared to the large motion inducer condition, and is consistent with previous research that indicates that as the area of the global motion stimulus decreases, thresholds increase (Hutchinson et al., 2014). Nonetheless, it is important to note that different threshold estimates for the small and large inducer conditions do *not* reflect differences in difficulty across the two conditions. Instead, they reflect the number of dots required in a motion stimulus for an observer to determine the motion direction with an accuracy of 75%. Critically, this results in perceptual difficulty being equivalent for the small and large motion inducers. Furthermore, thresholds did not vary between the spatial and temporal gap task, F (1, 30) <.01, p = .995, η_p^2 <.001, nor was there an interaction, F (1, 30) = 1.93, p = .175, η_p^2 = .060. Taken together, this indicates that participants were equally engaged with the attentional induction task in both the spatial and temporal gap detection blocks.

Table 7.2. *Global Motion Thresholds (%) as a function of inducer size, and gap task.*

	Small Inducer	Large Inducer
Spatial Task	M = 28.34 , SD = 26.02	M = 13.11, SD = 17.89
Temporal Task	M =25.74 , SD = 20.55	M = 15.73 , SD = 23.01

Spatial and Temporal Acuity Data

Next**,** accuracy for gap detection block was calculated. A repeated measures ANOVA was conducted, where inducer task (small vs. large), and gap task (spatial vs. temporal), were within subject factors. Overall, the effect of inducer size was significant, F (1, 30) = 5.95, p =.021, η_p^2 = .166. Accuracy in the gap tasks were greater for the small motion stimulus versus large motion stimulus blocks. The effect of gap task (i.e. spatial versus temporal) was also significant, F (1, 30) = 8.06, p =.008, η_p^2 = .212, where accuracy was higher on average in the spatial compared to the temporal gap task. Critically however, the interaction between inducer size and gap task was non-significant, F (1, 30) = .08, p = .785. η_p^2 = .003, $M_{Small\ Spatial}$ = 89.06 ($SD_{Small\ Spatial}$ = 13.20), $M_{LargeSpatial}$ = 85.02 ($SD_{LargeSpatial}$ = 14.06), $M_{Small\ Temporal}$ = 82.49 ($SD_{Small\ Temporal}$ = 14.21), $M_{Large\ Temporal}$ = 77.77 ($SD_{Large\ Temporal}$ = 13.23). As shown in Figure 7.3, this suggests that changes in attentional scale influenced both spatial and temporal acuity where accuracy was higher in both tasks for narrow compared to broad attention.

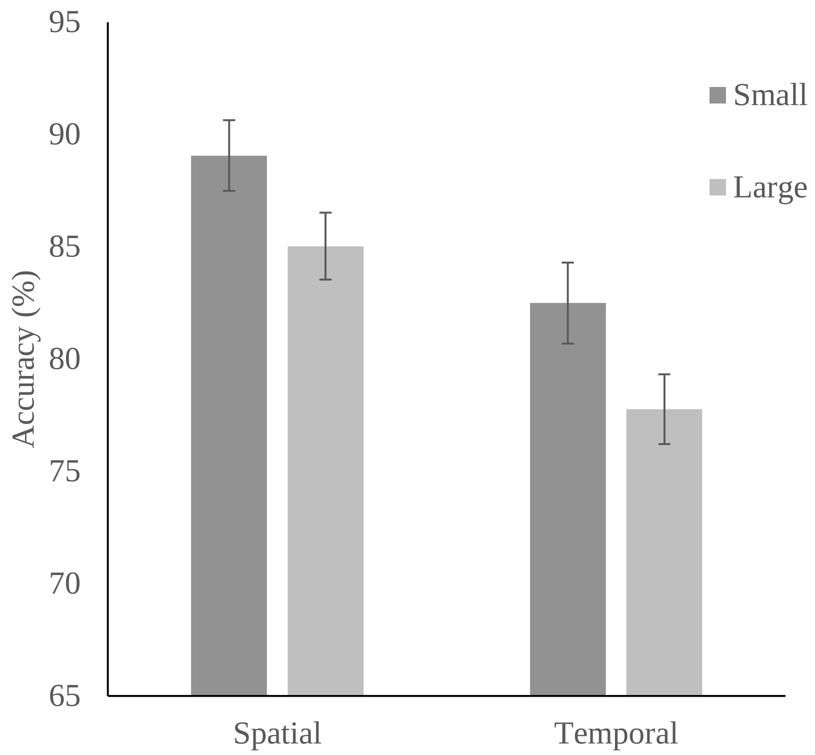


Figure 7.3. Accuracy (%, vertical axis) in the spatial and temporal gap tasks for the small and large inducer conditions. Within subjects error bars displayed (Cousineau, 2005).

Response Time Data

Finally, while accuracy was the primary dependent variable and the task was unspeeded, mean response time for the spatial and temporal acuity tasks were calculated for the four experimental blocks to check for speed-accuracy trade-offs. Firstly, at the individual level, response time outliers were defined as responses that were less than 200ms, or greater than two standard deviations away from the participant's mean response time across all conditions of the experiment. These outlier data points were removed before group level analyses. On average, 3.12% of trials from each participant were excluded. Change in response time over the four blocks were calculated by determining participants' average mean response time for either the spatial or temporal acuity task in each block. Overall, inducer size did not influence response time, where individuals were equally as quick to respond in the small and large inducer blocks, $F(1, 30) = .77$, $p = .784$, $\eta_p^2 = .003$. However, there was a main effect of task, $F(1, 30) = 4.83$, $p = .036$, $\eta_p^2 = .139$, where participants responded more quickly for the spatial, compared to the temporal acuity tasks across both inducer sizes (Table 7.3). Finally, there was no interaction between inducer size and task, $F(1, 30) = .54$, $p = .475$, $\eta_p^2 = .017$. Taken together, this suggests there were no trade-off in speed versus accuracy for the small versus large inducer size conditions.

Table 7.3. *Mean response time (ms) in the spatial and temporal acuity trials for both the small and large motion inducer conditions.*

	Small Inducer	Large Inducer
Spatial Task	*M* = 773 , *SD* = 229	*M* = 781 , *SD* = 238
Temporal Task	*M* = 857, *SD* = 275	*M* = 832 , *SD* = 205

7.4.3. Discussion

In Experiment 1, we used a global motion inducer to manipulate attention scale. The method of attentional induction used here had a significant advantage over previously used shape inducer tasks. By nature, the motion task encouraged participants to spread attention across the entire region that the stimulus occupied. This contrasts with Goodhew and colleagues' shape inducer task, where it would have been possible for participants to shape attention as an annulus and attend to only the perimeter of the inducers (e.g. Egly & Homa, 1984). Therefore, using the motion inducer, we can be more confident that participants actually spread attention across the entire region intended. Critically, we found that narrowing attention scale improved *both* spatial and temporal acuity. This is in contrast to the selective spatial enhancement model, which predicts that changes in attention scale would only influence spatial acuity, and not temporal acuity. Instead, the results of Experiment 1 are consistent with the zoom lens model. That is, that narrowing attention scale improved both parvocellular and magnocellular mediated processing.

That a qualitatively different pattern of results was observed in Experiment 1 suggests that the shape inducer previously used by Goodhew et al. (2016) may not have manipulated attentional scale. Instead, using a shape inducer, it appears likely that in Goodhew et al. (2016), participants deployed attention as an annulus. Therefore, as the distance between the attended region and target changed, the amount of attentional resources falling on the centre of the screen would also vary. If Goodhew et al. (2016) manipulation caused an annulus distribution of attention, whereas the current study encouraged attention scaling, it is likely that the two types of attention deployment have different effects on magnocellular mediated perception. That is, while different sized annuli distributions of attention might not influence temporal acuity, narrowing of an evenly spread distribution of attention might improve temporal acuity.

Nonetheless, although the shape inducer task and the global motion inducer task used in the current study differ in their inferred manipulation of attention, it is also possible that the two inducer tasks were predominantly processed by different areas the visual system. These are the ventral visual pathway and the dorsal visual pathway. Although the ventral and dorsal streams are not entirely separate anatomically, they do appear to differ in their functions, and the types of information they are best suited to process (Mishkin et al., 1983). For example, the ventral visual stream has direct connections to the parvocellular stream, and is involved in color and form processing, while the dorsal visual stream has connections to the magnocellular visual channel, and is involved in motion processing (Goodale & Milner, 1992; Mishkin et al., 1983; Van Essen & Maunsell, 1983; although see Nassi & Callaway, 2009). Specifically, in the shape inducer task, participants had to detect small distortions in a circle, and then indicate whether they saw a circle or an ellipse. Object identification, such as that used in the inducer task is a hallmark function of the ventral stream (Mishkin et al., 1983). Indeed, it has been demonstrated that simple geometric shapes, similar to the inducer stimuli are processed by ventral area V4 (Wilson & Wilkinson, 1998). In contrast global motion processing has been shown to require input from magnocellular neurons (although there is also input from parvocellular neurons), and the processing of global-motion stimuli has been strongly linked to area V5/MT in the dorsal pathway (e.g. Chapman, Hoag, & Giaschi, 2004; Newsome & Pare, 1988). Thus, the motion inducer used in the current study is likely to have engaged the dorsal visual pathway.

The two different types of visual processing required by the shape inducer and motion inducer might have resulted in the different pattern of data observed in the current study compared to Goodhew et al. (2016). This is because the different processing requirements of the shape and motion inducers could lead to visual channel specific priming via trial repetition. Specifically, when trials containing a consistent feature are repeated, performance on subsequent trials containing that same feature are enhanced (Kristiansen & Campana, 2010; Kristjánsson, Vuilleumier, Schwartz, Macaluso, & Driver, 2006; Maljkovic & Nakayama, 1994). In Goodhew et al. (2016), the shape inducer and the spatial gap task had similar processing requirements, such that they were likely processed via parvocellular related mechanisms. Therefore, it is possible that trial repetition of the shape inducer led to selective enhancement of spatial gap processing as they both required parvocellular input. In contrast, the motion inducer task used in the current study does not require a large amount of detailed form processing. Furthermore, in comparison to the shape inducer task, it is likely that the task requires a larger amount of magnocellular input. Therefore, it is possible that this task would be influenced by both parvocellular, and in particular, magnocellular and/or dorsal visual processing.

Consequently, there are two possible explanations for the discrepancy between the results obtained in the Experiment 1, and those obtained by Goodhew et al. (2017, 2016). Firstly, the attentional requirements between the shape inducer and the motion inducer differed. While the shape inducer task encouraged an annulus of attention, the motion inducer task was far more likely to require attentional scaling. Secondly, the visual processing requirements of the two tasks differed. While the shape inducer task required more ventral input, the motion task required more dorsal visual input. Therefore, the aim of Experiment 2 was to test whether the attentional, or visual properties of the motion inducer led to the zoom lens pattern of results observed in Experiment 1.

7.5. Experiment 2

Experiment 2 tested whether the zoom lens pattern of results obtained in Experiment 1 was due to either the attentional requirements of the motion inducer, or the visual properties of the motion inducer itself. To do so, we developed a Glass pattern inducer stimulus to manipulate attention scale (Glass, 1969). This is because Glass pattern stimuli have similar attentional, but different visual processing requirements to the global motion stimulus used in Experiment 1. In particular, Glass patterns require the ability to pool local orientation signals to perceive form (Glass, 1969; Wilson & Wilkinson, 1998). They are created using a field of randomly placed dots. One or more copies of these dots are geometrically transformed, so that pairs of dots (dot dipoles) are arranged to form a global pattern. Importantly, each individual dot does not provide information about the overall structure of the pattern. Rather, information from dot pairs must be pooled to perceive the pattern. Therefore, similar to the motion inducer, participants are encouraged to spread their attention across the entire stimulus for coherent pattern perception. However, in contrast to the motion stimulus, which is processed by the dorsal visual system, Glass patterns require form processing, which is mediated by the ventral visual stream.

As such the Glass pattern inducer allows us to disentangle the ‘attentional’ and ‘visual processing’ accounts of the pattern of results obtained in Experiment 1. Specifically, if the results of Experiment 1 are driven by attentional mechanisms, in Experiment 2, we expect that changes in the size of the Glass pattern inducer would influence both spatial and temporal acuity. However, if the results are driven by the ‘visual processing account’, then changes in the size of the Glass pattern inducer would only influence spatial acuity. This is because similar to the shape inducer, the Glass pattern requires form processing, and might selectively influence parvocellular processing via inter-trial priming.

7.5.1. Method

Thirty-six (11 male) individuals participated. Of these, 27 were right handed, 3 were left handed, and 1 was ambidextrous. Mean age was 21.94 years (*SD* = 4.65 years). All reported normal or corrected to normal vision, and provided informed consent. $10 compensation was offered for participation.

