Attentional competition between visual stimuli in healthy individuals and neurological patients

Thesis submitted for the degree of Doctor of Philosophy

By

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December 2012

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I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another neither person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or any other institute of learning.

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The work presented in this thesis has led to the following publications:

Peer-reviewed manuscripts:

Watling, R., Danckert, J., Linnell, K., and Cocchini, G. (2013). Extinction and anti-extinction: the “attentional waiting” hypothesis. *Neuropsychology, 27*, 275-279.*

A second paper on Experiments 3 and 4 is in preparation.

Conference proceedings:

Watling, R., Cocchini, G. and Danckert, J. (2010, 22-24 September). *Anti-extinction and binding of targets by time: a single case study.* Poster session presented at the Second Meeting of the Federation of the European Societies of Neuropsychology (ESN), Amsterdam, Netherlands.

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* Presented in Appendix A of this thesis.

For Mike

Abstract

In the rich and complex visual environment that surrounds us, visual stimuli compete for attention in a limited capacity perceptual system (Broadbent, 1958; Duncan, 1980; Treisman, 1969). In this competition, the winners reach perceptual awareness and the losers are disregarded and fail to reach awareness (Ward, Goodrich & Driver, 1994; Mattingley, Davis & Driver, 1997). Theories of visual attention can be guided and informed by the study of brain damaged patients who show specific impairments in attending to visual stimuli, in particular visual extinction, commonly following right hemisphere damage and resulting in an inability to perceive a contralesional stimulus when it appears with a simultaneous ipsilesional item, but no such impairment when it appears alone. The studies reported in this thesis created an extinction-like pattern of errors in healthy volunteers using a bottom-up (stimulus-driven) paradigm when a simple task of detection was employed. When a more demanding task of stimulus identification employed, both in bottom-up and top-down (cueing) paradigms, a rarely previously described pattern of anti-extinction was observed, in which perception of a weaker item was facilitated (rather than impaired) by a simultaneous ‘stronger’ item in the display. Extinction and anti-extinction were then explored in brain damaged patients. A novel ‘attentional waiting’ hypothesis was discussed, which proposes that extinction and anti-extinction may be part of the same attentional mechanism where the latter manifestation may be observed in larger proportion of patients showing extinction if duration of stimuli is increased.

“Assuming, as is natural, that of two simultaneous sensory stimuli, the stronger always tends to extrude the weaker from consciousness, is it conceivable or not that one should be able to discern the objects coinstantaneously in the same individual time?” (Aristotle, trans. 2006, p.25)

This research was made possible by the financial support of the Economic and Social Research Council (ESRC) in the form of an ESRC 1 + 3 studentship award.

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Published paper arising from work reported in this thesis:

Watling, R., Danckert, J., Linnell, K., and Cocchini, G. (2013). Extinction and anti-extinction: the “attentional waiting” hypothesis. *Neuropsychology, 27*, 275-279.

Chapter 1

Introduction

1.1 A brief overview of attention

1.1.1 What is attention?

What is attention? The question has a semblance of paradox about it because, whilst the word is used frequently in everyday parlance, as a phenomenon its definition is equivocal. Hunter (2009) asks whether it is an energy, a function, a power or a relationship. Loosely, it can be described as an adaptive mechanism that allows us to focus on one aspect of the environment whilst ignoring others. On closer reflection though, it seems to have a number of specific features including selection on the bases of location and object properties, selection primed by expectation, automatic processes triggered by environmental changes and re-orienting of attention after distraction. A significant feature of attention is that its capacity is limited. Take a scenario that is familiar to most of us today: waiting to reclaim one's luggage from a baggage carousel at an airport. Having established the baggage reclaim area where the carousel is located, we are able to select one conveyor belt over others on the basis of its spatial location. We keep looking at one point on the moving conveyor belt, hoping to see our suitcase. We have an expectation of what the suitcase will look like, driven by top-down processes. A similar looking case appears – the same colour and size as the one we are expecting – and, momentarily, we are misled into thinking this is our case: the perceptual input has triggered, bottom-up, two of the attributes (colour and size) that have been primed by our expectations. Whilst we are focused on one area of the conveyor belt a loud alarm bell rings and we are distracted and look around the arrivals area for any sign of impending danger: an automatic process has detected an important environmental change outside the current focus of attention and drawn attention to it. The ringing stops and a loudspeaker announcement informs us that there is no cause for alarm, so we re-engage our attention to where it was before: we have remembered what we were doing and can direct our attention back to the original task. If our suitcase fails to appear after more than a few more minutes it becomes increasingly difficult to stop our attention from wandering; we start to observe other passengers and their luggage: attentional capacity is limited. After a while, our suitcase appears and we move to grasp it from the conveyor belt: our attention has shifted from the location of the conveyor belt to the suitcase itself; it has changed from being location-based to object-based. In our everyday interactions with the visual world, attention is guided both by bottom-up (stimulus-driven) factors, such as colour, shape and brightness, and top-down (cognitive) factors, for example current goals and expectations, and prior knowledge.

1.1.2 Historical overview

The visual system is perhaps the most important of our sensory systems in terms of providing us with detailed information about the world around us, and the processes underlying the interpretation of this information have been the foci of many decades of research. Probably the earliest recorded thoughts on attention date back to Aristotle’s contemplations, in which he makes explicit reference to the difficulty in attending to more than one stimulus at a time (Aristotle, trans. 2006). The long-held Aristotelian conception of the soul, which was believed to be the capacity of a living thing to interact with the world, and which incorporated perception and intellect, was replaced in the seventeenth century by Cartesian dualism. Descartes made a distinction between the mind (responsible for consciousness and self-awareness) and the brain (the seat of intelligence).

When psychology emerged as a discipline during the mid eighteenth century, Wolff (1738, cited in Mole (2009) devoted an entire section to the topic of attention, marking the introduction of attention to psychology as a major field. Despite the fact that Wolff's observations were not empirically tested, he nevertheless made a significant contribution to the thinking on cognitive processes at the time. A number of textbooks followed (e.g. Bonnet, 1755; Abel, 1786) that addressed the topic of attention. According to Hatfield (1988), little is known about the experimental techniques in psychology that doubtless emerged in the early nineteenth century, but it is agreed that psychological theory of the time followed a strong continuity from the writings of eighteenth century psychologists. It was Titchener (1908) who brought the study of attention to the fore by writing of the realisation that, "the doctrine of attention is the nerve of the whole psychological system" (1908, p. 173, as cited in Hatfield, 1988). He noted that the onset of a sudden movement or change could bring about an involuntary shift of attention and, conversely, that the termination of a previously unnoticed stimulus could also summon attention. Unlike some earlier theorists (e.g. Bonnet, 1755, cited in Hatfield, 1988; Abel, 1786, cited in Hatfield, 1988) who asserted multiple degrees of attention, Titchener postulated that there are only two levels of attention or 'degrees of clearness', focal, conscious attention and what is outside it. For Titchener, the role of attention in perception was its most fundamental attribute whereas for other theorists of the time attention's role in action was significant (e.g. Bain, 1888) and for yet others (e.g. Stout, 1891), its role in reflective thought. By the end of the nineteenth century a number of disparate claims about the role of attention had been made and it was from this collection of ideas that James (1890) put forward his somewhat reductionist approach suggesting that "Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought." (1890, p.403). James suggested that the role of attention in higher cognitive processes was minimal, and focused more on "the accommodation or adjustment of the sensory organs" (1890, p.411), meaning the processes of reacting, for example, to a flash of light by turning one's eyes towards the stimulus.

In the early twentieth century following the work of Pavlov, Thorndike, Watson, Skinner and others the predominant approach to psychology was behaviourism. The behaviourist movement heralded an important change towards advances in experimental psychology and the advocacy of empirical testing, but this came at the expense of the study of cognitive constructs such as attention. Attention, being an internal process that is difficult to observe, became relegated to philosophical discussion.

In the second half of the twentieth century psychologists were driven by the events of the two World Wars to study not only the extremes of human behaviour but also cognitive constructs. Prompted by knowledge of the particular difficulties experienced during warfare (for example soldiers having to attend to multiple locations on the battlefield, pilots having to attend to several sources of information simultaneously in the cockpit and outside the aircraft, radar operators having to maintain concentration), cognitive psychologists wanted to learn more about the human capacity for attention and its processes.

Vigilance is a term used to describe a situation in which randomly occurring, infrequent signals have to be responded to over a long period of time. It became a topic of interest in the 1940s and '50s when after it was noted that detection of enemy aircraft by radar operators deteriorated rapidly within just 15 to 30 minutes of starting the task (Mackworth, 1950). Vigilance studies have important implications for understanding attention during monotonous and prolonged monitoring tasks and, more recently, vigilance research has been applied to issues such as road safety (e.g.

Ting et al., 2008), train driving (Haga, 1984) and patient care in hospital intensive care units (Balas et al., 2008).

Another early researcher into attentional processes was Welford (1952), who looked at attention to two stimuli presented in rapid succession. He found that when a second stimulus is presented, reaction to the second stimulus was slower if the stimulus onset asynchrony (SOA) was very short, and that there was an inverse relationship between SOA and reaction time to the second stimulus: for each millisecond decrease in SOA there was a corresponding increase in reaction time to the second stimulus. Welford proposed an attentional ‘bottleneck’ model, in which processing of the second stimulus cannot begin until processing of the first has been completed. Welford’s theory of attentional processing proved to be the cornerstone on which several decades of attention research were later built, and these will be discussed in Section 1.2.1.

According to Allen (1948), the phenomenon of extinction was first described by Anton (1883) and by Oppenheim (1885), and further alluded to by Poppelreuter during the First World War. Termed ‘visual inattention’, it concerned the inability of patients to detect a visual stimulus on one side if a rival stimulus were simultaneously presented on the opposite side. Bender and Furlow (1945) noted that the size or luminosity of the intact stimulus can have an effect on the contralesional stimulus that may be neglected, and suggested that the term ‘extinction’ may be more appropriate, based upon the premise that a stronger stimulus extinguishes or suppresses a weaker one. Critchley (1966) criticised the use of this new term, nevertheless the expression remains widely used today. The phenomenon of extinction is further described in Section 1.3.2.