The experimental set up and stimuli was identical to that used in Experiment 1, except that Glass patterns, instead of global motion stimuli were used to manipulate the spatial scale of attention. Similar to the motion inducer used in Experiment 1, the small glass pattern inducer had an outer radius of 1.5° of visual angle, and an inner radius of .024° of visual angle, and contained 26 white dot pairs approximately .048° in size. The large glass pattern had a diameter of 10° and contained 834 dot pairs. Thus, both inducers had a dot density of a dot density 7.37 dots/degree^2. The signal dots contained either a radial, or concentric pattern, and were presented for approximately 134ms. Following stimulus presentation , participants decided whether they saw a radial or concentric pattern, by pressing “<” or “>” on a keyboard respectively. Further, the intertrial interval was approximately 1027ms. Overall, the design and procedure of the experiment was also largely similar to Experiment 1, and took participants approximately 35 minutes to complete.

7.5.2. Results

Exclusion Criteria

One participant's data was removed as they did not complete all four experimental blocks. Participant's accuracy data for the spatial and temporal gap tasks were then screened using the same criteria applied in Experiment 1. No outliers were detected. This left a total sample of 35 participants.

Glass Pattern Thresholds

Next, we analysed glass pattern thresholds for the four experimental blocks. Similar to the motion inducer, Glass pattern thresholds were significantly higher for the small inducer compared to the large inducer, $F\,(1, 34) = 122.62$, $p < .001$, $\eta_p^2 = .783$. Even though different numbers of dots were required to achieve coherent form perception for the two conditions, this does not mean that the difficulty of the task varied. As for Experiment 1, thresholding technique was used to equate task difficulty for the small and large inducer conditions. Again, thresholds were similar for both the spatial and temporal gap tasks, $F\,(1, 34) = .18$, $p = .676$, $\eta_p^2 = .005$, and there was no interaction between size and task on overall thresholds, $F\,(1, 34) = 1.04$, $p = .316$, $\eta_p^2 = .030$. Mean thresholds are presented in Table 7.4.

Table 7.4. *Glass Pattern thresholds (%) as a function of inducer size, and gap task.*

	Small Inducer	Large Inducer
Spatial Task	M = 68.57, SD = 15.99	M = 35.76, SD = 20.43
Temporal Task	M = 71.17, SD = 18.39	M = 35.34, SD = 21.47

Spatial and Temporal Processing

To explore the effect of inducer size on spatial and temporal acuity, a repeated measures ANOVA was run. There was a main of effect of size on performance, F (1, 34) = 6.16, p = .018, η_p^2 = .154, such that narrow attention improved performance on both the spatial and temporal acuity tasks. There was also a non-significant effect of task, F (1, 34) = 3.25, p = .080, η_p^2 = .087, where participants were more arcuate in the spatial compared to the temporal gap task. Finally, and crucially, there was no interaction between inducer size and task on performance, F (1, 34) = .01, p = .898, η_p^2 < .001. Along with the results of Experiment 1, this provides strong converging evidence favouring the zoom lens model. Specifically, in contrast to the process specific models of attention scaling (i.e. selective spatial enhancement), it appears that attentional scaling influences both parvocellular, and magnocellular mediated processing. As shown in Figure 7.4, accuracy in both the spatial and temporal gap tasks was higher for the small inducer conditions compared to the large inducer conditions, $M_{Small\ Spatial}$ = 88.27 ($SD_{Small\ Spatial}$ = 13.38), $M_{LargeSpatial}$ = 85.41 ($SD_{LargeSpatial}$ = 12.05), $M_{Small\ Temporal}$ = 84.08 ($SD_{Small\ Temporal}$ = 13.57), $M_{Large\ Temporal}$ = 80.92 ($SD_{Large\ Temporal}$ = 14.98).

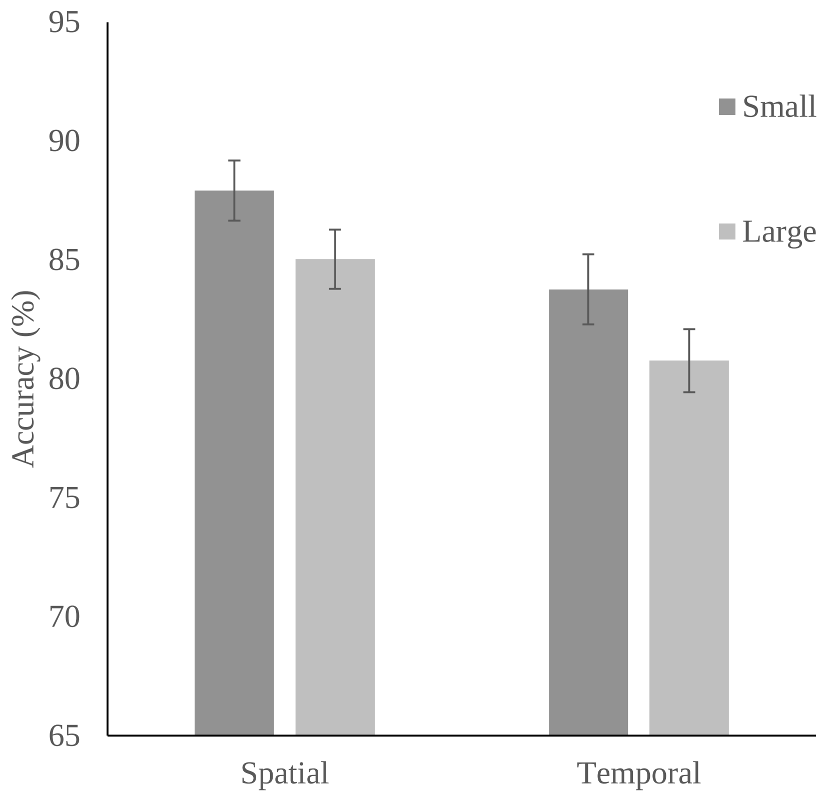


Figure 7.4. Accuracy (%, vertical axis) in the spatial and temporal gap tasks for the small and large inducer conditions (horizontal axis). Within subjects error bars displayed (Cousineau, 2005).

Response Time Data

Next, we checked response time data for speed accuracy trade-offs (Table 7.5). The same RT exclusion criteria used in Experiment 1 were applied, and on average, 3.15% of trials were excluded. Overall, there was no main effect of inducer size, F (1, 34) = .80, p = .376, η_p^2 = .023, an effect of task, F (1, 34) = 6.66, p = .014, η_p^2 = .164, and no interaction between inducer size and task, F (1, 34) = .61, p = .439, η_p^2 = .018.

Table 7.5. *Mean response time (ms) in the spatial and temporal acuity trials for both the small and large motion inducer conditions*.

	Small Inducer	Large Inducer
Spatial Task	*M* = 735 , *SD* = 264	*M* = 736 , *SD* = 172
Temporal Task	*M* =801 , *SD* = 191	*M* = 829 , *SD* = 185

7.6. Checking the Assumption of Normality

Finally, it is important to note that across both experiments, accuracy data in the spatial and temporal gap tasks often violated the assumption of normality. This was the case even though no univariate outliers were detected in the data. Although ANOVAs are relatively robust to violations of normality (Glass, Peckham, & Sanders, 1972), to check whether this unduly influenced our results, we also ran non-parametric analyses to confirm the effect of attention scaling on visual perception. As no non-parametric analysis for a 2x2 repeated measures ANOVA exists, we ran four non parametric t-tests. For Experiment 1, a Wilcoxon signed ranks test revealed a significant effect of motion inducer size on spatial acuity, $Z = -2.55$, $p = .011$, and a non-significant effect on temporal acuity, $Z = -1.78$, $p = .075$. For Experiment 2, the effect of Glass inducer size was non-significant for the spatial gap task, $Z = -1.90$, $p = .058$, and the effect of inducer size on temporal acuity was non-significant, $Z = -1.55$, $p = .121$. However, non-parametric tests typically have lower power (e.g. Nahm, 2016). Therefore, to increase statistical power, we analysed the data from both experiments to test the effect of inducer size on both spatial and temporal acuity generally (i.e. the type of inducer used to manipulate attention was not included in this model).[4] Overall, this non-parametric analysis revealed an effect of inducer size on both spatial acuity, Z = -3.16, p = .002, and temporal acuity, Z = -2.38, p =.017. Thus, taken together, this is broadly consistent with the finding that inducer size influences both parvocellular mediated spatial acuity, and magnocellular mediated temporal acuity.[5]

7.7. General Discussion

The ability to narrow or broaden spatial attention resources enhances processing in challenging visual tasks. The zoom lens model assumes that attention scaling influences all aspects of visual perception, however, recent empirical evidence suggests that narrowing attention might have discrepant effects on parvocellular-mediated, spatial acuity, versus magnocellular-mediated, temporal acuity (Goodhew et al., 2017, 2016; Mounts & Edwards, 2017). Nonetheless, these recent models of attention scaling and visual processing have only been tested using different sized unfilled shapes, or shape segments to manipulate attention. These unfilled shapes may have caused participants to distribute attention as an annulus, rather than scale their attention across the entire intended manipulated region. To address this, we used a new method to manipulate attention scale, which encouraged participants to spread attention, rather than shape it as an annulus. Specifically, in Experiment 1 we used global motion stimuli of different sizes, and Experiment 2 we used Glass pattern stimuli. Unlike the shape inducer, these two types of inducer stimuli encouraged individuals to spread attention across the entire manipulated region to pool local level visual signals. Critically, across both experiments, we found that attentional scaling influenced both parvocellular mediated, spatial and magnocellular mediated, temporal acuity. This contests the recently proposed selective spatial enhancement model of attention as well as the spatiotemporal trade-off model.

That attentional scaling influenced both spatial and temporal acuity is consistent with the zoom lens model of attention scaling (Eriksen & James, 1986). In line with this, previous studies have found attentional narrowing to improve the ability to perceive temporal detail. For example, Poggel et al. (2006) asked participants complete a visual search for a temporal target for a small and a large sized search array (i.e. small array = narrow attention; large array = broad attention). Thresholds to detect a flickering target in this search array were lower in the small array condition, suggesting improved temporal resolution under narrow attention. Alongside the results of the current study, it therefore appears likely that an endogenously narrowed scale of attention improves magnocellular mediated processing.

Here, it is important to note that the results of the current study are unable to be directly reconciled with the findings of studies exploring the effect of *exogenous* attentional scaling on temporal perception. Recall that in Mount and Edwards (2017), the effect of exogenous attention scaling on spatial and temporal acuity was tested using a cueing task. Specifically, different sized shapes segments were used as peripheral cues to alter attention scale, which may be thought to encourage an annulus distribution of attention. However, unlike Goodhew et al. (2016), targets were presented adjacently to inducer shape segments, meaning that the distance between the inducer and target did not vary with inducer size. Thus, it is unlikely that in Mounts and Edwards (2017), attention was distributed as an annulus, even though unfilled shape segments were used to manipulate attention. Critically, although the small cued condition led to improved spatial acuity compared to the large cued condition, the opposite pattern of results was obtained for temporal acuity. That is, temporal acuity was improved for the large cue condition compared to the small cue condition. This is in contrast to the results of the current study. As such, future work should aim to systematically study the effects of endogenous and exogenous attention scaling on temporal acuity, using a single experimental paradigm.

Critically, the results of the current study directly call into question the use of unfilled shapes to manipulate the scale of attention such as those used in Goodhew et al. (2017, 2016). Based on the current study, it appears that the shape inducer used in Goodhew et al. (2017,

2016) encouraged an annulus distribution of attention. This is vitally important, as a lot of research exploring attentional scaling and visual perception uses unfilled shapes to alter the scale of attention (e.g. Castiello & Umiltà, 1990; Greenwood & Parasuraman, 1999; Yeshurun & Carrasco, 2008). Instead, it is likely that unfilled shapes provide spatial structure to a visual scene, thus altering the region over which attention is deployed (Jefferies and Di Lollo, 2015; Lawrence et al., 2018; Taylor et al., 2015). For example, Jefferies and Di Lollo (2015) tested the effect of adding spatial structure to a visual attention display using placeholder stimuli. The participant's task was to identify two peripheral letters shown in a rapid serial visual presentation, while a stream of distractor digits was presented centrally. In one condition, placeholder boxes were presented alongside the stimuli, which indicated potential locations the critical target could appear. These placeholders were arranged as an annulus, providing the object contours of an annulus to the visual display. In the other condition, no placeholders were present. Crucially, the addition of placeholder stimuli led to higher levels of accuracy in the peripheral letter rapid serial visual presentation task. This suggests that the spatial structure afforded by the placeholders allowed participants to distribute attention as an annulus, reducing the amount of distraction (i.e. attention given) to the central letter display. Therefore when manipulating attention, future research should move to use methods similar to those adopted in the current study. This will ensure valid conclusions regarding spatial attention scaling are made.

Nonetheless, it is also important to recognise early research which suggests that unfilled shapes *can* be used to effectively manipulate attention scale. For example, using a variant of the Posner cueing task, Castiello and Umiltà (1990) utilised different sized unfilled boxes to manipulate attention scale. Critically, following the cue, target stimuli were presented at various eccentricities within and surrounding the unfilled box. This allowed the authors to quantify the distribution of attention both within the inducer, as well as around it. Overall, the authors found that response times for target detection were largely equivalent for targets falling within the shape inducer, regardless of their eccentricity. Further, in line with the zoom lens model, response times increased with larger shape cues. This suggests that the unfilled shape stimulus encouraged attention scaling, rather than an annulus deployment of attention.

However, one key difference between the shape inducer task used by Goodhew et al. (2017, 2016), and that used by Castiello and Umiltà (1990) is the manner in which attention scale was manipulated within and across experimental blocks. While Goodhew et al. (2016) used unfilled shapes that were of the same size within a block of trials, it appears as though the size of the unfilled shapes used in Castiello and Umiltà (1990) varied on a trial by trial basis. Therefore, whereas Goodhew et al. (2016) required participants to sustain a single focus of attention across many trials, requiring endogenous attention, Castiello and Umiltà (1990) required participants to re-orient and resize attention flexibly each experimental trial.

It is possible that an annulus deployment of attention requires a sustained effort across a series of trials. Indeed, recent research suggests that observers can utilize an annulus deployment of attention when deploying spatial attention endogenously to a consistently presented spatial structure, but not when deploying attention exogenously to transiently presented stimuli (Jefferies & Di Lollo, 2017). Therefore, in Castiello and Umiltà (1990), the transiently presented, differing sized attentional cues may not have allowed enough time for participants to sustain an annulus distribution of attention. In contrast, although the shape inducers were presented briefly in Goodhew et al. (2016), they were presented at a sustained size over a series of trials, which may have allowed an annulus deployment of attention.

Finally, although the current work suggests that endogenously narrowing attention improves all aspects of visual processing, there are many cases in which a broad scale of attention might be most beneficial. For instance, Chong and Treisman (2005) observed that when conducting a visual search of unbroken and broken circles (i.e., visual search was parallel, and required distributed attention), participants found it easier to make judgements of the mean size of the search array compared to when they conducted a serial search, and presumably narrowed attention to a smaller focus. Likewise, it has been found that narrow attention can worsen performance on texture grouping tasks, which require the pooling of local form signals (Carrasco & Yeshurun, 1998). Finally, our data suggests that broad attention might improve local motion, and form pooling. That is, in both experiments, thresholds for coherent motion and form perception were lower when the stimuli were large (i.e. spreading attention broadly), compared to when they were small (i.e. spreading attention narrowly). This suggests that participants were better at perceiving global, complex visual signals when they were able to pool information over a broader region of the visual field. Therefore, future work should aim to directly explore the effects of attentional scaling on ventral and dorsal mediated visual perception.

To conclude, the critical finding of the current study was that attentional scaling influenced performance in both a spatial acuity and a temporal acuity task. This favours the zoom lens model of attention scaling, which argues that narrowing attention improves all aspects of visual processing (Eriksen & James, 1986). Critically, we have demonstrated that the method used to manipulate attention scale qualitatively influences the relationship between spatial attention and visual perception. As such, we encourage future researchers to carefully consider the method of manipulation they choose to alter spatial attention scale before testing the effects of attention on vision.

7.8. Notes

1. One participant reported being colour blind, but this would not alter performance in the spatial acuity task, and their vision was deemed normal. One participant chose not to wear glasses, but performed above chance in all conditions, so was deemed their vision was still within normal range.
2. There was a slight difference in the inter-trial interval for small versus large inducer block, where the inter-trial interval was approximately 300ms longer in the large inducer blocks. However, we deemed this unlikely to have influenced the obtained pattern of results. The most likely effect that a longer inter-trial interval would have would be to cause the effect of the large inducer to dissipate, leading to a constriction of attention to a more focal region. This would make it less likely to observe an effect of inducer size on spatial acuity and temporal acuity. Nonetheless, this error was rectified in Experiment 2.
3. In Experiment 1, two sets of participant's acuity data were recoded due to reverse responding. In Experiment 2, one data set was recoded. Reverse responding this was determined by checking whether in either the spatial or the temporal task, a participant scored below 50% accuracy in both the small, and large inducer conditions.
4. Some individuals participated in both Experiment 1 and Experiment 2 of the current study. However, participants never completed both experiments within the same testing session. Before running the combined non-parametric analyses, we first conducted an ANOVA with inducer size, and gap task as within subject factors, and inducer type as a between subject factor. This analysis revealed that the type of inducer (motion versus glass), did not influence the overall relationship between inducer size and accuracy, F (1, 64) = .42, p = .522, η_p^2 = .006.
5. The assumption of normality was also violated across both experiments for threshold, and response time data. Non-parametric analysis of this data yielded largely similar results to the parametric analysis. As such, parametric analyses are reported in the manuscript.

Chapter 8: General Discussion

This thesis aimed to understand the causes and consequences of spatial attention scaling on visual processing. The first half of the thesis evaluated the effect of healthy ageing and cultural background on attention distribution. Specifically, an inhibition of return (IOR) task was used, which allowed us to directly measure changes in attention across space. Chapter 4 measured age differences in attention. Previous work exploring age differences in attention used placeholder stimuli to cue attention in the IOR task, and found no effect of age. However, placeholders limit attention spread. Therefore, age differences in attention were compared without placeholder stimuli. In contrast to past research, Chapter 4 found that across the lifespan, older adults tended to adopt a focused scale of attention. Chapter 5 then tested the effect of East Asian versus Western cultural background on attention distribution. However, little evidence of a cultural difference in spatial attention scale was found. Instead, there was a cultural difference in response time, where East Asian participants were slower to respond to targets compared to Western participants. Therefore, the current thesis argued that factors other than attentional processing, such as motivation and response criterion might drive cultural differences in cognition.

The second half of the thesis assessed how differences in attentional scale influence visual perception, and in particular, parvocellular and magnocellular mediated processing. Chapter 6 critically analysed major models of attention scaling and visual perception. This analysis suggested that the different methods used to manipulate attention scale potentially explain the specific effects of scaling on parvocellular and magnocellular processing. Finally, Chapter 7 directly tested the zoom lens, and the selective spatial enhancement models of attention scaling. Previous research measuring attention scaling and vision used unfilled shapes to manipulate attention. These shapes might have encouraged observers to deploy attention as an annulus. Therefore, a new method of attention scale manipulation was used, which encouraged participants to spread attention across the entire induced region, by requiring the pooling of local level visual information. In support of the zoom lens model, Chapter 7 found that scaling influences both parvocellular and magnocellular processing. This was in contrast to recent work which suggested that attentional scaling only influenced parvocellular processing. The following chapter evaluates the main findings of the thesis and suggests possible avenues for future research.

8.1. Individual Differences in Attention Scaling

The first half of the thesis explored whether two relatively stable factors, healthy ageing, and cultural background influence spatial attention scale. To do so, participants completed an IOR task. Here, response times for target detection across multiple cue-target distances were measured to infer attentional gradient and the distribution of attention. Critically, an IOR task was chosen as it allowed for a direct measurement of space-based attention while controlling for known age and cultural differences in attention flexibility (Caparos et al., 2013; Jefferies et al., 2015).

8.1.1 Age Differences in Attention Scale

Chapter 4 questioned whether healthy ageing influenced spatial attention distribution. Previous literature attempting to answer this question is mixed (Greenwood & Parasuraman, 2004; Hartley & Kieley, 1995; Kosslyn et al., 1999; Langley et al., 2011; Madden & Gottlob, 1997). Some studies argue that older adults adopt a narrow attention distribution (e.g. Hüttermann et al., 2012), while others have suggested there are minimal, or no age differences in attention scale (e.g. Langley et al., 2011). It was hypothesised that these discrepancies might have been due to the methods past research studies have used to infer age differences in attention distribution. Previous work claiming minimal age differences in attention distribution used an IOR paradigm that may have been inappropriate for measuring individual differences in attention distribution across space (Langley et al., 2011). Specifically, Langley et al. (2011) used placeholder stimuli to cue attention. Placeholder stimuli add structure to a visual scene, which is known to shape where attention is distributed in the visual field (Jefferies & Di Lollo, 2017; Taylor et al., 2015). This structure might have decreased how sensitive the method was to detect potential individual variation in attention scale.

To address this, in Chapter 4 of the thesis, differences in older and younger adult's attentional distribution was compared using an IOR task that either included or excluded placeholder stimuli. When placeholders were included, age differences in attention scale were minimal. Critically, when placeholders were removed, a reliable age difference emerged, where older adults had a narrower attention scale. As such, it can be concluded that placeholders have a substantial influence on the region over the distribution of attention in a cueing paradigm. Future work should, therefore, opt to remove placeholder stimuli from visual displays when attempting to measure individual differences in attention distribution.

That the older adult group adopted a narrower attention scale is consistent with previous studies using experimental paradigms other than the IOR task to measure age changes in spatial attention (e.g. Hüttermann et al., 2012; Kosslyn et al., 1999; Pesce et al., 2005). For example, Hüttermann et al. (2012) compared age differences in attention distribution using a ‘breadth of attention’ test. Participants were required to fixate on a central region of the screen, while different coloured shapes appeared at equidistant eccentricities in the visual field on either side of fixation. The participant's task was to determine how many shapes were shaded a particular colour. To measure the breadth of attention, the distance of the shapes from fixation was varied. The maximum eccentricity at which participants could reliably identify targets was assumed to reflect attention breadth. Overall, younger adults were able to accurately identify targets at greater eccentricities than older adults, suggesting that they were able to adopt a broader scale of attention. Nonetheless, it is likely that this task might encourage participants to split attention resources to the disparate target locations rather than scale attention. This splitting would occur because the task required that targets were presented at two separate locations in the visual field. Therefore, the current study adds to the current literature by showing that in a simple task, which does not require attention splitting, age differences in attention spread still emerge. Two potential mechanisms could account for this age difference. These are (1) changes in working memory capacity across the lifespan, and (2) declines in sensory processing in older age.

Working memory and visual attention

Differences in working memory capacity across the lifespan might explain the effect of age on attention distribution (Rolle et al., 2017). An individual's working memory capacity is their cognitive control, or the ability to manipulate temporarily stored information (Baddeley, 2012; Engle, 2002). Typically, working memory capacity declines across the lifespan (Hedden & Gabrieli, 2004; Mattay et al., 2006; Verhaeghen & Salthouse, 1997). For example, in an early study, Dobbs and Rule (1989) measured the working memory capacity of 228 adults aged 30 to 99 years using a digit recall task. Participants heard a series of spoken numbers and then reported one number from the list. The number to be reported could be presented either zero, one, or two numbers before the last letter heard. Overall, the study found a gradual decline in performance as age increased, though declines were particularly steep for those aged 60 years and over. This suggests that there is a significant drop in working memory capacity with age. Furthermore, there are known functional changes in brain regions responsible for central processing and cognitive control in healthy ageing. Mattay et al. (2006) showed that during a high working memory load task, older adults show decreased activation in the frontal, executive areas of the brain compared to younger adults, which was correlated to worse behavioural performance. Finally, white matter integrity, known to decline with age, has been associated with working memory (Charlton, Barrick, Lawes, Markus, & Morris, 2010).

Critically, there is an association between working memory and spatial attention (Ahmed & De Fockert, 2012; Awh & Jonides, 2001; Bleckley et al., 2003; Kreitz et al., 2015). For example, Krietz et al. (2015) demonstrated that lower working memory capacity might be related to a narrower breadth of attention. Here, working memory was measured using an automated operation span task (Aospan; Unsworth, Heitz, Schrock, & Engle, 2005), the spatial 2-back task, and the verbal 2-back task (Kane, Conway, Miura, & Colflesh, 2007). In the Aospan task, participants are required to solve mathematical equations that are interspersed with a memory task. In the spatial and verbal 2-back tasks, participants are shown streams of information (circles at particular locations and letters respectively), and following the presentation, are asked to report the stimulus shown two presentations prior. Attention breadth was measured using two tasks. These were the useful field of view task (Ball & Owsley, 1993; Wood & Owsley, 2014), and Hüttermann and colleague's breadth of attention test (Hüttermann et al., 2012; Hüttermann & Memmert, 2017). In the useful field of view task, participants are required to detect briefly appearing targets that appear at varying eccentricities from a central fixation region. In the breadth of attention test, participants complete a visual search of two targets of variable spatial separation. Overall, there was an association between the attentional breadth measures and working memory measures, whereby lower working memory capacity was associated with a narrower attention distribution.

Furthermore, supporting the link between working memory and spatial attention are a growing number of experimental studies which directly manipulate working memory load and measure the consequences of this for spatial attention processes (Caparos & Linnell, 2010; Lavie, 2000; Lavie, 2005). For example, Caparos and Linnell (2010) found that changes in working memory load could alter the distribution of attention as measured in a flanker task.

Here, participants were shown a central letter and asked to determine whether the letter had a small gap at the top or bottom of it. The central letter was also flanked by a distractor letter. Critically, under high working memory load, the distractor letter interfered with letter processing to a greater degree than under low working memory load. Therefore, it is possible that high working memory load led to a broader distribution of attention, and caused the increased distractor processing.