1.2 Theories of attention

1.2.1 Early versus late selection in visual attention

The question of how and when attentional processes occur has been central to a long-standing debate. On one hand, early selection theory (Treisman, 1969) proposed that we have a limited capacity perceptual system and that perception is restricted to attended items, hence attention can prevent early processing of irrelevant or ignored stimuli. According to this model, of the many stimuli that surround us at any given moment, only one is attended and processed to the level of detection and the others are filtered out and fail to reach conscious awareness. Proponents of late selection theory (Deutsch & Deutsch, 1963, Duncan, 1980), on the other hand, suggest that the perceptual system is limitless in capacity and that all stimuli are perceived and that attention occurs later after all stimuli have been semantically processed, affecting post-perceptual processes such as memory or response selection.

A central question regarding the point at which stimuli are processed (before or after selection) is whether the unattended information reaches awareness at any level. One of the earliest theorists to address this question was Cherry (1953), who carried out a dichotic listening task in which participants were played two different spoken messages simultaneously, one in each ear. To ensure that attention was directed to one of the messages, participants were required to repeat it aloud, a process known as shadowing. Participants were able to report whether the speaker of the unattended message had been male or female, however they were unable to report the content of the message. Broadbent (1958) based his ‘filter’ model of attention on a similar study, in which participants were presented dichotically with pairs of digits and failed to report the unattended digits. Broadbent concluded that unattended stimuli are not semantically processed and discarded. Analogous research in the visual domain by Neisser (1969) showed that in a selective reading task in which participants ignored printed material appearing between the lines of relevant text, they were later unable to report the ignored text. In later studies containing simple images rather than more complex semantic material (e.g. Goldstein & Fink, 1981), participants were presented with superimposed line drawings and told to attend to one of the pair and ignore the other. In a subsequent recognition test in which both images were presented singly, participants recognised significantly more of the attended than the unattended stimuli. A number of studies in the 1970s and ‘80s presented dynamic scenes, superimposing two semi-transparent video clips and requiring participants to focus on one aspect of the scene whilst ignoring others (e.g. Becklen & Cervone, 1983; Littman & Becklen, 1976; Neisser, 1979; Neisser & Becklen, 1975; Stoffregen & Becklen, 1989). During the task, an unexpected event occurs that participants do not report having seen, although it is clearly noticeable to other observers not engaged in the task. A renewed interest in this inability to perceive an unexpected object, even if it is prominent, has led to the term ‘inattentional blindness’ (Mack & Rock, 1998). A more recent and frequently cited demonstration of inattentional blindness is a study by Simons and Chabris (1999), in which participants are asked to count the number of times a ball is passed between three members of a team wearing white t-shirts, and to ignore the three members of a second team wearing black t-shirts, who are throwing a second ball between themselves (Figure 1.2.1). During the short course of the ball game, a person dressed in a gorilla suit walks across the scene, stops in the centre and beats his chest, and continues to walk across the screen. Participants frequently report having had no perception of the gorilla, suggesting that perception is restricted to attended items.

Figure 1.2.1: *A frame from the video clip used by Simon and Chabris (1999) illustrating inattentional blindness.*

Thus far, the studies reviewed have offered support for early selection, but there are also an appreciable number of studies supporting the late selection model. Even if unattended stimuli fail to reach overt perceptual awareness, there is an abundance of evidence that suggests that unattended stimuli are processed to some degree. A number of researchers showed that when meaningful material was presented to the non-attended ear in dichotic listening studies, it was processed effectively. In a study by Mackay (1973), for example, participants had to report the sentence they had heard. When the sentence contained the word *bank*, responses were influenced by whether the word *river* or *money* had been presented to the non-attended ear. Additional evidence comes from the effect of unattended stimuli on reaction times, for example in the classic Stroop paradigm (Stroop, 1935), in which participants read colour stimulus words printed in different coloured inks. When the word and the colour are congruent (e.g. the word ‘blue’ printed in blue ink), response times are faster than when they are incongruent (e.g. the word ‘pink’ printed in green ink). Despite being told only to report one attribute of the stimulus, the fact that responses are slower to incongruent words suggests that the unattended attribute is still processed to some extent. Further support for the notion that stimuli that are unattended are processed to some extent comes from implicit processing in visual neglect patients. Patients with visual neglect tend to ignore stimuli on the contralesional side of space, but there is compelling evidence to suggest that these stimuli are processed to some extent, though not reaching conscious awareness. A detailed discussion of these studies may be found in Section 1.3.1 of this thesis.

As can be seen, there is much evidence to support both early and late selection theories of attention. Lavie (1995) proposed a hybrid model of attention that encompasses key aspects of both theories and, to some extent, offered a resolution to the ongoing debate. Lavie's (1995) load theory states that there is a limit to the capacity of the perceptual system, as proposed by early selection theory, but also that all stimuli are processed *until perceptual capacity is exhausted.* According to this theory, the level of perceptual load determines the extent to which stimuli are processed. In instances of high perceptual load, early selection will occur and when perceptual load is low and capacity is not exhausted late selection will occur enabling distractor interference.

1.2.2. Focused and selective visual attention

In the complex environment that surrounds us, it is the visual system that provides us with more detailed information than any other sensory system (Milner & Goodale, 1995). Visuospatial attention is crucial to our interaction with the people and objects around us and to our perception of depth, movement, space and colour. In order to make sense of the myriad of visual sensory stimuli with which we are presented at any waking moment, the brain must process not only the visual qualities of people and objects, but also their position in relation to us and to one another, their size, depth and perspective.

Posner (1980) found that when participants' attention is fixated on a particular item in the visual field, they can still attend to additional stimuli placed at around 7 degrees either side of fixation. Furthermore, attention can be shifted more rapidly when a stimulus appears in an expected, rather than an unexpected, location and attention can be directed covertly, that is without movement of the eyes. Posner made an analogy between attention and an internal mental spotlight surrounding a region of space. LaBerge (1983) reported that the speed of identifying a stimulus was a function of the distance from the centre of the attentional spotlight. In a task requiring central fixation, reaction times were faster for items appearing at the centre of an array of stimuli than for those at the periphery, suggesting that visual attention is most efficient at the centre of the internal spotlight and least at its peripheral edges.

An influential model proposed by Treisman and Gelade (1980) is the feature-integration theory, which proposes that visual arrays are encoded serially, initially in terms of separable dimensions (colour, size, orientation, brightness, direction of movement). It is only at a later stage, when such features are the subject of focused attention, that they are combined to form a unitary representation of an object or scene. Accordingly, the model proposes that without focused attention dimensions cannot be related to one another to form a unitary whole. This notion raises the paradox of the way in which unattended surrounding areas are processed not as empty space but as vague perceptions. The authors suggest that the top-down processing of unattended features allows access to past experience and contextual information. Without focused attention conjunctions of these unattended features can be formed on a random basis and give rise to a lack of accuracy in perception.

Cave a Wolfe (1990) observed that the serial processing model proposed by feature-integration theory failed to account for data showing that conjunction searches can be performed efficiently and quickly by some participants (Wolfe, Cave and Franzel, 1989). They proposed a guided search theory, which modified feature-integration theory to account for these observations. Guided search theory postulates that, under some circumstances, visual search can be a parallel rather than a serial process; guided search assigns saliency to items in the visual field, such that items with nontarget features are inhibited and items with target features are excited. In such instances the parallel stage guides the serial stage as it selects the target features that are to be processed.

Desimone and Duncan (1995) differentiate between top-down and bottom-up biases for object selection. Top-down biases on visual attention are contingent on prior knowledge of the task at hand and include selection based on spatial location and on features. Bottom-up neural mechanisms appear to be largely automatic processes that do not depend on cognition or task demands. A number of studies have further explored this apparent interaction between top-down and bottom-up processing in extinction patients (e.g. Gilchrist, Humphreys & Riddoch, 1996; Mattingley, Davis & Driver, 1997; Ptak, Valenza & Schnider , 2002; Riddoch, Humphreys, Edwards, Baker & Willson, 2003; Riddoch, Humphreys, Hickman, Clift, Daly & Colin, 2006; Soto & Humphreys, 2006; Geng & Behrmann, 2006).

Recent studies have also demonstrated that attention can be a supramodal resource, that is, it can involve more than one modality. Spence et al. (2000) observed that a visual cue (such as an arrow) can improve detection of tactile stimuli presented in the visually cued position. In line with this finding, neuroimaging studies have demonstrated that similar anatomical areas (i.e., superior parietal lobe, intraparietal sulcus and superior temporal gyrus) are activated during attentional tasks involving either visual or tactile stimuli (Macaluso, Frith & Driver, 2002; see also Eimer and van Velzen, 2002 for similar results using ERP). These findings suggest that attention resources for different modalities may be coupled. However, Chambers, Stokes and Mattingley (2004) observed that inferior parietal areas may be differently involved in covert attention of visual and somatosensory stimuli. In particular, they observed that TMS of the right supramarginal gyrus disrupted orientation of visual attention, but not somatosensory, suggesting some modality-specific activity of this brain areas. Moreover, while this part of the inferior parietal lobule may be involved in covert attention, the right angular gyrus seems to be involved in disengaging attention following an invalid cue and later processes in discrimination of the target (Chambers, Payne, Stokes & Mattingley, 2004).

Theories of visual attention can be guided and informed by the study of brain damaged patients who show specific impairments in attending to visual stimuli, in particular spatial neglect and visual extinction. These impairments are discussed in Section 1.3.

1.3 Disorders of spatial attention

One can learn much about the processes of spatial attention in healthy individuals by studying ways in which they break down after brain damage. The study of spatially specific neurological disorders falls broadly into two categories. The first concerns hemispatial or unilateral neglect, an impairment in the processing of one half of perceptual space. The second, and the main focus of this thesis, concerns visual extinction, in which patients are able to perceive a single stimulus in either visual field; however, when presented with stimuli simultaneously in both left and right visual fields, they ignore or 'extinguish' the stimulus on the contralesional side of visual space.

1.3.1 Visuospatial neglect

Visuospatial neglect is a common and debilitating syndrome that follows stroke damage to the right hemisphere. Attention is inexorably shifted towards the ipsilesional (usually right) side of space and the analogy of a magnet has been used to describe the attentional pull towards ipsilesional space (Halligan & Marshall, 1993; Halligan, Fink, Marshall, & Vallar, 2003; Danckert & Ferber, 2006). Patients will neglect items that appear in contralesional space; they may leave food uneaten on the left side of a plate, fail to notice someone approaching from their left side or fail to groom the left side of the body (personal neglect). When asked to copy a simple picture they will ignore the left hand side of the image (Figure 1.3.1), indeed if given a blank circle and asked to fill in numbers to draw a clock, they may crowd all twelve numbers into the right hand space of the circle (Figure 1.3.2).

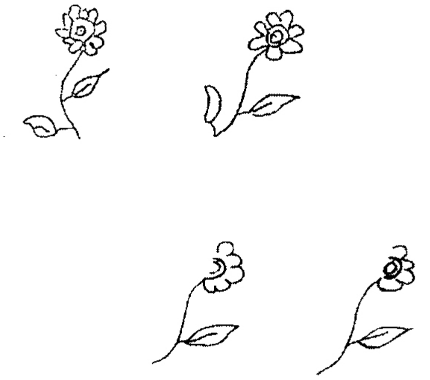

Figure 1.3.1*: Performance on a copying task by a patient showing evidence of object-centred neglect. From Logie and Della Sala, 2005.*

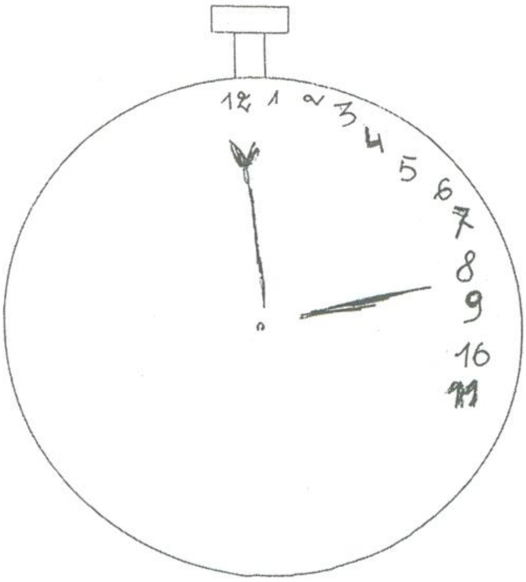

Figure 1.3.2: *A representational task showing a drawing by a patient of a clock in which the left side has been omitted, transposing all details to the right side. From Beschin, Basso and Della Sala, 2000.*

Various studies have reported how neglect patients may still be able to move their eyes or perform movements with their limbs towards the contralesional space. Despite this, they may be unable to consciously report information presented in contralesional space (Bisiach & Rusconi, 1990; Ferber, Danckert, Joanisse, Goltz, & Goodale, 2003).

Neglect usually arises following right hemisphere damage, but it can be observed following damage to the left hemisphere, in which case the deficit is reported to be less severe and less persistent (Beis et al., 2004; but see also Rorden & Karnath, 2012 for contrasting findings).

Neglect patients often have a striking lack of awareness of their deficits on the affected side, known as anosognosia (Heilman, Barrett & Adair, 1998; Vallar, Bottini & Sterzi, 2003).

Of the many tests used to assess spatial neglect, line bisection is the most commonly used (Jewell & McCourt, 2000). When asked to estimate the midpoint of a horizontal line, neglect patients consistently misjudge the central point towards the right hand side of the veridical centre (e.g. Heilman, Watson & Valenstein, 1985; Mesulam, 2000; Robertson & Halligan, 1999; Schenkenberg, Bradford & Ajax, 1980), as if ignoring the majority of the line if left hemispace. Neglect is clinically assessed by a number of additional tests including the Bells Test (Gauthier, Dehaut, & Joanette, 1989) which consists of seven columns each containing five targets (bells) amid 40 distracters and the patient is asked to draw a line through all the bells on the page (Figure.1.3.3) and line cancellation tasks, in which the task is to draw a line through (or cancel out) a series of short lines drawn at varying angles. In these tests, a patient showing neglect will cancel the stimuli on the right hand side of the page and neglect those on the left. Ferber and Karnath (2001) undertook a comparison of neglect assessment tests and reported that line bisection should be treated with caution in clinical diagnosis since 40% of their patients performed well in bisecting horizontal lines despite impairment on other tasks. Line cancellation was found to be less sensitive than tests with distracters, such as the Bells test. The sensitivity of a test is increased when the stimuli have a high density and are interspersed with distracters. Bickerton, Samson, Williamson and Humphreys (2011) have recently assessed evidence of different forms of neglect on a large sample of 115 acute stoke patients by means of the Apples Test (Figure 1.3.4), which seems to be a useful diagnostic tool to differentiate allocentric (i.e. tendency to neglect one side of an object) and egocentric neglect (i.e. the tendency to neglect all stimuli in one side of the patient's body).

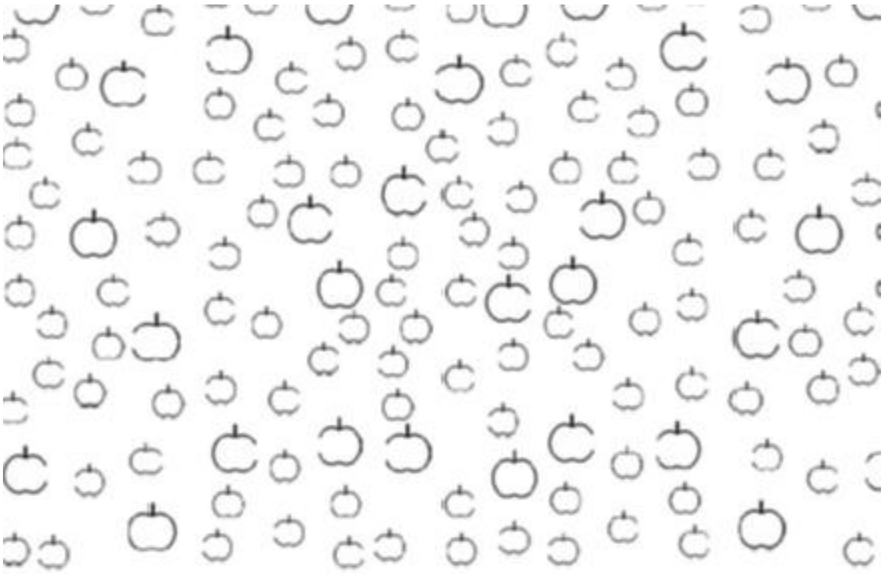

Figure 1.3.3: *Apples Test cancellation sheet, in which some apples have an opening on the left, some on the right and some are complete apples. Participants have to cancel all complete apples, ignoring all the others.*

Personal neglect is another form of neglect often assessed by means of tests such as the Comb and Razor/Compact Test (Beschin & Robertson, 1997), in which the patient is asked to demonstrate the use of a comb and a razor or make-up compact and the Fluff Test (Cocchini, Beschin, & Jehkonen, 2001), in which small cardboard circles are attached with velcro to the patient's clothing at predefined locations on the body, and the patient is required to remove all the targets attached to their clothes whilst blindfolded.

Neglect can occur not only in the visual modality, but also in tactile, auditory, proprioceptive and olfactory domains (Heilman, Watson & Valenstein, 1993; Mesulam, 1981; Pavini, Làdavas & Driver, 2003; Vallar, Guaraglia, Nico & Bisiach, 1995; Brozzoli & Farne, 2012). Interestingly, recent studies have investigated the multi-modal effects of some rehabilitation techniques. Kerkhoff et al. (2012) demonstrated that techniques such as optokinetic stimulation can ameliorate both auditory and visual neglect. Neglect affects not only the external sensory world, but also visual imagery: Bisiach and Luzzatti (1978) asked patients to imagine they were standing with their back to the cathedral in Milan's Piazza del Duomo, a busy meeting place well known to residents of Milan, and to describe the imaginary scene. Patients described the historic buildings, shops and restaurants on the right hand side of the scene, but omitted details from the left. When asked to imagine that they had walked across the square and were now facing the cathedral, they then described the buildings on the opposite side of the square, again omitting the details on their left hand side. The concept of representation neglect has been further replicated (Bartolomeo, D'Erme & Gainotti, 1994) and investigated by means of different tasks involving number line (e.g., Zorzi, Priftis, Meneghello, Marenzi & Unilta, 2006; Vuilleumier, Ortigue, & Brugger, 2004) and word (Arduino et al. 2012) representations.

A number of studies have shown that, despite profound neglect of contralesional space, there can be an implicit awareness of items in the contralesional visual field. Marshall and Halligan (1988) presented their patient with two line drawings of a house which were identical, apart from smoke and flames appearing in the left hand window. The patient stated that the two drawings were identical however, when asked which one she would prefer to live in, she consistently chose the house that was not on fire (Figure 1.3.5).