Nonetheless, the measures of attention breadth used in both Krietz et al. (2015) working memory capacity study, and Caparos and Linnell's (2011) working memory load study may not have accurately measured the distribution of attention. Specifically, the Hüttermann et al. (2012) breadth of attention test used in Krietz et al. (2015) is likely to cause attention splitting, rather than measuring attention spread (Chapter 4). Furthermore, both the useful field of view task adopted by Kretiz et al. (2015), and the flanker task adopted by Caparos and Linnell (2011) are thought to be measures of attention control, rather than directly measuring spatial attention distribution (e.g. see Avital-Cohen & Tsal, 2016; Chapters 3 & 5; Cosman et al., 2012; Gaspelin et al., 2014; Lachter et al., 2004; Lunsman et al., 2008; Matas et al., 2014). Therefore, future research should aim to explore the relationship between working memory and the distribution of attention, using highly sensitive measures of spatial attention processing, such as the IOR task.

Furthermore, across these studies, while lower working memory *capacity* is related to a narrow breadth of attention, lower working memory *load* results in a broader scope of attention. It is, therefore, possible that the effect of working memory load might differ for those with low and high working memory capacity. For instance, an individual with higher working memory capacity might invest more in a task compared to an individual with low working memory capacity. In turn, this individual would experience a high level of load, which would broaden their distribution of attention. Consequently, future work should explore how changes in working memory load influence attention for individuals of low versus high working memory capacity, using more appropriate measures of spatial attention distribution. Specifically, using the IOR task, a future study could measure the distribution of attention of high and low working memory capacity participants, while they completed the IOR task under differing levels of cognitive load.

Finally, in the current thesis, working memory was not measured directly. As such, the claim that age changes in working memory capacity directly cause a narrower attentional distribution cannot be assessed based on the data collected in Chapter 4. One possibility is that working memory capacity did not differ greatly between the two age groups tested. In both experiments, the older adult participant sample was primarily recruited from the University of the Third Age, a community program offering educational classes for those aged over 60 years of age. Furthermore, although the mini-mental state (Folstein et al., 1975) is a diagnostic tool for dementia, and not a highly sensitive measure of executive functioning generally (e.g. Mitchell, 2009), in Chapter 4, scores obtained on the measure were mostly equivalent for the two groups, with the older adult group actually outperforming the younger adult group in Experiment 2. Taken together, this tentatively suggests that working memory differences might have been small between the two samples groups used in Chapter 4. As such, future work should aim to directly test the relationship between healthy ageing, working memory, and the gradient of attention. Here, younger and older adults would first complete an IOR task similar to that used in the current thesis. Following this, the participants could complete a brief working memory capacity measure, such as the Aospan to determine individual variation in cognitive function. Age differences in attention scale could then be compared with working memory capacity included as a mediator variable in analyses.

Changes in sensory processing with healthy ageing

Apart from cognitive changes across the lifespan, vision also declines with healthy ageing. For example, spatial contrast sensitivity, the ability to perceive changes in luminance across space, decreases in older age, particularly for the perception of fine spatial detail (Elliott et al., 1990; Kline et al., 1983; Owsley, 2011, Owsley et al., 1983; Tulunay-Keesey, Ver Hoeve, & Terkla-McGrance, 1988). This is due to an increase in the density of the lens of the eye, as well as pupillary miosis (constriction of the pupil), which leads to less light reaching the retina, as well as the increased scattering of light in the eye (Xu, Pokorny, & Smith, 1997). Furthermore, electrophysiological studies with monkeys have demonstrated that with ageing, the sensitivity of cells in the primary visual cortex to high spatial frequencies declines (Yang, Liang, Li, Wang, & Zhou, 2009; Yang, Kang, Li, Wang, Zhou, & Leventhal, 2008). Therefore, it appears that both physical changes to the eye, as well as changes at the neural level, contribute to declines in vision in old age.

Interestingly, it has been repeatedly demonstrated that changes in visual sensory processing are related to changes in cognitive processing (Anstey, Luszcz, Giles, & Andrews, 2001; Lin et al., 2004; Lindenberger & Ghisletta, 2009; Rogers & Langa, 2010). For example, Lin et al. (2004) measured visual acuity and cognitive ability in a large sample of older adult women across two years, finding that declines in visual acuity were associated with declines in cognitive performance as measured by the mini-mental state examination. Furthermore, Anstey et al. (2001) found that declines in visual acuity were correlated with declines in memory. Finally, it has been suggested that visual processing deficits might be linked to dementia when left untreated (Rogers & Langa, 2010).

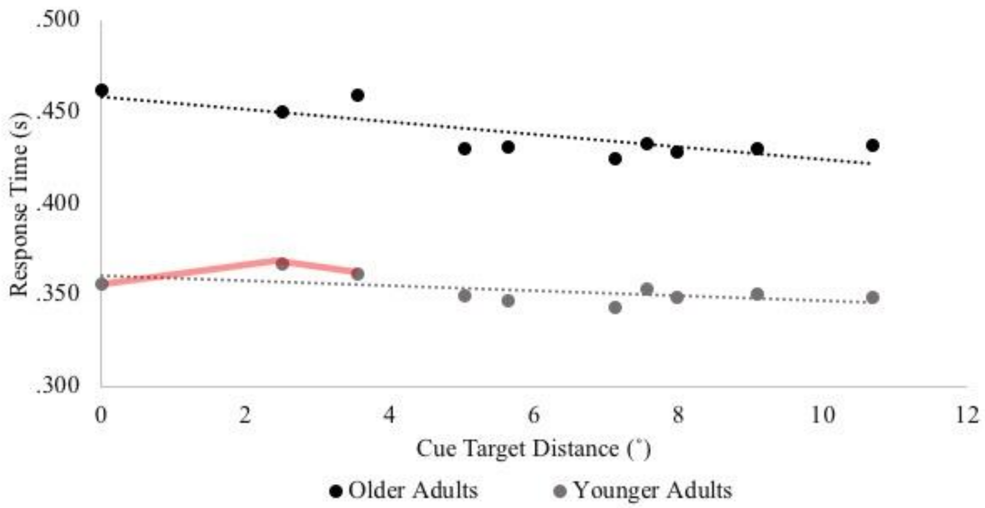
Consequently, it is possible that changes in vision across the lifespan might contribute to the age difference in attentional distribution observed in Chapter 5. Specifically, older adults may narrow attention to offset declines in visual processing. The zoom lens model of attentional proposes that compared to a broad spread of attention, narrow attention improves visual processing within the attended area scaling (Eriksen & James, 1986). For example, target detection response times are consistently faster for a smaller, compared to a larger attention scale (Castiello & Umiltà, 1990; Eriksen & James, 1986). Given that older adults show visual processing declines, it may have been optimal for them to adopt a narrow scale of attention to have better visual processing capacity within a smaller attended region. That is, a narrow attentional scale may have compensated for declines in visual processing, and increased the older adult group's ability to detect targets appearing in the visual field.

The idea that narrow attention may be beneficial for older adults' performance in the IOR task is similar to proposed models of compensation in healthy ageing (Reuter-Lorenz & Cappell, 2008). These models argue that older adults' brains are overactive, so to compensate for functional declines that occur with ageing. For example, Payer et al. (2006) demonstrated that during a visual working memory task, compared to younger adults, older adults showed lower levels of specialised processing for faces in the ventral visual processing area of the brain. However, in the same study, older adults showed increased levels of activation in prefrontal areas of the brain, more typically associated with executive processes such as working memory and attention. The authors suggested that the increased activation in the prefrontal cortex may have been compensatory neural activity for lowered specialisation in visual processing areas.

Given the possibility that lower visual processing capacity of older adults may influence attentional spread, future research should aim to directly test how changing the quality of visual input might impact the attentional spread an individual adopts in the IOR task. Specifically, this could be done using a sample of younger adults, who were either exposed to normal or a visually degraded scene (e.g. Monge & Madden, 2016). The spatial contrast of stimuli in the IOR task could be experimentally manipulated (e.g. Gilmore, Spinks, & Thomas, 2006; Toner et al., 2012) and attentional spread for a high contrast and low contrast condition could be compared for the younger adult group (i.e., a within-group rather than a between-group comparison). Because older adults have lower spatial contrast sensitivity, the physically lower contrast of the stimuli for the younger adults could simulate the effects of ageing on vision. Therefore, it would be expected that the lower contrast condition would lead the younger adult group to have a narrower attention spread compared to the high contrast condition, presumably to compensate for the poorer quality visual input.

The role of uncertainty in determining the spatial distribution of attention.

Finally, an unexpected finding in Chapter 4 of the thesis was that across two experiments, the younger adult group were consistently faster to detect targets at the cued location compared to the locations immediately surrounding the cue. As shown in Figure 8.1, this led to an inverted ‘V’ shaped pattern of data observed in both Experiment 1 and Experiment 2. This finding was particularly surprising, as it is expected that using an IOR task, participants would be slowest to detect targets at the cued location. One possible explanation for this pattern of results is target uncertainty. In the IOR task used, there were between 25 (Experiment 2) and 40 (Experiment 1) possible locations a target could appear. Given this uncertainty, participants might have been more likely to interpret the cue (which could only appear at one of four locations) as meaningful, and attempt to direct some attention facilitation resources towards it. In turn, this would lead to faster response times at the cued location compared to the immediate surrounding target locations.



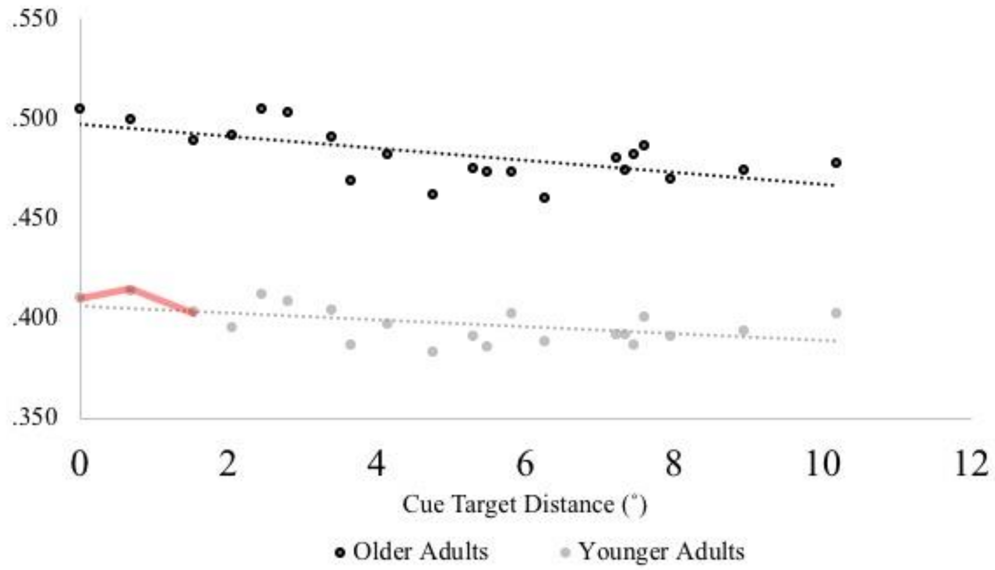


Figure 8.1. The pattern of data obtained in the IOR task in Experiment 1 (above) and Experiment 2 (below) of Chapter 4. As indicated by the red lines, in both experiments, younger adult participants were faster to respond at the cued location, compared to locations immediately surrounding the cue, leading to an “inverted v” pattern of data.

Nonetheless, it is important to note that the particular pattern of results observed in Chapter 4 was not observed in Chapter 5 for the cultural differences study. This was the case, even though an as almost identical IOR task was used to measure attention distribution in both chapters. However, one key difference in the methods used in Chapter 4 and Chapter 5 were the instructions given to participants regarding the attentional cue. In Chapter 4, participants were not given direct instruction regarding the significance, or predictability of the cue. Instead, they were merely told that a green circle would appear. In contrast, in Chapter 5, participants were told that the cue was uninformative. Therefore, across the two studies, participants may have assigned different meaning to the cued location. Specifically, because participants in Chapter 4 did not know the cue was uninformative, they may have been more likely to attend to the cue compared to those in Chapter 5. This too could lead to faster response times at the cued location. Therefore, future work should also examine how explicit instructions regarding exogenous cues may influence spatial attention and attention distribution.

Summary

Chapter 4 of the thesis explored age differences in spatial attention scale using an IOR task without placeholder stimuli. In turn, this allowed for a highly sensitive measure of attention distribution, and thus, an optimal method to detect potential group differences in spatial attention processes. Overall, it was demonstrated that older adults adopt a narrower attention scale. Two reasons for this age differences are changes in working memory capacity across the lifespan, and changes in visual processing capacity. Future work is needed to disentangle which of these two factors is largely responsible for age differences in attention distribution.

8.1.2. Culture and Attention

Having determined that the IOR task was a suitable method with which to measure individual differences in attention distribution, Chapter 5 explored whether cultural background also influenced attentional spread. Past research using alternative methods in an attempt to measure cultural differences in attention suggested that East Asian participants may adopt a broader distribution of attention compared to Western participants. However, these studies had used measures of attention which could require categorical/feature based, rather than space-based attention, as well as not controlling for eye movements. Furthermore, a recent series of studies have failed to replicate previously observed cultural differences in visual attention. Therefore, chapter 5 aimed to measure cultural differences in attention using the IOR task, which is a more sensitive measure of attention scale. However, using this more direct measure of spatial attention scale, Chapter 5 found no cultural difference in the spatial distribution of attention. Instead, compared to the Western participant group, the East Asian participant group were slower to respond to targets overall. Overall, this suggests that factors other than attention, such as motivation, and response criterion may differ across cultures.