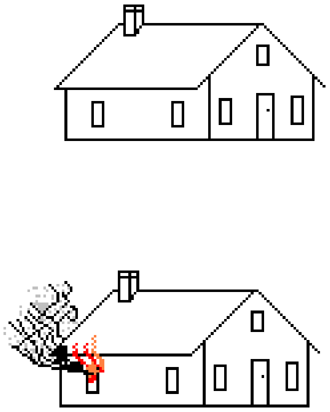

Figure 1.3.4: *The 'Burning House' study, adapted from Marshall and Halligan (1988)*

This study was carried out with only one patient. It has since been replicated using different images such as two wine glasses, one with a chip on the left hand rim and two bank notes, one with the top left hand corner torn away (Bisiach & Rusconi, 1990), however with equivocal results. Of Bisiach and Rusconi's four patients, two showed no consistent preferences for any of the images but two did show preferences (although not always for the more rationally appealing of the two images), suggesting that they did notice some difference between the pairs of pictures and were able to make choices on the basis of this difference without any conscious justification of their selections.

Whilst neglect is often more severe in the acute stage of brain damage, in the first weeks immediately following a stroke, recovery is possible – the majority of patients show spontaneous recovery within days or weeks (Manly, 2001). Recovery is aided by occupational therapy, in which the patient is encouraged to move his or her eyes towards the left and to actively search for stimuli in left hemispace, as well as by plasticity, the brain's unique capacity for undamaged neural structures to take over the functions that the damaged structures can no longer perform. While the deficits in spatial awareness from neglect may, in time, become ameliorated (Hier, Mondlock, & Caplan, 1983), patients often still display visual extinction.

1.3.2 Visual Extinction

Visual extinction refers to an impairment in detecting a contralesional stimulus when presented simultaneously with an ipsilesional stimulus, whilst able to detect a single stimulus presented alone in either visual field (Bender & Teuber, 1946; Critchley, 1966; Wortis, Bender, & Teuber, 1948). Extinction is thought to arise from a competition between the ipsilesional and contralesional stimuli, leading the ipsilesional stimulus to extinguish the contralesional one from awareness (Driver, 2001; Driver & Vuilleumier, 2001; Mattingley, Davis, & Driver, 1997). When both stimuli must compete for attention simultaneously the intact (left) hemisphere processing the ipsilesional stimulus is thought to divert attention from the damaged (right) hemisphere's processing of the contralesional stimulus, resulting in extinction of the contralesional stimulus.

Extinction is clinically assessed by the Visual Confrontation Test, in which the tester stands centrally in front of the patient with both hands raised. The patient is instructed to fixate on the tester's nose, and to detect movements in the fingers of the tester's left or right hand, or both hands simultaneously. One would expect a patient with visual extinction to detect movements in either hand when made unilaterally, but in bilateral stimulation to detect only the movement in the tester's left hand (i.e. the patient's right visual field). Stimuli are well above threshold (Mattingley, 2002) so performance for *single* contralesional events is often at ceiling. Computerised tests can be used in the assessment and investigation of extinction, in which stimuli are briefly displayed unilaterally and bilaterally in both visual fields. Such tests allow more precise control of stimuli, including their duration, salience, size and location.

Whilst a number of theories have been proposed to account for this deficit, a definitive explanation remains yet to be accepted. Early researchers (e.g. Bender & Teuber, 1946; Denny-Brown, Meyer & Horenstein, 1952; Birch, Belmont & Karp, 1967) and more recent studies (e.g. Farah, Monheit & Wallace, 1991; Vallar, Rusconi, Bignamini, Geminiani & Perani, 1994; Marzi et al., 1996) posited a 'sensory hypothesis', suggesting that extinction is a result of weakened afferent input to the damaged hemisphere. In contrast, the 'attentional hypothesis' (Bisiach, 1991; Heilman & Watson, 1977; Mesulam, 1981; Rafal, 1994) accounts for extinction as a biased competition for attentional selection, in which a stimulus presented in ipsilesional space is favoured over one in contralesional space in double simultaneous stimulation. There is evidence to support the notion that extinction is an attentional deficit rather than a sensory one. For example, patients fail to detect a single contralesional target (even in the absence of an ipsilesional one) if their attention is cued towards the ipsilesional field (Posner, Walker, Friedrich, & Rafal, 1984). Similarly, if instructed to ignore an ipsilesional target and attend to the contralesional one the target can be detected (Di Pellegrino & De Renzi, 1995; Karnath, 1988). Moreover, if two stimuli are presented to the ipsilesional hemifield, patients often extinguish the leftward of the two stimuli (Kinsbourne, 1987; Di Pellegrino & De Renzi, 1995).

One factor that has been shown to modulate extinction is the perceptual grouping of visual stimuli. Ward, Goodrich and Driver (1994) investigated the effects of perceptual grouping on two patients with extinction following right parietal damage. Experiment 1 investigated the effect of grouping on the number of extinction errors by presenting bilateral displays of either grouped (two aligned square brackets) or ungrouped (a bracket and a dot) bilateral stimuli, as well as unilateral and blank displays. The task was to indicate verbally whether stimuli had been seen on the left, the right, both sides, or neither. For both participants, left bracket detections were significantly greater in the grouped than in the ungrouped double displays, lending support to the idea that grouping modulates extinction. In order to address the question of whether reduced extinction occurred as a result of the similarity and/or symmetry of the items displayed in Experiment 1, Experiment 2 consisted of stimuli that formed a familiar configuration (an arrow) when grouped, whilst controlling for similarity and symmetry. The stimuli were a horizontal line and a ‘V’ shape, presented singly or in combination. In the grouped trials, the ‘V’ was presented rotated 90° so that, when displayed to the right or left of a horizontal line, the two stimuli formed the familiar shape of an arrow (Figure 1.3.6).

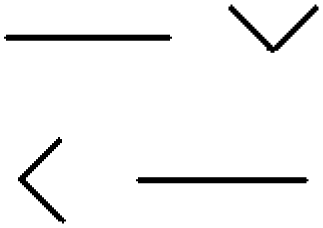

Figure 1.3.5: *Ungrouped and grouped stimuli from Ward, Goodrich and Driver (1994). When ungrouped, the stimuli represent a horizontal line and a ‘V’ shape; when grouped, they form the shape of an arrow.*

For both patients, extinction in the grouped ‘arrow’ displays occurred less often than in the ungrouped displays. Ward et al. explained their results in terms of weight linkage; when a contralesional item and an ipsilesional item are grouped they are assigned a common selection weight, thus eliminating the competition for selection between the two items whereby the contralesional item becomes extinguished.

Gilchrist, Humphreys and Riddoch (1996) further explored the role of low-level grouping processes in modulating visual extinction by minimizing the reliance on stored memory templates. They investigated the modulating effect of edge-brightness-based grouping, achieved by presenting pairs of light and dark circles and squares. Grouping was manipulated in terms of collinear edges and brightness (e.g. when two squares of the same polarity were presented, grouping was deemed to be present in both collinear edges and brightness; in contrast when two circles of opposite polarity were presented, there was neither collinearity nor the same brightness to support grouping). Each of the features was found to have a strong modulating effect on extinction and the effect was greater when both features were present together. Gilchrist et al. argue that grouping on the basis of low-level processes based on the elementary relationships of collinearity and brightness can modulate extinction without recourse to stored representations of known objects. A further experiment (Experiment 3) found that these low-level grouping processes have similar effects when both items are presented in the same hemifield, rather than across the midline. Experiment 4 assessed the effect on grouping of the proximity of items. This was achieved by presenting items that were grouped on both collinearity and brightness (light coloured squares), but manipulating the distance between the two items on the screen. Extinction was reduced on trials in which the items were closely spaced together but performance decreased as the separation increased. These data support the notion of a bottom-up process in modulating extinction.

Mattingley, Davis and Driver (1997) noted that a prediction arising from the attentional hypothesis of extinction is that, if extinction arises when two events compete for attention, then preattentive visual processes should occur normally on the contralesional side, with a bias towards the ipsilesional side arising only at a later stage. They tested this prediction using a paradigm of illusory figures that induce visual filling-in in normal healthy participants. The first of these was a Kanizsa figure in which edges and brightness are illusorily perceived, and in a subsequent experiment a 3-D representation of a cube that occluded a bar in some trials (see Figure 1.3.7). In all conditions their participant responded with greater accuracy when bilateral events were grouped together. These data extended the previous findings (which had all been based on grouping by 2D alignment) to show that extinction can operate at the level of interpretation of depth in perceptually filled-in surfaces.

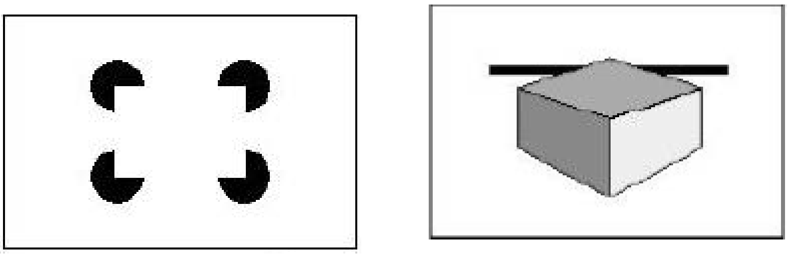

Figure 1.3.6: *Kanizsa figure and 3-D image of a bar occluded by a cube.*
Figures taken and adapted from Mattingley, Davis and Driver (1997).

Extending the research on the effects of perceptual grouping on object selection, Riddoch, Humphreys, Edwards, Baker and Willson (2003) found that action relations between objects can also influence selection. Stimuli consisted of drawings of pairs of everyday objects (for example a wine bottle and corkscrew) placed in the correct positions for use, and in incongruent positions. Either a single item was presented to the left or right of fixation, or a pair of pictures was presented with one to either side of fixation. The experiment clearly showed that extinction between separate objects can be reduced if the objects are grouped in terms of being placed in the correct relative positions for action. Similar findings emerged from a second experiment which controlled for objects that are associatively related, for example a witch and a cauldron; on trials in which the pictures were related merely as associative pairs rather than pairs positioned for action, extinction was found to be greater. A third experiment found no equivalent mediation of extinction when action-related words were presented, suggesting that the effect was not at an associative semantic level. The study shows that grouping between visual stimuli is crucial in selective attention, not only when they are grouped on the basis of Gestalt factors, but also when they are grouped by familiarity of actions. Interestingly, the intrinsic knowledge of actions between objects seems to be of greater influence than simply the association between the two objects.

A later study by Riddoch, Humphreys, Hickman, Clift, Daly and Colin (2006) investigated the effect of action familiarity on recovery from extinction in greater depth, with particular emphasis on (*a*) whether the effect changed when the objects displayed were frequently used together in actions, rather than objects that simply *could* be used together, (*b*) the location of the objects and (*c*) whether the effect was different if the objects were coloured images rather than line drawings. In support of Riddoch et al.'s 2003 study, patients were more likely to select both items on bilateral trials where there was an action relation between the objects than when there was not. Moreover, the effect is influenced by the frequency of joint usage, for example a bottle positioned for pouring into a wine glass was more likely to be perceived than a bottle positioned for pouring into a bucket. When the objects were plausibly positioned for action (a bottle positioned for pouring into a wine glass) they were more likely to be selected than when they were paired but not positioned for action (a bottle standing next to a wine glass). Hence, the advantage for selection was due not only to the fact that the objects formed a familiar pair, but also to the fact that they appeared as they would in action. The authors propose a two-stage model of attention in which attention is initially focused on either a single object or on a pair of objects. This first stage is influenced by whether the objects can be used together and are positioned for action. This is followed by a second stage in which the objects are selected serially for report, driven by the familiarity of the action and the frequency of each object.

Ptak, Valenza and Schnider (2002) sought to investigate whether it is only perceptual factors that can modulate extinction, or whether strategic factors and expectation biases also play a role in facilitating access to perceptual information. The first of their three experiments was designed as a baseline measure to determine the rate of extinction in their patient. Stimuli were green or red squares or diamonds and a characteristic pattern of extinction was found in bilateral trials, regardless of whether the stimuli were grouped by colour or shape. Experiment 2 investigated whether a grouping effect would emerge when the processing of features was enhanced by top-down cues; the participant was asked to report features of contralesional stimuli rather than simply on the presence or absence of the stimuli. The participant was explicitly informed that there would be stimuli on *both* sides in every trial and was asked to try to identify the colour and/or shape of one of the features in each trial, even if he was unaware of having consciously seen it. Unlike the findings of Experiment 1, performance was significantly enhanced when the two stimuli were grouped on the basis of similarity of colour or shape when either one or both features had to be reported. Experiment 3 assessed the effect of expectation bias; this was achieved by alerting the participant to which feature (colour or form) he would be asked to report on each trial, prior to presentation of stimuli. These cues were either coherent (e.g. the word ‘colour’ was presented and he was asked to report the colour), or incoherent (e.g. the word ‘colour’ was presented and he was asked to report the shape). The participant was informed that the coherent cues would appear more often than the incoherent cues and he could enhance his performance by attending to the feature indicated by the cue. As well as determining whether there was a ‘validity effect’ (dependent upon whether cues were coherent or incoherent), this experiment also allowed a comparison between the top-down effect of cueing validity and the bottom-up effect of grouping by similarity. A significant effect of validity was found for both features (colour and shape) whilst there was no effect of grouping, suggesting that grouping by similarity alone is not sufficient to modulate extinction whereas top-down cueing enhances processing of relevant features.

In a priming paradigm similar to that of Ptak at al. (2002), Soto and Humphreys (2006) emphasized the function of working memory in expectation bias, and suggested that extinction may be modulated through priming, based on the assumption that a primed display will remain in stored knowledge and will influence selection. In contrast to Ward et al.’s (1994) paradigm, which demonstrated that grouped double displays which formed a familiar configuration (an arrow) modulated extinction, Soto and Humphreys (2006) invoked stored knowledge by a cueing process, and proposed that it is the match between the contents of the primed working memory and the stimuli presented in the visual field that enhances awareness. Their five patients were presented with a variety of shapes (square, circle, triangle or diamond), each in one of three colours (red, blue or yellow) and were asked to report the colour and shape of the target objects. A cue was displayed for 1 second at the start of each trial, and participants were asked to retain the cue in memory. Either one or two target objects were then displayed in the left or right visual field, with one object matching the memory cue on just over half of the trials. In the bilateral trials, when the memory cue did not match the target there was clear extinction but there was a reduction in extinction when the cued shape matched one of the target shapes, most notably when it matched the target on the contralesional side. In order to address the question of whether this effect was simply due to visual similarity of the properties of the cue and the target, the experiment was re-run with two participants, using verbal memory cues (e.g. ‘green square’) rather than visual cues. Weaker effects of modulation of extinction were found and these were not specific to contralesional items, so it was concluded that the semantic properties of the item held in memory need to be complemented by a visual memory representation in order for the effect to be strong enough to modulate extinction. Interestingly, a second experiment showed that presentation of the visual cued memory items without instruction to retain them in memory did not modulate extinction, suggesting that bottom-up cueing is not sufficient to overcome competition for selection. To confirm that the primes were being retained in memory and not simply processed to the level of identification, a third experiment required participants to verbalise the features of the memory cue before the target was displayed. Contralesional items were extinguished under this condition, showing that priming effects did not take place when primes were processed to the level of identification but not committed to memory. A final experiment was carried out presenting the cued items for 3 seconds (the time taken to verbalise the prime in the previous experiment) rather than 1 second. This produced a strong extinction effect, as in Experiment 1. These data show that extinction is modulated when a contralesional stimulus is matched by the contents of working memory, but there is no effect when the cue is not committed to memory, even when its properties are verbalized.

A recent study by Geng and Behrmann (2006) demonstrated the dynamic nature of both bottom-up and top-down attentional processes in determining perceptual outcomes. In a controlled, repeated measures study, attention was directed to the expected stimuli in a top-down manner by manipulating the probability of the target's location, reducing the effects of bias towards the ipsilesional side. This was achieved by presenting the target in Position 2 of 6 possible positions on 50% of trials, so that there was a probability bias in terms of the target location. Conversely, a second experiment included a distractor on the opposite side of space, thus introducing a bottom-up factor that should increase neglect of contralesional stimuli. A crucial question was whether the reduction in contralesional extinction induced by location probability would reduce interference from the ipsilesional distractor. The results suggested that this was indeed the case; the cost in terms of neglect of contralesional stimuli when a distractor was present was less when facilitation was afforded by location probability. The authors describe this dynamic process as a 'push-pull' relationship between bottom-up and top-down attentional factors.

Testing extinction patients has its drawbacks. For example, Mattingley et al. (1997) report that the performance of one of their participants improved significantly in the interval between testing sessions due to rapid recovery from extinction. There are additional difficulties in drawing inferences about the premorbid function of lesion patients. Moreover, since lesions can produce deficits to adjoining cortical areas, there can be difficulties in sourcing patients who exhibit extinction in isolation without additional neurological complications.

The study of extinction patients has nonetheless contributed enormously to our understanding of early visual attention. The debate as to whether extinction is a sensory or an attentional deficit remains, however there is clear evidence to advocate the legitimacy of an attentional explanation. Extinction is modulated by a number of bottom-up and top-down factors; indeed it has been shown that there is a dynamic interaction between these two types of attentional processes in their combined effect on extinction.

The notion of attentional competition between stimuli is not confined to brain damaged patients, but has parallels with studies showing that neurologically healthy individuals can have difficulties in attending to simultaneous stimuli. Puleo and Pastore (1978) reported that, in a test of auditory attention, healthy volunteers were able to report single targets presented to each ear, but not two targets presented simultaneously. Using a visual discrimination task, Duncan (1980) reported that participants were able to indicate whether a target was present in a display as long as there was only a single target present. When two targets appeared simultaneously, performance declined significantly. These studies suggest that healthy individuals have an attentional limitation that is manifested when two or more targets require simultaneous processing, akin to visual extinction after unilateral damage. The difference, of course, is that brain damaged patients show a spatial bias not present in healthy individuals, with impairment for targets in contralesional space.

1.4 Neural correlates of spatial attention

1.4.1 Disentangling neglect and extinction

Neglect and extinction are closely linked and commonly co-occur in patients with right brain damage. Phenomenally, they are similar to one another in that both reflect an attentional pull towards the right side of space and away from the left, resulting in leftmost stimuli being ignored or unprocessed[1]. However, the two deficits are operationally distinguishable: neglect reflects a failure to spontaneously explore the contralesional side of space, whilst extinction requires the presence of a competing ipsilesional stimulus presented simultaneously. One could make the distinction that neglect reflects a deficit in *exploration* of contralesional space, whereas extinction affects *detection* of distinct stimuli or changes in the environment. Neglect patients are drawn to the ipsilesional side of space and this tends to be reflected in their general posture (more readily turning the head towards the right) as well as their attentional inclination. When assessed with typical tasks such as cancellation or copying, the patient is free to move his or her head and eyes. Tasks assessing extinction, on the other hand, always require central fixation.

Whilst some early authors saw extinction as one of the clinical manifestations of neglect (Heilman & Valenstein, 1972), or even as a mild form of neglect (Denny-Brown & Banker, 1954; Heilman & Watson, 1977), numerous instances of extinction without neglect and of neglect without extinction have been reported (e.g. Hier, Mondlock & Caplan, 1983; Ogden, 1985; Vallar et al., 1994; Stone, Halligan, Marshall & Greenwood, 1998; Cocchini, Cubelli, Della Sala & Beschin, 1999; Vossel, Eschenbeck, Weiss, Weidner, Saliger, Karbe, & Fink, 2011). Such a double

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[1] Neglect is most commonly reported after right hemisphere damage. However, patients with right-sided visual neglect after left hemisphere damage have been reported (e.g. (Beis et al., 2004; Vallar & Peroni, 1986; Vallar, Rusconi, Gemiani, Berti, & Cappa, 1991)

dissociation is often taken to indicate separate underlying anatomical processes (Shallice, 1988), but a number of authors have exercised caution in accepting this assumption in the case of neglect and extinction, for example Driver, Mattingley, Rorden & Davis (1997) suggested that apparent lack of extinction in a patient may be due simply to insufficiently demanding tasks that lack sensitivity. However, Cocchini et al. (1999) pointed out that the standard tasks used to assess the two deficits are qualitatively different: neglect tests (cancellation, drawing, copying) involve exploratory motor processes, whereas those used to assess extinction generally rely on perceptual-sensory tasks. The authors suggested that the neglect-extinction dissociation may be explained by the parallel/serial dichotomy, whereby classic extinction tasks would be classed as parallel and neglect tasks as serial.