No cultural difference in the spatial distribution of attention

In Chapter 5, it was predicted that there would be a reliable cultural difference in the spatial distribution of attention. Specifically, due to a relatively holistic thought style, East Asian participants were predicted to adopt a broad distribution of attention in the IOR task. In contrast, due to their relatively analytic thinking style, Western participants were predicted to adopt a narrow distribution of attention in the IOR task (Boduroglu et al., 2009; Nisbett et al., 2001). However, in the IOR task, East Asian and Western participants had similar attention slopes, and therefore adopted relative similar attention distributions. This was surprising, as it was in contrast to a large body of theoretical and empirical research demonstrating that there are reliable cultural differences in cognition more generally (e.g. Boduroglu et al., 2009; Caparos et al., 2013; Doherty, Tsuji, & Phillips, 2008; Goh et al., 2007; Gutchess, Welsh, Boduroglu, & Park, 2006; Hedden, Ketay, Aron, Markus, & Gabrieli, 2008; Ji, Peng, & Nisbett, 2000; Kitayama et al., 2003; McKone et al., 2010; Nisbett & Miyamoto, 2005).

Nonetheless, the results of the current thesis are consistent with a growing series of studies which have failed to replicate key cultural differences in visual attention (Boduroglu & Shah, 2017; Evans et al., 2009; Hakim et al., 2017; Rayner et al., 2009). For example, Hakim and colleagues (2017) recently conducted a large scale pre-registered study testing whether East Asian and Western participants differed in their performance of a visual change detection (Boduroglu et al., 2009), and a Navon task (McKone et al., 2010). Participants were recruited from both an American university, and a Chinese university, allowing the authors to make two critical cultural comparisons: 1) Asian International university students vs. American university students and 2) Chinese university students vs. American university students.

Recall that in the change detection task developed by Boduroglu and colleagues (2009), participants are required to detect colour changes in shapes that either expand (i.e. broad attention), or contract (i.e. narrow attention) across the visual field (Figure 5.1). Originally, Boduroglu et al. (2009) found that East Asian participants were better at detecting the colour change when the shapes expanded, whereas Western participants were better at colour detection when the shapes contracted. Critically, in contrast, Hakim et al. (2017) only partially replicated these findings. Although Chinese participants had higher accuracy in the expand condition of the experiment, American participants did not show an advantage in the contract condition. Further, there were no reliable cultural differences when comparing the performance of Asian International versus American students attending the same university.

Likewise, Hakim et al. (2017) failed to replicate the observed cultural difference in global processing originally observed in McKone et al. (2010) in the Navon letter task. In the Navon task, participants are instructed to detect targets which appear at either the global or local level of a compound Navon stimulus (Figure 5.2). A global processing preference score is determined by calculating the difference in global versus local target response speeds. Originally, McKone et al. (2010) found that East Asian participants had a stronger global preference compared to Western participants. However, using Bayesian analysis, Hakim et al. (2017) found no compelling evidence to support this distinction. Instead, their analysis favoured the null hypothesis (i.e. no cultural difference in global and local processing). Taken together, this suggests that in visual attention tasks, East Asian and Western participants used similar visual attention processing strategies. Therefore, in light of these findings, the results of Chapter 5 provide strong converging evidence that cultural differences in basic attentional processes may be minimal.

Interestingly, earlier studies finding cultural differences in attention used smaller sample sizes compared to more recent studies failing to observe East-West differences (Hakim et al., 2017). For example, in Boduroglu and colleague's (2009) change detection study, the total sample sizes of Experiment 1 and 2 were 56, and 28. Likewise, McKone et al. (2010) had a total sample size of 47 for their main cultural analysis. In contrast, the sample size used in Hakim et al. (2017) was upwards of 100. The small sample sizes used in earlier studies can be problematic, as they are typically associated with low statistical power. Not only does low power lead to a decreased ability to detect a real psychological effect, but it can also lead to an increase in false positive findings (Hakim et al., 2017; Ioannidis, 2005). This is because smaller sample sizes result in imprecise estimates of real effects present in the population (Anderson et al., 2017; Hakim et al., 2017; Marszalek, Barber, Kohlhart, & Cooper, 2011; Simons, Holcombe & Spellman, 2014). Therefore, the lower sample sizes used in earlier research may have led to an increased number of false positive findings reported. Given that the sample size in Chapter 5 was relatively large (more than double, i.e. 126 participants), it, therefore, appears that the current thesis had adequate power to determine whether a cultural difference in spatial attention distribution exists. Therefore, future research should be encouraged to ensure they have adequate power to detect group differences in visual attention with reliable precision. Doing so will allow for valid and reliable conclusions regarding cultural differences in cognition to be made.

Measurement of culture

The results of Chapter 5 provide strong converging evidence that there are none or minimal cultural differences in spatial attention distribution. Nonetheless, it is possible that the measure of culture used in the current thesis might not have created clear groups representing East Asian versus Western cultures, which in turn, could result in a null finding. In particular, in Chapter 5, culture was determined by an individual's birth country. This method is typical of cognitive psychology research exploring cultural differences in visual attention processes (e.g. Boduroglu et al., 2009; Hakim et al., 2017). For example, a recent review paper by Masuda (2017) comparing East Asian versus Western thought styles classified individuals of Western culture as being from Western Europe or North America, and East Asian individuals as being from China, Korea, and Japan. However, rather than birth country alone implying cultural background, culture can be thought of as a constellation of factors such as language, religion, ethnicity, values, and geography which together influence thought processes (Ferraro & Andreatta, 2011).

In an attempt to address this, the current thesis aimed to capture a comprehensive measure of culture, by developing a cultural background and demographic questionnaire (Appendix A). This questionnaire measured language, time spent living in Australia, self-identified group (East Asian versus Western), level of multiculturalism, and strength of the self-identified culture. Ultimately, this allowed for a thorough exploration of the demographic profile of all participants completing the study. Although a pragmatic choice was made to classify cultural groups via birth country, an examination of the demographic survey revealed that many participants identified with multiple cultural groups (instead of identifying solely as East Asian or Western). This level of multiculturalism is likely due to the East Asian participant sample having lived in Australia for a significant amount of time (e.g. some participants having resided in Australia for 21 years). Furthermore, our East Asian participant group comprised mainly of International students who had moved to Australia to study. This distinction is important, as there is a possibility that Chapter 5 was measuring the influence of student status (i.e. an individual who chooses to be a domestic versus an international student), rather than culture on attention. As such, in order to better measure cultural differences in cognition, future work should aim to use more sensitive measures of cultural group, rather than birth country. For example, research should aim to explicitly study how acculturation processes might influence the effect of culture on cognition by testing participants who have recently moved to a country comprising of a new culture (less than one year ago), compared to those who had been living in a new culture for five years or longer. This would allow researchers to determine whether the results observed in Chapter 5 of the thesis generalize to either East Asian or Western participants who have more recently moved to a country. Further, research could aim to use cultural groups of participants who are currently residing in their birth country, Finally, directly testing the role of language (i.e. monolingual versus multilingual) or conducting a more extensive measure of multiculturalism would be beneficial.

Alternatively, rather than measuring culture, future research should also aim to measure how thought styles influence attention processing. Recall that cultural differences in visual attention have typically been attributed to group differences in thought styles, where East Asian participants are seen as holistic, and Western participants are seen as analytic (e.g. Boduroglu et al., 2009; McKone et al., 2010). Therefore the effect of analytic versus holistic thinking on the spatial scale of attention in the IOR task should be evaluated. One potential test which could be used to do this is the Analytic-Holistic Scale (AHS; Choi, Koo, & Choi, 2007). The AHS is a 24 item self-report scale which measures whether an individual tends to adopt an analytic or a holistic thinking style. The scale has good discriminant and predictive validity, and has been used to differentiate East Asian versus Western cultures (e.g. Choi et al, 2007; Jen & Lien, 2010; Kim et al., 2010; Konrath, Bushman, & Grove, 2009; Lechuga, Santos, Garza-Caballero, & Villarreal, 2011). To explore the relationship between thought styles and attention, participants within a single culture would complete the IOR task, followed by the AHS scale. Groups of analytic and holistic thinkers could then be created. If thought style predicted the spatial distribution of attention in the IOR task, we would expect analytic thinkers to adopt a narrower distribution of attention compared to holistic thinkers.

Finally, instead of measuring cultural differences in thought styles, an experiment which directly manipulates thinking style, and then measures attention could be conducted. This would allow researchers to directly assess whether thought styles *cause* group differences in attention processing. Kimchi-Palmer figures could be used to manipulate thought style (Figure 8.2; Kimchi & Palmer, 1982). Typically, when viewing Kimchi-Palmer figures, participants decide whether the top figure is more similar to the bottom left or the bottom right figure. The assumption is that if participants think analytically, they would attend to the local elements of the top figure, and thus decide the figure looked most similar to the bottom right figure (the triangle made out of triangles). In contrast, if an individual is a holistic thinker, they are more likely to attend to the global shape of the top image and thus link it to the bottom left figure (the square made out of squares).

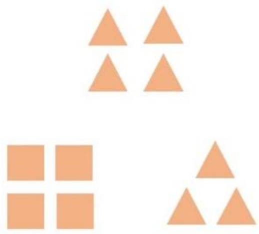


Figure 8.2. Example of Kimchi-Palmer stimuli which could be used to prime analytic versus holistic thinking.

Although Kimchi-Palmer figures have been used to assess differences in thought styles (e.g. Oishi et al., 2014), Kimchi-Palmer figures could be used to shift thinking within an individual to become more analytic or more holistic. Specifically, before measuring attention distribution, participants could be asked to categorise Kimchi-Palmer figures based on their global structure or local elements. This categorisation would shift participants' thinking to become more holistic or analytic respectively. Following this, the participant's attention distribution could be measured. If thinking styles lead to differences in attention distribution, then individuals who are primed to think analytically are more likely to adopt a narrow distribution of attention, while those primed to think holistically are more likely to adopt a broad distribution of attention.

A similar method has been used to explore the relationship between culture, self-construal and attention. Self-construal refers to whether an individual sees themselves as independent, or interdependent (Markus & Kitayama, 1991). Those with an independent self-construal perceive themselves as existing as a separate entity and believe they have stable personal characteristics which exist across contexts. In contrast, those with an interdependent self-construal believe that they are dependent upon the group around them. Independent thinking is associated with Western cultures, while interdependent thinking is associated with East Asian cultures. In particular, Lin and Han (2009) experimentally manipulated self-construal within a Chinese participant sample, and then measured visual attention processing in a Flanker task (Experiment 1), and a Navon task (Experiment 2). To manipulate self-construal, participants read passages and circled the words "I" or "we" to shift construal to be independent or interdependent respectively. Following this, participants completed the Navon and Flanker tasks. Critically, the authors found that following interdependent priming, interference in the flanker task was greater compared to independent priming. Further, following independent priming, participants showed a local preference in the Navon task. Therefore there is compelling evidence that thinking styles might modulate attention processing, regardless of cultural background. As such, future work should explore whether priming analytic versus holistic thinking might alter spatial attention processes. In turn, this would allow for better measurement of the relationship between culture, thought and attention.

Cultural differences in response time

Even though Chapter 5 did not find a cultural difference in the spatial distribution of attention, a group difference in overall response speeds was observed. Specifically, East Asian participants were slower to respond to targets in the IOR task compared to Western participants. Nonetheless, the finding that East Asian participants were slower to respond is consistent with the broader literature exploring cultural differences in attention. For example, Boduroglu et al. (2009) found that in a focal target detection trial, East Asian participants were slower to respond compared to Western participants. Likewise, when measuring East Asian and Western participants' functional field of view, East Asian participants were found to respond more slowly compared to Western participants (Boduroglu & Shah, 2017). Previous research has attributed cultural differences in response speed to group differences in the spatial distribution of attention (Boduroglu et al., 2009; Boduroglu & Shah, 2017). This attribution is based on the zoom lens model of attention scaling, which purports that a broader spread of attention leads to less processing efficiency within the attended region (Eriksen & James, 1986). In particular, if an individual has adopted a broader scale of attention in a task, it is likely that they will be slower to respond to targets, due to this lower level of processing efficiency.

Nonetheless, in Chapter 5, it appears unlikely that cultural differences in visual attention caused a response time difference between East Asian and Western participants. If this were the case, a cultural difference in both response time and spatial attention distribution should have been observed. Nonetheless, to test this possibility, in Chapter 5, a multiple regression analysis was conducted. This analysis predicted mean response time in the IOR task, with both attentional slope and cultural background as independent variables. The logic here was that this analysis would be able to tease apart whether the observed cultural difference in response time was due to potential cultural variation in attention, or whether some other third factor also contributed to slower response times. Interestingly, both variables predicted participants' mean response time. Therefore, even after accounting for response time differences related to attention scale, cultural differences in overall response time were still present. This distinction is critically important, as it suggests that cultural variation among other cognitive factors are responsible for differences in response speed. Two such factors are response criterion, and motivation.