1.4.2 Anatomical correlates of neglect and extinction

Traditional accounts of neglect and extinction (e.g. Heilman, Watson & Valenstein, 1985) assumed that they are parietal impairments. More recently, Milner and Goodale (1995) suggested that the two disorders are dissociable, reflecting damage to different areas of the parietal cortex: damage to the superior parietal lobe (SPL) resulting in extinction and to the IPL in neglect. Mattingley (1999) suggested that extinction cannot be attributed to any one cortical or subcortical site, but that it can arise from damage to a number of areas of the brain.

Neglect has been suggested to be associated with lesion of the IPL and perisylvian areas, particularly the angular and supramarginal gyri (Brodman areas 39 and 40), according to Mort et al. (2003). Damage to the right frontal ventral lobe has also been implicated in neglect (e.g. Damasio, Damasio & Chui, 1987), consistent with the notion that anterior sites such as the frontal lobe might form part of an integrated circuit with more posterior regions. However neglect is characterised by a wide heterogeneity of symptoms and it is possible that different anatomical areas and networks play different roles (Verdon et al., 2010). The authors suggested that more severe forms of neglect may be due to lesions of white matter causing intra-hemispheric disconnection. The notion that extinction arises from an attentional competition between two stimuli, with the stimulus processed by the intact hemisphere winning the competition has already been described in Section 1.3.2. The neural basis for the competition between stimuli is addressed by Ungerleider and Mishkin (1982) who describe a network of over 30 cortical visual areas organised within two major cortical pathways for visual processing, both originating in the primary visual cortex, or V1. The first of these, a ventral stream, is directed from the primary visual areas to the inferior temporal cortex and is crucially implicated in object recognition. The second, a dorsal stream, is directed to the posterior parietal cortex and is important for spatial perception and visual performance. It is this dorsal stream that appears to be disrupted in visual extinction arising from damage to the parietal area, though this assumption has been disputed by some authors (e.g. Milner & Goodale, 1995, see below). Ungerleider and Mishkin's 'two visual systems' model made a major impact on visual neuroscience (according to Goodale and Milner, 2004, it has been cited more times than any other paper in the field of visual neuroscience), but has been criticised by some (e.g. Turnbull, 1999) for its simple dichotomous concept, which has been thought to underestimate the complexities of the human brain. Milner and Goodale (1995) offered a new interpretation of this 'two visual systems' model after noting that their patient DF, a visual agnostic patient, was unable to process information on a visuo-perceptual task, whilst being remarkably accurate in using the same visual information on a visuo-motor task. Milner and Goodale suggested that a more accurate description of the dorsal pathway would be the control of motor behaviour. They argued that disorders of spatial attention do not arise from a disruption of the dorsal visual stream for a number of reasons. Firstly, animal studies have shown that is extremely difficult to mimic neglect in monkeys by disrupting the posterior parietal area. Secondly, the human dorsal stream terminates not in the inferior parietal lobe (with which many cases of neglect are associated), but in the superior part. Thirdly, given the findings of Bisiach and Luzzatti (1978, see Section 1.3.1 above) that neglect affects mental imagery as well as overt visual representation, it is difficult to see how the dorsal stream could be responsible for mental imagery and thus lead to neglect when disrupted. Milner and Goodale (1995) tentatively suggested a possible third stream of processing, which leads visuo-spatial information from the primary visual cortex to the inferior parietal lobes. This tentative ‘three visual stream’ model is illustrated in Figure 1.4.1.

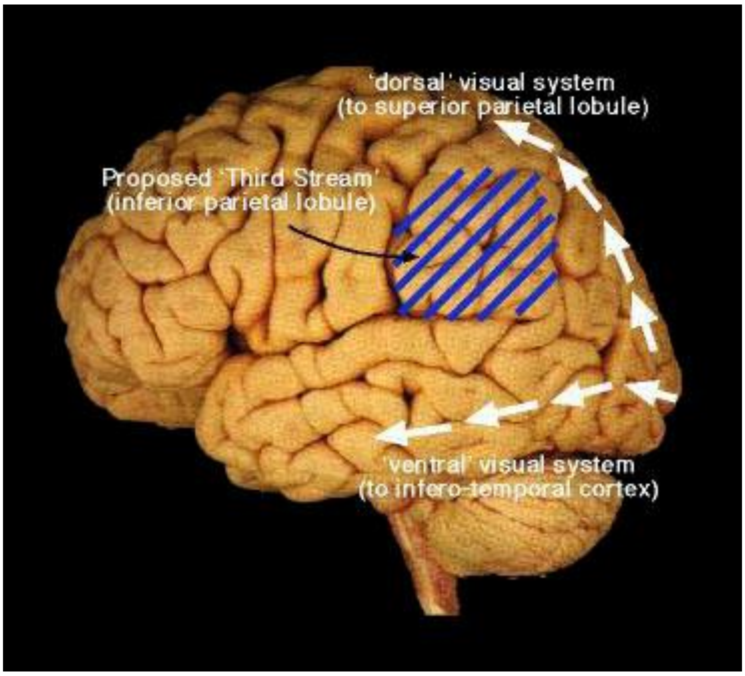
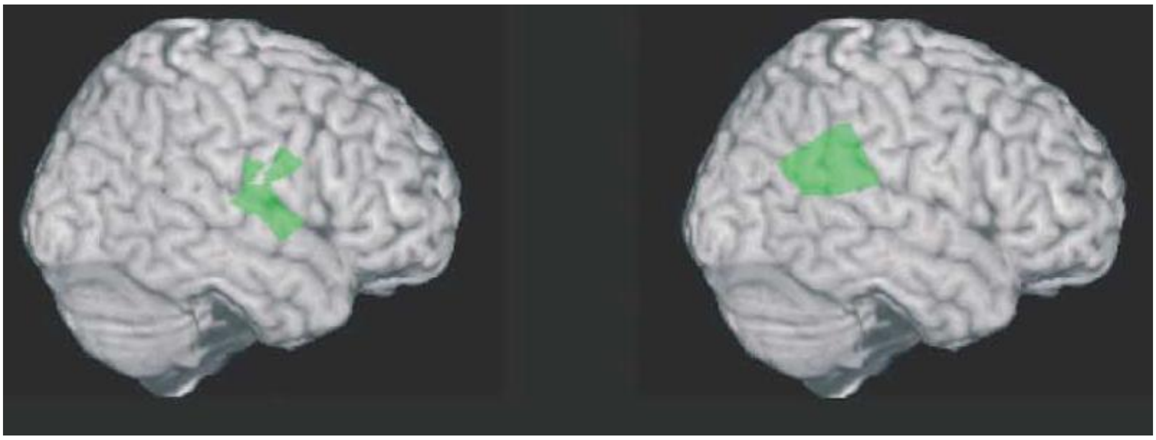


Figure 1.4.1: *Diagram illustrating Ungerleider and Mishkin's (1982) model of two streams of processing (indicated by white arrows) and a third stream tentatively proposed by Milner and Goodale (1995), in which a third stream transmits information to the inferior parietal lobule.*
Taken from Turnbull (1999).

In a neuroimaging study, Karnath, Himmelbach and Küker (2003) aimed to clarify whether or not neglect and extinction arise from discrete underlying mechanisms. 27 acute stroke patients with unilateral right hemisphere cortical lesions were clinically tested for visual, auditory and tactile extinction. After being categorised either as showing extinction plus neglect, pure extinction (no neglect) or pure neglect (no extinction), as well as a control group with right hemisphere damage but neither extinction nor neglect, their lesions were mapped and superimposed to find regions of neural involvement.



A) Neglect B) Extinction

Figure 1.4.2: Surface views of the centres of lesion overlap for patients with A) pure neglect and B) Pure extinction. Figure taken and adapted from Karnath, Himmelbach and Küker (2003)

Patients with pure neglect showed a centre of lesion overlap in the superior temporal gyrus, extending into the ventral area of the inferior parietal lobule. Patients with pure extinction, on the other hand, were found to have lesions that overlapped more caudally and dorsally at the temporo-parietal junction (TPJ). The authors claim that the TPJ appears to be the neural correlate of visual extinction, and thus the crucial area responsible for the detection of distinct stimuli or changes in the environment. This finding does fit with earlier reports that patients with lesions to the TPJ area showed extinction (Friedrich, Egly, Rafal, & Beck, 1998) and also with the notion that the TPJ is part of the stimulus-driven (bottom-up) attentional system (Corbetta & Shulman, 2002). However, final participant numbers were small (7 with pure neglect and 4 with pure extinction) and the point made by Cocchini et al. (1999) may well apply also to this study: the tests used to categorise patients with extinction relied on perceptual-sensory tasks, whilst those used to categorise neglect patients relied on exploratory motor processes. This being the case, it may be that the anatomical differences shown by Karnath et al. (2003) reflect not areas implicated in neglect and extinction, but areas responsible for different methods of perceptual processing.

More recent studies on right brain damaged patients confirm that neglect and extinction share different neural substrates but reach slightly different conclusions. Indeed, while extinction seems more related to lesions of the right inferior parietal lobe, neglect would be more related to damages in fronto-parietal areas (Vossel et al. 2011). Recent fMRI studies confirm that different pattern of activation may be observed during visuo-spatial tasks in acute stroke patients. The authors found that while patients showing visual spatial neglect**,** but not visual extinction, tend to show a reduced activation of the right parietal cortex, right occipital cortex and left frontal areas, patients showing extinction, but not neglect, show an increased activation of the left prefrontal areas (Umarova et al., 2011).

In summary, the question of whether neglect and extinction are two discrete, dissociable disorders or not remains unresolved, but evidence from neuroimaging studies suggests that this may be the case with neglect arising from damage to different areas than extinction.

1.5 Attentional asymmetry in healthy individuals

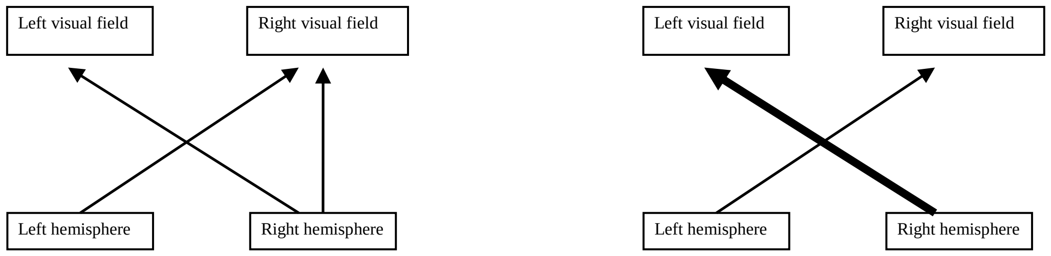
1.5.1 Theories of attentional asymmetry

Given the diverse specialisations of each of the two cerebral hemispheres and the right hemisphere's involvement with visuospatial attention, it would not be surprising to learn if attention were functionally more efficient in the right hemisphere than the left in the healthy brain. An early empirical observation (Dallenbach, 1920) noted that the same patch of light appeared more vivid when presented to the left than to the right of fixation. However, subsequent studies found an underlying rightward superiority for visual (e.g. Barton, Goodglass & Shai, 1965) and auditory (Kimura, 1961, 1966) stimuli based on speed of response. This right-sided asymmetry for speed of response applies not only to written and verbal material, but also to simple reaction time to light (Kerr, Mingay, & Elithorn, 1963) and sound (Simon, 1969). Davidoff (1975) explored the relationship between handedness and the perception of lightness in shades of colour and reported that right-handers judged stimuli in the left visual field as lighter than that in the right visual field (with both grey and red stimuli). In the light of earlier studies (e.g. Kappauf & Yeatman, 1970; Jeeves & Dixon, 1970; Jeeves, 1972) that reported faster responses by right-handed individuals to stimuli in the left visual field, these data supported the notion that (in right-handers at least) the right hemisphere is more important for perceptual functions. In a later study, Davidoff (1976) reported right hemisphere advantages in colour perception, both in hue (the degree to which a shade differs from a stimulus that can be described as red, green, blue or yellow) and saturation (ratio of coloured to white light), with a greater discriminability for left visual field (right hemisphere) presentations. Davidoff (1977) reported two experiments using healthy volunteers which showed a significant advantage for detection of dots in the left visual field. This was found to be more pronounced when stimulus contrast was reduced and was more robust in male participants than female. It was suggested that the right hemisphere is more efficient than the left in dealing with simple perceptual stimuli. A number of studies (e.g. Cohen, 1975) have found that in healthy right-handed adults verbal stimuli elicit faster response times when presented to the right than the left sensory channel (ear, visual hemifield, hand). Traditionally, these findings have been ascribed to an anatomical pathway-transmission model, which states that stimuli are more readily processed when they have direct access to the hemisphere that is more specialised in processing them. Thus, verbal and language-based stimuli are more readily processed by the left hemisphere and non-verbal stimuli by the right hemisphere.

However, researchers challenged this assumption on a number of levels. Firstly, studies have suggested that attentional factors play a part in the extent to which these asymmetries are seen (Kinsbourne, 1974; Klein, Moscovitch & Vigno, 1976). Secondly, it was suggested by Goldstein and Lackner (1974) that spatial variations have an effect on the asymmetry of verbal stimuli in a dichotic listening task. Thirdly, as Heilman at al. (1987) point out, there is a paradigmatic confound in traditional laterality tasks, namely that in (for example) visual half-field studies, stimuli are presented to one hemifield; however hemispace is not the same as the visual half-field, but refers to the corporeal and extracorporeal half-space to the left and right of body midline. Because of this confound between sensory channel and hemispace, laterality effects could be attributed either to the anatomical relationship between each hemisphere and the contralateral input/sensory output apparatus, or to the ability of each hemisphere to attend to stimuli in the contralateral spatial field. This third observation was supported in a study by Bowers and Heilman (1980) in which healthy participants were blindfolded and presented with a wooden stick, in which they were asked to point out the midline. Bisection performance was significantly more accurate when performed in the left hemispace than at midline or in right hemispace and there was a significant interaction between hand and hemispace with best performance made by left hand in left hemispace and worst performance made by right hand in right hemispace. These findings suggested that the laterality effects found stemmed from a combination of some attentional mechanism involved in the contralateral spatial field and the anatomical connections between the specialised hemisphere and the contralateral hand.

To account for the attentional bias seen in right hemisphere-damaged patients with neglect and extinction, Kinsbourne (1970) postulated that both hemispheres direct attention towards contralateral space, and that when one hemisphere is injured, attentional processes in the other become excessively active, resulting in an ipsilateral bias. Heilman and Watson (1977) concurred with Kinsbourne to the extent that each hemisphere directs attention towards contralateral space and that there is an ipsilesional bias following damage to one hemisphere. However they suggested that this bias is due to *underaction* in the damaged hemisphere, rather than attentional *overaction* in the undamaged hemisphere. There followed a hypoactive vs. hyperactive hemisphere attentional bias debate. However, the two views are not mutually contradictory and it seems reasonable to conclude that both contribute to our understanding of disorders of spatial attention.

According to Heilman and Van Den Abell (1980), healthy individuals are more likely to be unaware of targets in right than left hemispace (in line cancellation tasks), suggesting that a normal participant’s attention is slightly biased towards the left part of space; stimuli that fall in the left visual field (and hence are directed to the right hemisphere) are attended to more than those that fall in the right visual field. Heilman and Van Den Abell suggested that the right hemisphere directs attention to *both* visual fields whilst the left hemisphere directs attention only to the right visual field. Thus, when the attentional mechanisms of the right hemisphere are damaged (as in spatial neglect), the result is an inability to attend to stimuli in the left visual field. Mesulam (1981) concurred with this view that the right hemisphere has attentional functions that span both hemispaces, whereas the left hemisphere seems to be mainly responsible for attention in right hemispace. He suggested that the right hemisphere of dextrals has a functional specialisation for distribution of directed attention in extrapersonal space. On the other hand Kinsbourne (1974) suggested that two attentional vectors in the two hemispheres inhibit one another, but one (in the right hemisphere) is stronger than the other. These opposing models are illustrated in Figure 1.5.1. In conclusion, both Heilman and Van Den Abell (1980) and Kinsbourne (1974) predict a leftward attentional bias in healthy individuals, but speculate contrary underlying mechanisms.



A. Heilman and Van Den Abell’s (1980) model B. Kinsbourne’s (1974) model

Figure 1.5.1: *Schematic representation of Heilman and Van Den Abell’s and Kinsbourne’s opposing models of the mechanisms underlying attention in healthy individuals.*

1.5.2. PSEUDONEGLECT

Pseudoneglect refers to a phenomenon found in healthy individuals, in which both dextrals and sinistrals consistently and significantly err towards the left when asked to mark the midpoint of a visually presented horizontal line (e.g., Bowers & Heilman, 1980; Heilman et al., 1987; McCourt, Garlinghouse, & Reuter-Lorenz, 2005; Nicholls & Loftus, 2007)

Despite the phenomenon of pseudoneglect was initially dismissed by some authors (e.g. Mozer, Halligan & Marshall, 1997) as an artefact due to sampling error in small sample sizes. More recent research has refuted this criticism, thus acknowledging considerable variability and inconsistency in the degree to which participants err. Jewell and McCourt (2000) conducted a comprehensive meta-analysis of the pseudoneglect literature comprising 73 studies and over 2000 participants. They reported that a number of factors seem to modulate pseudoneglect including age (older participants made more rightward errors that younger participants) (Fujii, Fukatsu, Yamadori, & Kimura, 1995; Stam & Bakker, 1990); handedness (right handed participants err slightly more to the left than left handed participants) (Luh, 1995; Scarisbrick, Tweedy, & Kuslansky, 1987); hand used to perform the task (the left hand produced more errors to the left than did the right hand) (e.g. Bradshaw et al., 1986; Brodie & Pettigrew, 1996; Suavansri, Falchook, Williamson & Heilman, 2012) and, most significantly, the direction in which participants initiate motor scanning, with left-to-right scanning of the line producing more leftward errors and the reverse direction more rightward errors: e.g. Chokron et al., 1998). Despite this wide variability in findings, Jewell and McCourt (2000) concluded from their meta-analysis that an overall leftward bisection error of moderate effect size does indeed exist. More recent studies have now provided strong support about this attentional bias in healthy volunteers. Indeed, some authors have reported evidence of pseudoneglect also with tactile stimuli (Brooks, Della Sala & Logie, 2012), representational stimuli (Cocchini, Watling, Jansari & Della Sala, 2007; Loftus, Nicholls, Mattingley, & Bradshaw, 2008; Nicholls & Loftus, 2007; Longo, Lourenco, Francisco, 2012; Darling, Logie & Della Sala, 2012) and it can be observed in everyday life tasks, such as walking through doors (Hatin, Tottenham, Sykes Oriet, 2012) or playing golf (Roberts & Turnbull, 2010).