Firstly, it is possible that East Asian and Western participants may differ concerning their response criterion. An individual's response criterion refers to their tendency to respond 'target present' versus 'target absent' on a trial by trial basis (Green & Swets, 1974; Lynn & Barrett, 2014). When an individual tends to respond 'target present', they are said to have a liberal response criterion. In contrast, a tendency to respond 'target absent' (or withhold responding as in the IOR task), indicates an individual may have a conservative response criterion. Western participants might on average require less perceptual evidence to accumulate before responding ‘target present’ in the IOR task compared to East Asian participants. This difference in response tendency could lead Western participants to have average faster response times. That is, Western participants’ quicker response times might be indicative of a more liberal response criterion, where Western participants might on average require less perceptual evidence to accumulate before responding ‘target present’ in the IOR task compared to East Asian participants.

A general cultural difference in response criterion is consistent with research exploring cultural differences in decision-making styles (Choi, Dalal, Kim-Prieto, & Park, 2003; Mann et al., 1998; Smith et al., 2016; Weber & Hsee, 2000). For example, there are known cultural differences in evidence accumulation processes, where East Asian participants have been shown to use a greater amount of information when making a decision compared to Western participants (Choi et al., 2003). In Choi et al. (2003), Korean and American participants were presented with a short scenario describing socially deviant behaviour, as well as a list of information varying in relevance related to that description. The participants were asked to select which information from the list they deemed relevant to making a causal attribution of the scenario, or discarding information they deemed irrelevant. Critically, in the discard condition, Korean participants tended to exclude less information compared to American participants, suggesting that East Asian participants may consider more information in a decision-making scenario.

Furthermore, Hakim and colleagues (2017) observed a cultural difference in response criterion for the Boduroglu et al. (2009) change detection task. In particular, across both expand and contract conditions of the experiment, Chinese participants adopted a relatively conservative response criterion. That is, they showed a greater tendency to state that no colour change occurred in a trial compared to American participants. This finding provides direct evidence that in attention tasks, East Asian participants may respond conservatively, which could lead slower overall target response times for target detection, such as those observed in the IOR task. Nonetheless, to determine whether attentional factors drive these differences in response criterion, future work should explore whether or not cultural differences in response criterion might also emerge in non-attentional, simple perceptual tasks (e.g. a gap detection task; Figure 6.2).

Alternatively, cultural variation in response times in the IOR task may have been driven by group differences in motivation (Hamamura et al., 2009; Heine et al., 2001). For instance, there are cultural differences in how East Asian, and Western participants respond to positive and negative feedback (Heine et al., 2001). In Heine et al. (2001), Japanese and North American participants completed a word association task that was either easy or difficult. Participants then graded their performance on the task and compared it to a distribution of ‘standard' test scores. In the difficult task condition, the distribution of scores was skewed, so it would appear to the participant that they performed worse than average. Thus, the participant received negative feedback. In the easy task condition, the distribution was skewed, so it appeared that the participant performed above average. Thus the participant received positive feedback. Following feedback, participants were given a new word association task which included both easy and challenging questions. To measure motivation, the experimenters timed how long participants persisted with this task. Overall, Japanese participants persisted with the task for a greater amount of time following negative, compared to positive feedback. The opposite was true for North American participants. Taken together this suggests that East Asian participants were motivated to a greater degree by negative feedback.

Critically, Chapter 5, negative feedback was used to minimise catch trial errors made by participants in the IOR task. Specifically, when a participant responded incorrectly, a red warning message appeared on the screen for 3 seconds, telling participants to ‘wait for the dark grey circle’ (the target). This negative feedback could have had a different influence on East

Asian and Western individuals motivation, where East Asian participants may have been more motivated to avoid the negative feedback message compared to Western participants. To avoid negative feedback, East Asian participants may have adopted a more conservative response criterion, thus leading to slower overall responding in the task. As such, to test whether cultural differences in response criterion are related to motivation, future research could examine whether East Asian versus Western participants motivation, and response criterion for a simple target detection task varied as a function of the type of feedback provided (positive, negative, or no feedback).

Finally, it is important to note that the cultural differences in response time observed in Chapter 5 of the thesis are unlikely to be driven by the same factors leading to age differences in overall response time in the IOR task. Recall that in Chapter 4, it was found that older adults were on average, slower to respond to targets than younger adults. Typically, age differences in overall response time (such as in the IOR task) are attributed to generalised slowing across the lifespan, which are thought to occur due to global changes in the ageing brain, such as changes in white matter (Charlton et al., 2010; Verhaegen & Salthouse, 1997). However, it is almost certain that a similar process is *not* responsible for cultural differences in speed of response. Firstly, in the current study, all participants were drawn from a highly educated, university sample. Therefore, it is likely that these participants have a high cognitive capacity, which would not differ between cultural groups. Secondly, while there are known effects of cultural background on the visual system of the brain (e.g. Hedden et al., 2008), these changes have not been associated with global deficiencies in cognition, such as those related to healthy ageing and generalised slowing. Finally, apart from differences in response time solely reflecting cognitive capacity, other factors, such as personality can lead to overall differences in response time (e.g. Brebner & Cooper, 1974). Thus, it is more likely that differences in response bias or motivation caused cultural differences in response time in IOR task.

Summary

In Chapter 5 of the thesis, an IOR paradigm was used to test potential cultural differences in attention scale. Overall, no cultural differences in the spatial distribution of attention were observed. This finding is consistent with a growing body of literature finding none, or only minimal cultural differences in attention. There was also an observed cultural difference in overall response time. Specifically, East Asian participants had slower response speeds compared to Western participants. Future work should study whether this response time difference is due to cultural differences in response criterion and/or motivation.

8.1.3. Evaluation of the IOR Task as a Measure of Attention Distribution

Across Chapter 4 and 5 of the thesis, an IOR task was successfully used to measure group differences in spatial attention distribution. Older adults were found to adopt a narrower attention distribution compared to younger adults, while minimal cultural differences in the spatial distribution of attention were observed. The IOR task was chosen, because it places minimal demands on cognitive and perceptual resources, allowing for a clean measure of attentional changes across space. Indeed, compared to Navon and Flanker tasks, which contain competing visual information, the participant's task is simple; they only need to detect a single target, in an otherwise blank visual field. However, the IOR task still places some task demands on participants. In particular, there are multiple cue-target combinations that the observer must attend to in order to detect the target as quickly as possible. This might encourage participants to utilise a particular distribution of attention to complete the task. Therefore, in the following section, the consequences of these task demands on the measurement of attentional distribution are evaluated.

Across both chapters, the IOR task used required participants to detect targets presented at a large possible number of locations (25 or 40). Given this broad range over which targets appeared, it would be most beneficial for an individual to distribute attention broadly to complete the IOR task. For example, Huang, Xue, Wang, and Chen, (2016) has shown that increasing the number of cued locations in a typical spatial attention paradigm leads to an increase in the distribution of attention. In this study, participants completed a simple target detection task. The number of regions cued was varied to manipulate spatial uncertainty. As spatial uncertainty increased, so too did response times for target detection. This slower responding was interpreted as reflecting a broader attention distribution. Therefore, it is reasonable to expect that regardless of an individual's tendency to distribute attention narrowly or broadly, in the IOR task, most participants would attempt to spread attention across a large region of the visual field to process as many target locations as possible. As such, rather than measuring overall group differences in attention distribution generally, the IOR task may measure differences in the ability to spread attention broadly to meet task demands.

The idea that attention tasks measure group differences in the optimal allocation of attention has been tested in studies exploring the effect of mood on attention processing. Specifically, using a priming technique, Huntsinger (2012) has found that the effect of mood visual attention is dependent upon task demands. In Huntsinger (2012), participants were first primed to have a narrow or broad focus of attention using Navon letters. They then watched a happy or a sad movie to induce positive or negative mood respectively. Finally, to measure the visual attention, a flanker task was used. When a broad attention distribution was induced, positive mood was found to broaden attention, and negative mood to narrow attention. However, when a narrow focus of attention was induced, positive mood was found to narrow attention in the flanker task, while negative mood broadened attention. Although Navon and Flanker tasks may not be optimal tools to manipulate and measure spatial attention (see Chapter 3), overall, this suggests that observed group differences in attention processing can be dependent upon the context, and the strategy participants have chosen (or primed) to adopt.

As discussed in Chapter 4, there is a discrepancy in the literature regarding the directionality of age differences in attention distribution. While some argue that older adults distribute attention narrowly (Hüttermann et al., 2012), others have suggested that ageing causes individuals to adopt a broader spread of attention (Greenwood & Parasuraman, 2004). Therefore, one reason for the discrepancy in the literature on healthy ageing and attention distribution might be due to the different task demands imposed by the various methods used to measure attention across the lifespan. For example, Greenwood and Parasuraman (2004) explored the effect of differently sized cues on visual perception across the lifespan. Here, participants were cued to a location with either a valid or invalid cue which varied in size. Following this, they were required to search for a letter target which required either feature or conjunction processing. Overall, the authors' results indicated that following a small cue, in comparison to older adults, younger adults were more able to focus their attentional narrowly to the small cue size. Specifically, this meant that in this particular scenario, older adults were adopting a broader distribution of attention. However, rather than this meaning that older adults adopt a broad scale of attention in all scenarios, it is likely that this difference is reserved for situations where a narrow attention distribution is required for optimal performance. Similarly, in the IOR task used in the current thesis, older adults may have been less able to spread attention broadly to all target locations, while younger adults had relative ease in doing this. Furthermore, it is important to note that the use of unfilled shapes to cue attention is questionable (Chapter 7). In Greenwood and Parasuraman (2004), rather than scaling attention to the size indicated by the cue, it is possible that participants merely shifted attentional resources within the cued region in order to search for the target. Therefore, future research should aim to explore if and how, individual differences in attention distribution might emerge when either a narrow, or broad spread of attention is more appropriate relative to task demands and context.

8.1.4. Individual Differences in Attentional Scale: Summary

Taken together, chapters 4 and 5 of the thesis highlight the fundamental role that experience has on how individuals interact with the world. Although age influenced the spatial distribution of attention, cultural background did not. Overall, this is broadly consistent with a literature which shows that many different factors coalesce and influence attention distribution such as personality, mood, and emotion (Huntsinger, 2012; Hüttermann & Memmert, 2015; Wilson et al., 2016). Furthermore, that reliable individual differences in attention scale were found suggests that current models of attention scaling and vision need to be updated to reflect this variation. For instance, the classic model of attentional scaling, the zoom lens model, does not consider how individual experiences might shape the relationship between attentional scaling and vision (Eriksen & James, 1986). Instead, the model assumes that relative to task demands, narrow attention always improves visual processing. However, different individuals may use different strategies to process information in the visual world, leading to potentially different effects of attentional scaling on vision. This highlights the fundamental importance of combining individual differences and experimental paradigms to understand the dynamics of attentional scaling fully.

8.2. The Influence of Attentional Scaling on Vision

The second half of the thesis shifted from measuring individual differences in attentional scaling, to exploring the effect of attentional scaling on visual processing. The zoom lens model is the predominant model explaining the relationship between attention and vision (Eriksen & James, 1986). This model predicts that narrow attention improves all visual processing, and is supported by a large body of empirical evidence (Barriopedro & Botella, 1998; Benso et al., 1998; Castiello & Umiltà, 1990; Eriksen & James, 1986; Eriksen & Yeh, 1985; Poggel et al., 2006; Umiltà, 1998). However, some recent studies have found that attentional scaling can either have no impact, impair, or improve visual processing mediated by the magnocellular channel of vision (Goodhew et al., 2017, 2016; Mounts & Edwards, 2017; Poggel et al., 2006). Therefore, to better understand the relationship between attention scaling and magnocellular processing, Chapter 6 included a critical review of major theoretical models, and recent work exploring attentional scaling and visual processing. Finally, in Chapter 7, the zoom lens, and selective spatial enhancement models of attention were tested in a single experimental paradigm. The zoom lens model assumes that narrowing attention improves all aspects of visual perception (Eriksen & James, 1986). In contrast, the selective spatial enhancement model argues that endogenous narrowing of attention has no impact on magnocellular mediated, temporal acuity (Goodhew et al., 2017, 2016). However, the selective spatial enhancement model had only been tested using one method of attentional manipulation. This method was likely encouraging participants to deploy attention as an annulus, rather than scaling attention. Therefore, in Chapter 7, a new attentional inducer manipulation was developed, which was more likely to encourage attention scaling. Critically, using this inducer, it was found that narrowing attention improved both spatial and temporal acuity. Below, a summary of the key findings of Chapter 6 and Chapter 7 are presented. The implications for the broader field of spatial attention research are highlighted, which emphasise the fundamental importance of appropriate, and considered operationalisation of spatial attention variables in cognitive psychology research.

8.2.1. Recommendations for Attention Scaling Research

In Chapter 6, empirical evidence investigating the effect of attentional scaling on parvocellular and magnocellular mediated visual processing was evaluated. While some research has found narrowing attention to improve magnocellular mediated processing, others have found it to impair, or have no effect on magnocellular processing. Overall, four factors were discussed as influencing the relationship between scaling and vision. These were (i) the roles of endogenous versus exogenous attention, (ii) the use of unfilled shapes to manipulate attention, (iii) task complexity, and (iv) stimulus eccentricity. As the use of unfilled shapes was directly addressed in Chapter 7 of the thesis, the following discussion focuses on endogenous versus exogenous attention, task complexity, and stimulus eccentricity.

Endogenous versus exogenous attention

Firstly, the effect of automatic and voluntary attention scaling on magnocellular processing was evaluated. Recent empirical work suggested that endogenous attentional narrowing might not influence magnocellular mediated processing (Goodhew et al., 2016), while exogenous attentional narrowing might impair magnocellular mediated processing (Mounts & Edwards, 2017). In particular, a recommendation of the review was that future research systematically explore the effects of endogenous versus exogenous attention on all aspects of visual processing. Nonetheless, it is essential to recognise the challenges associated in developing an attentional task which manipulates attention in either a purely exogenous or endogenous manner. As discussed in Chapter 6, Mounts and Edwards (2017) attempted to measure the impact of attention scaling on parvocellular and magnocellular visual processing using a peripheral cueing task to manipulate attention exogenously. Here, differently sized attention cues were briefly presented in peripheral vision to capture, and exogenously scale attention resources to the area demarcated by the cue. Following this, participants completed spatial and temporal acuity tasks which measured parvocellular and magnocellular mediated processing respectively. Overall, while narrowing attention improved parvocellular mediated spatial acuity, it impaired magnocellular mediated temporal acuity.

Although on the surface, Mounts and Edwards (2017) appears to be a clean exogenous manipulation of attention scale, many factors make this conclusion questionable. As emphasised in Chapter 6, Mounts and Edwards (2017) "exogenous" cue was 100% predictive. Therefore, rather than being attracted to the cue only by automatic means, it is probable that the participants may have learnt that the cue was, in fact, predictive, and utilised both exogenous and endogenous attention where appropriate. Indeed, research has shown that individuals are sensitive to cue predictability in spatial attention tasks, regardless of whether or not they are aware of the predictive nature of the cue (Bartolomeo, Decaix, & Siéroff, 2007; López-Ramón, Chica, Bartolomeo, & Lupiáñez). Secondly, because deployments of exogenous attention in the study required a peripheral luminance change to capture an observer, the method requires that participants *shift* their attention, as well as scale it to an appropriate size. Therefore, the paradigm does not measure the unique effect of attention scaling on vision. As such, before exploring the relationship between attention scaling and vision, future research should develop a more direct, exogenous manipulation of attention, which does not require either peripheral cueing procedures, or 100% target predictability.

Task Complexity

The effect of task complexity on attention scaling was evaluated. This is because past studies manipulating attention scale have varied in both perceptual and cognitive load. For example, Mounts and Edwards' (2017) cueing procedure has relatively low levels of perceptual and cognitive load. Here, the participant is required to complete only one task throughout the entire experiment (i.e. detect whether the circle has a gap in it). In contrast, other studies manipulating attention have more complex task demands. For instance, Goodhew et al.'s (2016) shape inducer paradigm is a dual task. Here, participants have to decide whether they have seen a circle or an ellipse, while also monitoring for the presence of gaps in briefly presented circles.

Therefore, it is of relatively higher task complexity. Critically, task complexity can change the distribution of attention. Increases in perceptual load cause attention scale to narrow, while increases in cognitive load cause attention scale to broaden (Chen & Cave, 2013, 2014; Caparos & Linnell, 2009, 2010; Linnell & Caparos, 2011). As discussed in Chapter 6, Carmel et al. (2006) studied the effects of perceptual load on temporal resolution, finding high load impaired temporal processing. This high load was likely to narrow attention. In contrast, Poggel et al. (2006) found broad attention to impair temporal resolution, using a task which Carmel et al. (2006) argued required high perceptual load. Therefore, differences in the effects of attentional scaling on magnocellular mediated processing could be due to the different levels of task complexity used across various studies.

Consequently, future work measuring the effect of scaling on vision should systematically explore the effect of perceptual and cognitive load on attention scaling and visual perception. This research could be done using a visual search task (Figure 8.3). Specifically, simple and complex visual search tasks could be used to manipulate perceptual load, and subsequently, attention scale (Cave & Zimmerman, 1997; Chen & Cave, 2013, 2014; Chong & Treisman, 2005; Lavie & Cox, 1997; Roper et al., 2013; Theeuwes et al., 2004; Treisman & Gelade, 1980). For instance, a simple visual search task which requires feature processing can be considered a low perceptual load task (Lavie & Cox, 1997; Theeuwes et al., 2004). This would lead to a broad distribution of attention (Cave & Zimmerman, 1997). In contrast, a complex visual search task requires conjunction processing and can be considered a high perceptual load task (Lavie & Cox, 1997; Theeuwes et al., 2004). This would produce a narrow distribution of attention (Cave & Zimmerman, 1997). The effect of these different search tasks on perceptual sensitivity could then be measured using spatial and temporal acuity tasks. Overall, a blocked design similar to that used by Goodhew et al. (2016) could be used to manipulate visual search complexity, where the inducer task (i.e. the visual search array) would occur on 80% of trials, and the spatial and temporal acuity tasks would occur on 20% of trials. If task complexity does influence the relationship between attention scaling and vision, it would be expected that higher levels of performance for the acuity tasks in the complex, compared to simple visual search array conditions would emerge. Furthermore, different types of cognitive load could be introduced to the visual search tasks, such as digit rehearsal tasks, to explore how working memory differences might also influence the relationship between attentional scaling and visual perception. Taken together, this would allow for a methodical exploration of how perceptual and cognitive load influence the relationship between attention scaling and vision.

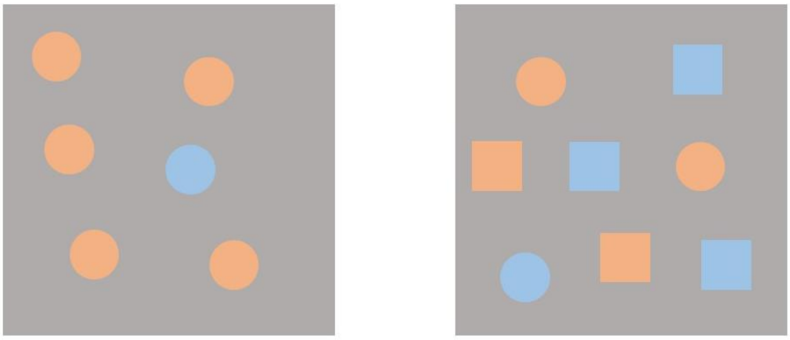


Figure 8.3. Complex (left) and simple (right) visual search tasks (Triesman & Gelade, 1980).

Stimulus Eccentricity

Finally, the influence of stimulus eccentricity on the relationship between attentional scaling and visual perception was evaluated. Apart from encouraging *shifts* of attention, peripheral presentation of stimuli might also encourage eye movements to the stimulus. Eye movements can lead to a reduction of the visual systems sensitivity to process sensory input (i.e. saccadic suppression; Krekelberg, 2010). Consequently, future research should aim either control eye movements when using peripheral stimuli to manipulate and measure attention scaling or should aim to use paradigms where eye movements are discouraged (i.e. central stimulus presentation). This will allow for a clean measure of attention scaling and vision effects.

8.2.2. A New Method for Manipulating Attention Scale

In Chapter 7 of the thesis, the predictions of the zoom lens and selective spatial enhancement model were directly tested using a new method to manipulate attention scale. According to the selective spatial enhancement model of attention scaling, narrowing attention does not affect magnocellular mediated processing (Goodhew et al., 2017, 2016). However, the model has only been tested using one method, a shape inducer task. Here, unfilled shapes of different sizes are used to narrow or broaden attention. The use of unfilled shapes is problematic, as these shapes are likely to have caused attention to be deployed as an annulus. Therefore, in Chapter 7, global motion (Experiment 1), and Glass pattern (Experiment 2) stimuli of different sizes were used to manipulate attention scale. These stimuli had an advantage over the shape inducer stimuli as they encouraged attentional scaling, rather than attentional re-shaping. Using this new method, it was found that attentional narrowing influenced both spatial and temporal acuity.

Implications for Selective Spatial Enhancement

Chapter 7 provides compelling evidence against the selective spatial enhancement model. According to the selective spatial enhancement model, endogenous narrowing of attention improves spatial acuity, to the exclusion of temporal acuity, by selectively enhancing parvocellular neurons in the visual system (Goodhew et al., 2017, 2016). In contrast to this, the current thesis found that narrowing attention improved both parvocellular mediated, spatial, and magnocellular mediated, temporal acuity. Therefore, the data supports the zoom lens model of attention scaling, which argues that narrowing attention improves all aspects of visual processing (Eriksen & James, 1986).

That narrow attention improved temporal resolution is consistent with early work conducted by Poggel et al. (2006) measuring the effects of broad and narrow attention in a visual search task for a temporal target. Recall that in this study, participants were presented with a nine-dot stimulus array, where one dot was presented centrally, and the other eight dots were presented concentrically around this. On each trial presentation, one of the nine dots was presented as a double pulse, which participants perceived as a flicker. The participant's task was to indicate the location at which the flicker occurred. To determine an individual's temporal sensitivity, the time delay of the double pulse was varied (i.e. the gap in time between the presentation of the two targets). A shorter time delay reflects higher temporal sensitivity. Further, to manipulate attention scale, the spatial layout of the nine-dot array was varied to cover a small or large region of the visual field. Overall, detection sensitivity for a double pulse occurring at the centre of the display decreased as the overall spatial layout of the display increased (i.e. targets appeared over a broader spatial area). It was therefore concluded that narrowing attention improved temporal sensitivity.

Furthermore, research measuring attentional shifting has found that endogenous orienting of attention improves magnocellular mediated visual processing (Hein et al., 2006). In this study, participants' attention was cued to one of two locations using a central arrow cue. The cue was 75% valid, and thus predictive, encouraging voluntary attentional shifts to the cued location. Following the cue, participants completed a temporal order judgement task, where they had to judge which of two quickly presented dots first appeared on the computer screen. Overall, participants were better at the temporal order judgement task for the valid, compared to the invalid cueing condition. The authors thus concluded that endogenous shifts of attention improve magnocellular mediated temporal processing.

Taken together, the current study therefore adds a unique piece of complementary evidence suggesting that endogenous attention narrowing can improve magnocellular sensitivity. Most importantly, this is in contrast to a body of research showing endogenous narrowing to have no impact on magnocellular mediated perception. As such, the current thesis demonstrates that the previous methods used to measure attention scaling have been inappropriate for measuring attentional effects on magnocellular perception, resolving much ambiguity present in the literature.

Why did Goodhew et al. (2016) observe a pattern of selective spatial enhancement?

Previous research exploring the effect of attentional scaling on parvocellular and magnocellular visual processing used a shape inducer task to manipulate attention (Goodhew et al., 2017, 2016). However, based on the findings of the current study, it appears that the shape inducer task used by Goodhew and colleagues might have been an inadequate manipulation of attention scale. Instead, it appears likely that the shape inducer task caused individuals to deploy attention as an annulus. In the shape inducer task, participants were briefly shown small or large shapes and were asked to determine their identity (circle or ellipse). These shapes were shown around a central fixation point and occurred on 80% of trials to set the scale of attention. On the remaining 20% of trials, spatial and temporal acuity tasks were presented at the centre of the screen. Overall, the authors found that scaling influenced spatial, but not temporal acuity.

In Goodhew et al. (2016), when a shape appeared on the screen, participants likely attended to the contours of the shape, directing most of their attentional resources to the periphery of the visual field. This would result in an annulus distribution of attention. Furthermore, according to the gradient model, attentional resources might also gradually dissipate around the attended region (LaBerge, 1983; LaBerge & Brown, 1989). Supporting this, Kravitz and Behrmann (2008) found that attentional resources spread within and around an object in a gradient fashion, similar to how spatial attention operates in a cueing paradigm. Here, attention was cued to an object (a dark grey barbell-shaped object). Following this, the target appeared at either the location indicated by the cue, somewhere inside of the object, an equidistant location outside of the object, or at a far-away location from the object. Overall, the authors found that response times for target detection decreased in a gradient pattern as the spacing between the target and object decreased linearly, similar to how spatial attention spreads around a location.

Consequently, rather than measuring the effect of attentional scaling on visual perception, Goodhew et al. (2016) shape inducer task was more likely measuring the effects of varying inducer-target distance on visual processing capacity (i.e. manipulating the size of an annulus shaped deployment of attention). In turn, this difference in attentional deployment may explain the pattern of selective spatial enhancement. Namely, is possible that whereas attention scaling influences magnocellular sensitivity, different sized attentional annuli do not. That is, the shape inducer itself may have caused the pattern of selective spatial enhancement reported by Goodhew and colleagues. This is plausible when considering the physiology of the visual system. While parvocellular neurons are more concentrated in foveal vision, magnocellular neurons are distributed in peripheral vision (Malpeli, Lee & Baker, 1996). Therefore, when attention is deployed as an annulus, for the small shape inducer, the distance between the attended area and the central spatial acuity task is small, leading to perceptual enhancement of parvocellular neurons located at the fovea. In contrast, for the large shape inducer, the distance between the attended region and the spatial acuity target is large, and would not activate foveal parvocellular neurons. This would lead to a relative performance difference for the small and large inducer shapes. Alternatively, a different pattern of results is likely to emerge for magnocellular mediated processes. Across both small and large inducer conditions, the temporal acuity target is located at the fovea, where there is a relatively lower concentration of magnocellular neurons. Therefore, changes in the size of annulus ring of distribution would not alter activation of magnocellular neurons relevant for the processing of the temporal acuity target.

A caution against using unfilled shapes to manipulate attention scale

The results of the current study strongly suggest that researchers move away from using unfilled shapes when manipulating attention scale. This is critically important, as a large body of literature has previously assumed that unfilled shapes are appropriate stimuli with which to alter, manipulate and measure attention scale (Burnett et al., 2013; Facoetti et al., 2003; Greenwood & Parasuraman, 1999; Mizuno et al., 1998; Umiltà, 1998; Yeshurun & Carrasco, 2008). Indeed, the finding that spatial structure unduly influenced attention in Goodhew et al. (2016) is consistent with the age differences study of Chapter 4 of the thesis, where it was found that spatial structure encouraged participants to attend to particular regions of the visual field, rather than distribute spatial attention broadly.

Furthermore, the results of the current study are consistent with a growing body of literature which demonstrates that when spatial structure is present in a visual scene, individuals are more likely to distribute attention as an annulus rather than scale attention (Jefferies & Di Lollo, 2015; Lawrence et al., 2018; Taylor et al., 2015). Nonetheless, here, it is important to highlight that functionally, spatial structure is an incredibly powerful guide for attention deployment. For example, Goodhew and Edwards (2017) recently compared the effectiveness of objects versus concepts to manipulate spatial attention, using shape inducers and words respectively. The shape inducers were similar to that used by Goodhew et al. (2016). In contrast, the words used were words such as "small" and "little" for the narrow attention condition, and "large" and "big" for the broad attention condition. Following the attention scale manipulation, target detection response times for a centrally appearing target were measured for both conditions. Overall, Goodhew and Edwards (2017) found that although changes in object size influenced target detection response times, concepts did not. This suggests that object structure is a central guide of spatial attention. Further, that object structure guides attention emphasises that both spatial, and object-based attention rarely operate as sole mechanisms. Instead, along with a growing body of literature, the results of the current thesis suggest that on a moment to moment basis, spatial attention, object attention, and feature-based attention all interact for effective processing of the visual world (Kravitz & Behrmann, 2011). Therefore, future work should aim to explicitly test how feature-based and object-based attention might alter the spatial scale of attention on a moment to moment basis. A good candidate task to drive these investigations would be Navon figures (Navon, 1977). This is because Navon figures likely require all three types of visual attention (e.g. Robertson et al., 1993). Specifically, an individual must be able to attend to the overall object of the Navon letter, while also attending to the features within that object (i.e. the local elements). Further, it is possible that when attending to the entire Navon stimulus, a broad spatial distribution of attention is deployed, whereas a narrow distribution is utilised when attending to local features.

Exploring the role of attention scaling and higher level visual processing

Finally, although the data from Chapter 7 provides support for the zoom lens model, the improvement of visual processing under a narrow scale of attention might only apply to stimuli processed by lower levels of the visual system. Although the current thesis has primarily focused on understanding the effect of attention scaling on parvocellular and magnocellular mediated processing, visual processing and the neural mechanisms associated with it extends far beyond the lateral geniculate nucleus (LGN). From the LGN, the parvocellular and magnocellular channels feed into the primary visual cortex. Visual processing then ascends along two predominant pathways: the ventral and dorsal cortical streams (Goodale & Milner, 1992; Maunsell & van Essen, 1983; Mishkin et al., 1983). The ventral pathway runs from the striate cortex, through visual area V4 to the inferior temporal areas, while the magnocellular dorsal pathway runs through areas MT and MST, projecting to inferior parietal areas (Mishkin et al., 1983). Similar to the magnocellular and parvocellular pathways, anatomically, the ventral and dorsal pathways are not wholly separable; however, they are thought to differ in their functional properties (Mishkin et al., 1983). That is, the ventral stream is thought to be mostly involved in the processing of form, colour, and object identification, while the dorsal stream is thought to be mostly involved in motion processing, and object localisation (Mishkin et al., 1983; Maunsell & Van Essen, 1983). Further, in comparison to parvocellular and magnocellular neurons in the LGN, the receptive fields of cells in the ventral and dorsal streams are comparatively larger (Gattass & Gross, 1981; Maunsell & van Essen, 1983). This allows information in both streams to be pooled across a broader spatial area, and for more complex types of visual information to be processed.

Although in Chapter 7 Glass pattern and global motion inducers were used to manipulate attention scale, these stimuli could also be used to assess the effect of attention scaling on ventral and dorsal visual processing respectively. To date, only one study has directly explored the effect of attention scaling on global motion processing, finding attention scaling to have minimal influence on magnocellular related, dorsal visual processing capacity (Burnett et al., 2013). However, this study used unfilled shapes to cue attention, and thus, may not have been an effective manipulation of attention scale. Therefore, future work could use a glass pattern inducer to manipulate spatial attention scale, and then measure the effect of this manipulation on global motion processing or vice versa. This method would allow for a fuller understanding of how attention scaling influences all aspects of visual processing.

8.2.3. Summary: Exploring the Effect of Attention Scaling on Vision

In the second half of the thesis, the effect of attentional scaling on parvocellular and magnocellular mediated vision was evaluated. Chapter 6 critically analysed current theoretical models of attentional scaling, concluding that future research needs to carefully consider the specific methodology used when testing the relationship between attention scaling and vision. Chapter 7 then directly tested the effect of attention scaling on parvocellular and magnocellular vision using a new method to manipulate attention scale. Compared to previous work which found attention scaling to selectively influence parvocellular processing, it was found that narrowing attention improved both spatial and temporal acuity. Overall, both chapters highlight the fundamental importance of careful operationalisation when measuring and manipulating attention scale.

8.3. Combining Individual and Experimental Approaches to Understanding the Dynamics of Attentional Scaling

A key strength of this thesis was its use of both individual and experimental approaches to understanding attentional scaling. In particular, this allowed for the exploration of how different individuals might distribute attention in a given scenario, as well as an evaluation of the consequences of attention scaling on visual processing capacity. However, for a full understanding of attentional scaling, future work should combine both approaches within a single experimental paradigm. That is, given that individual differences in attention scaling may have implications for models of attentional scaling more generally, future research should aim to explore whether individual differences in attention scale influence the relationship between attentional scaling and visual perception.

Specifically, in Chapter 7 of the thesis, when exploring the effect of attention scaling on vision, it was assumed that the effect of a narrow versus broad scale of attention would be stable for the entire participant group. However, it is reasonable to expect that the relationship between attention scaling and vision might also vary for different individuals. For example, in Chapter 4 of the thesis, it was demonstrated that age influences attention scale. Furthermore, there is substantial evidence demonstrating age differences in visual processing, where older adults tend to show a lower level of specialisation of visual processing in the ventral visual stream (Park et al., 2004). In Park et al. (2004), younger and older adults were presented with face and house pictures while activity in their ventral visual cortex was recorded using fMRI. Overall, younger adults showed more specificity of activation in category-specific processing areas of the ventral stream, in particular, the fusiform face area, compared to older adults. Given that there are known age differences in both attention scaling and visual processing, it is likely that the relationship between attention scaling and vision might also differ across the lifespan.

Therefore, future work could use an experimental paradigm similar to that used in Chapter 7 of the thesis to measure potential age differences in attention scaling and visual processing. It is predicted that in this task, the magnitude of the effect of attention scaling on vision might differ for younger versus older adults. Specifically, because visual processing capacity declines with age, one would expect that older adults would show a greater level of enhancement of visual processing under a narrow compared to a broad scale of attention. This would allow older adults to compensate for visual declines to a greater degree compared to younger adults. Studies such as this would allow researchers to specify how general models of attention scaling might apply to different individuals in a given scenario.

8.4. Conclusion

The current thesis aimed to understand the dynamics of attention scaling. This was achieved using both an individual differences and an experimental approach. In Chapter 4 and 5, an IOR task was employed to test how healthy ageing and cultural background influence attention scale. The use of the IOR task to measure individual differences in attention had a particular strength, as it was a highly sensitive tool which uniquely measures spatial attention. Chapter 4 found that older adults tend to adopt a narrower scale of attention compared to younger adults. However, Chapter 5 found no effect of culture on the spatial attention distribution. Instead, Western participants were on average, faster to detect targets compared to East Asian participants. In Chapter 6 and 7, the effects of attention scaling on parvocellular and magnocellular vision were evaluated. Again, it was found that the particular method used to measure and manipulate attention is crucial for valid theoretical conclusions about the dynamics of attention scaling to be made. Specifically, compared to past research which posits narrowing attention improves only parvocellular processing, using a new operationalisation of attention scaling, it was found that narrowing attention improves both parvocellular, and magnocellular mediated processing. Future work should explore the effects of attention scaling on higher level visual processing. Furthermore, future research should combine both individual differences and experimental approaches to understanding the dynamics of attention scaling. Together, this will provide a more nuanced understanding of how attentional scaling helps us navigate the world.

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Appendix

Cultural Background Questionnaire Administered in Chapter 5

Demographic Questionnaire

1. **What is your date of birth? (dd/mm/yyyy):**

2. **What gender do you identify with? Please circle one.**

   Male / Female / Other

3. **Are you left- or right-handed? Please circle one.**

   Left / Right/Ambidextrous

4. **How many years of formal education have you completed (include full time education from kindergarten through to college and/or university)**

5. **What is the current status of your vision?**

   [ ] Normal vision

   [ ] Corrected vision (Please circle: Near= or Far-sighted)

   [ ] Corrected with contact lenses (Correction, if known: _____)

   [ ] Corrected with glasses (Correction, if known: ________)

   [ ] Vision problems

   Further Details:

   ____

   ____
   _____

6. What group do you most strongly associate yourself with?

[ ] Aboriginal or Torres Strait Islander

[ ] South Asian

[ ] East Asian

[ ] Caucasian

[ ] Other (Please specify:__________________________)

Please Answer the following questions for the group you identified in question 6 (e.g. East Asian, Caucasian etc.)

	Not at all	A little	Somewhat	Quite a bit	Very much
I think of myself as a (group)	[ ]	[ ]	[ ]	[ ]	[ ]
I think of myself as part of another ethnic group to the one identified in question 6	[ ]	[ ]	[ ]	[ ]	[ ]

What group?

____

People can think of themselves in various ways. For example, they may feel that they are members of various ethnic groups, and they are part of the larger society, Australia. These questions are about how you think of yourself in this respect.

7. How do you think of yourself?

	Not at all	A little	Somewhat	Quite a bit	Very much
I think of myself as a (group)	[ ]	[ ]	[ ]	[ ]	[ ]

I think of myself as Australian	[ ]	[ ]	[ ]	[ ]	[ ]
I think of myself as part of another ethnic group to the one identified in question 6	[ ]	[ ]	[ ]	[ ]	[ ]

What group?

____

(Derived from the MIRIPS Questionnaire; Berry, J.W. (2010))

8. What is your country of birth? :

9. What country or countries have you lived in, and for how long did you live in each country?

Country	Time Spent Living in the Country (to the nearest year)

10. What is the first language you learnt?

11. What languages are you now fluent in?

12. What is the main language you use now?

13. What country or countries did you go to school in? :

	Country	Language Spoken at School
Primary School		
Middle School		
High School		

14. Which country or countries did your parents grow up in? :

15. How long have you lived in Australia for? :

________ years ________ months

ASQ-10

Please tick one option per question only:

	Definitely Agree	**Slightly Agree**	**Slightly Disagree**	**Definitely Disagree**
I often notice small sounds when	[ ]	[ ]	[ ]	[ ]

others do not				
I usually concentrate more on the whole picture, rather than the small details	[ ]	[ ]	[ ]	[ ]
I find it easy to do more than one thing at once	[ ]	[ ]	[ ]	[ ]
If there is an interruption, I can switch back to what I was doing very quickly	[ ]	[ ]	[ ]	[ ]
I find it easy to 'read between the lines' when someone is talking to me	[ ]	[ ]	[ ]	[ ]
I know how to tell if someone listening to me is getting bored	[ ]	[ ]	[ ]	[ ]
When I'm reading a story, I find it difficult to work out	[ ]	[ ]	[ ]	[ ]

the characters' intentions				
I like to collect information about categories of things (e.g., types of car, types of bird, types of train, types of plant etc.)	[ ]	[ ]	[ ]	[ ]
I find it easy to work out what someone is thinking or feeling just by looking at their face	[ ]	[ ]	[ ]	[ ]
I find it difficult to work out people's intentions	[ ]	[ ]	[ ]	[ ]

(Derived from Allison, Auyeung and Baron-Cohen, 2012)