Pseudoneglect is, of course, the antithesis of spatial neglect in which patients err towards the right. A number of researchers (e.g. Heilman & Valenstein, 1979) have suggested that neglect patients make these errors because attention is directed towards the right, the effect being that the right side of the line is judged to be larger than it really is. According to Kinsbourne's model, it could similarly be argued that in healthy individuals the right hemisphere's superior capacity for spatial attention results in the right hemisphere becoming more activated than the left when performing this task (Kinsbourne, 1970; 1974). This would result in attention being more directed towards left hemispace so that the left side of the line is estimated as being larger than it actually is. In line with this hypothesis, recent neuroimaging studies reported activation of the right posterior parietal areas in healthy volunteers performing visuo- spatial tasks (Foxe, McCourt, & Javitt, 2003; Harris & Miniussi, 2003; Gobel, Calabria, Farné, & Rossetti, 2006). Moreover, a recent study by Loftus and Nicholls (2012) using transcranial direct current stimulation (tDCS) reported that increased excitability of the left posterior parietal cortex (by means of anodal tDCS) resulted in reduced pseudoneglect, whereas no changes on pseudoneglect were found following tDCS (anodal, cathodal and sham) of the right posterior parietal cortex. These findings suggest that visuo-spatial attention is biased towards the field opposite to the most activated hemisphere and that the ‘superiority’ of the right hemisphere is due to a hemispheric asymmetry of neural activity.

Recent findings suggest that pseudoneglect may result from a left hemispace-right hemispheric visuospatial attentional upward bias and a relative left hemispheric-right hand upward action-intentional bias

To date, there is no unifying theory that links the underlying mechanisms of pseudoneglect to those of spatial neglect, but from the evidence thus far it would seem reasonable to speculate that the two are intrinsically linked.

1.6 Summary and thesis plan

Visual extinction is the tendency to ignore a contralesional stimulus when it is presented simultaneously with an ipsilesional one, whilst the ability to detect a contralesional stimulus when presented alone is preserved. Extinction commonly occurs in patients following right hemisphere damage. It is closely related to spatial neglect and the two disorders commonly co-occur, though the question of whether or not they are two discrete, dissociable disorders remains unresolved. Evidence from neuroimaging does suggest that there are dissociable cortical substrates for neglect and extinction (Karnath, Himmelbach & Küker, 2003; Umarova et al., 2011).

A number of factors have been found to modulate extinction including the perceptual grouping of stimuli on the basis of Gestalt factors (e.g. Ward, Goodrich & Driver, 1994; Mattingley, Davis & Driver (1997) and perceptual grouping of stimuli drawing on intrinsic knowledge of actions between objects and the top-down effect of cueing validity (e.g. Riddoch et al., 2003; Riddoch et al., 2006). The dynamic nature of both bottom-up and top-down attentional processes in determining perceptual outcomes has recently been described by Geng and Behrmann (2006) as a 'push-pull' relationship in which competition for attentional selection is determined by a combination of top-down and bottom-up factors.

An analogy can be drawn between extinction and an attentional limitation in healthy individuals in which two or more stimuli compete for attention. Whilst this competition between stimuli in healthy individuals has not been shown to be biased towards left or right space, a general attentional inclination towards leftward space is reported in healthy participants. This inclination is manifested in bisection tasks, in which healthy volunteers consistently err towards the left, a phenomenon known as pseudoneglect.

A key element of contemporary theories of attention (e.g. Bundesen, 1990; Desimone & Duncan, 1995; Duncan, 1996) is the notion that stimuli compete for attention. As such, extinction offers a unique insight into the effects of attention on perception and an opportunity to study how the brain represents space, attention and awareness and how these processes may be disrupted by brain injury.

This thesis examines how extinction-like phenomena can be induced in healthy adults via bottom-up processes (Chapter 2; Experiments 1, 2 and 3) and top-down processes (Chapter 3; Experiment 4). Chapter 4 investigates the responses of brain damaged patients to computerised tests of extinction (Experiments 5 and 6). Chapter 5 summarises and further discusses the findings reported herein in relation to competing stimuli in healthy adults and in brain damaged patients, and makes suggestions for future research.

Chapter 2

Visual extinction in healthy volunteers using a bottom-up paradigm

2.1. Experiment 1

Introduction

Clearly, the limitations of the visual and attentional systems create a competition for attention between the objects in the visual field and it seems reasonable to conclude that such a competition arises at an early stage of vision. Very few studies have investigated in healthy participants the competition between simultaneous stimuli in both visual fields so clearly seen in visual extinction patients (e.g., Gorea & Sagi, 2000; 2002). Gorea & Sagi (2002) observed that "at least some forms of extinction (and perhaps neglect) are contingent on *relative* sensory/perceptual impairments". Other studies have explored different competitive effects in visual processing. Farah, Monheit and Wallace (1991) responded to an earlier study by Volpe, Ledoux and Gazzaniga (1979) in which it was reported that patients were able to make same/different judgements about double simultaneous stimuli, despite 'extinguishing' the contralesional item, leading to the suggestion that both stimuli were perceived. Farah et al. argued that less visual information about the contralesional stimulus is required to make a same/different judgement than to identify it. To test this, Farah et al.'s first experiment reports degrading one side of a stimulus display with healthy volunteers and asking them either to decide whether or not the degraded stimulus was the same as a simultaneous intact stimulus, or to identify it in a forced-choice identification task. It was found that the dissociation between identification and same/different matching disappeared. In the light of Farah et al.'s investigations with healthy participants (and, subsequently, with three extinction patients), the evidence for intact perception of ‘extinguished’ items was regarded as inconclusive.

To test the hypothesis that healthy participants can detect either the location or features of briefly presented stimuli, but not both simultaneously, de Haan and Rorden (2004) presented healthy participants with three tasks: detect identity, detect location or detect identity *and* location. Participants performed significantly above chance when reporting either identity or location alone, but when reporting both features performance was at chance level. This suggests that, firstly, an attentional competition arises between simultaneous detection of identity and location and, secondly, information concerning identity and location can be preserved, even when both features are not bound together to generate awareness.

Transcranial magnetic stimulation (TMS) has been used by a number of researchers to explore the effects of attentional competition in healthy volunteers for short periods of time. In an early study, Pascual-Leone, Gomez-Tortosa, Grafman, Always, Nichelli and Hallett (1994) used an extinction paradigm to investigate the effects of rTMS on the occipital and parietal lobes in healthy volunteers. They reported that occipital rTMS produced a large number of misses of the contralateral stimulus regardless of whether single or double stimuli were presented. Parietal rTMS, on the other hand, reproduced the classic extinction phenomenon of misses of the contralateral stimulus only in double stimulation. After Pascual-Leone et al. (1994) had established that it was possible to temporarily induce attentional deficits in healthy adults using TMS, a number of more recent studies have used the technique to empirically test specific neuropsychological models and constructs. Hilgetag, Théoret, and Pascual-Leone (2001), for example, produced a model of neglect in healthy volunteers to test the hemispheric rivalry account of visual attention and found that found brief inhibition of the right or left parietal areas led to a shift of attention towards the ipsilateral space. Koch, Oliveri, Torriero and Caltagirone (2001) explored specific patterns of excitation and inhibition in the right parietal cortex using paired-pulse TMS (transcranial magnetic stimulation). This technique enables stimulation with two distinct stimuli through the same coil at a range of different intervals; hence, different groups of neurons in the parietal cortex could be disrupted during visuospatial attention tasks. Koch et al. reported that, compared with single-pulse TMS, paired-pulse TMS applied to the parietal cortex can either inhibit or enhance covert visuospatial attention, depending on the inter-stimulus intervals between pulses. Dambeck, Sparing, Meister, Weinemann, Weidemann, Topper and Boroojerdi (2006) explored the effects of single-pulse TMS applied over one hemisphere alone, compared with simultaneous TMS over both the right and left posterior parietal cortex. Their findings support the notion that an interhemispheric imbalance may underlie neglect and extinction. Meister, Weinemann, Buelte, Grünewald, Sparing, Dambeck and Boroojerdi (2006) conducted a further study using TMS to investigate the functional role of the superior temporal gyrus and the temporo-parietal junction of the right hemisphere for visuospatial attention. These studies demonstrate the twofold practicable uses of TMS in research with healthy volunteers: firstly in applying stimulation to different cortical areas in order to explore their role in underlying networks and secondly in temporarily mimicking patterns of neurological dysfunction in order to test specific hypotheses.

The temporo-parietal junction (TPJ) has been identified by Corbetta and Shulman (2002) as part of the stimulus-driven (bottom-up) attentional network. Karnath, Himmelbach and Küker (2003) concurred with this view and demonstrated that the TPJ is the neural substrate of visual extinction, suggesting a strong link between bottom-up attentional processes and visual extinction.

With this in mind, the aim of this experiment was to determine whether phenomena similar to those found in extinction patients could be produced in healthy adults using a bottom-up, stimulus-driven paradigm. Stimuli that are salient against a neutral background are processed preferentially over less salient stimuli at nearly all levels of the visual system (Desimone & Duncan, 1985). The argument for a bottom-up basis for visual extinction can be made in the light of Karnath et al.'s (2003) observation that the temporo-parietal junction is the neural substrate of visual extinction and that this area is considered to be a crucial part of the stimulus-driven attentional network (see Section 1.4.2).

A second research question arising from this paradigm concerns any attentional bias that might occur towards left or right hemispace. The phenomenon of pseudoneglect (Bowers & Heilman, 1980; Jewell & McCourt, 2000, and see pp.41-42 herein) dictates that healthy individuals typically misjudge the mid-point of a horizontal stimulus by biasing their estimation towards the left. This has been observed both in line bisection (e.g. (McCourt, 2001) and judgements of luminance, for example the Greyscales Task (Mattingley et al., 2004), in which horizontal stimuli are shaded on a gradient from black to white. In contrast to the leftward attentional bias displayed in pseudoneglect, there is a known rightward bias in the case of reading and eye movements, which is manifested in perceptual reading span. In English readers, more letters to the right of fixation can be processed than those to the left, and this bias is reversed in readers of languages such as Hebrew that are read from right to left (Pollatsek, Bolozky, Well, & Rayner, 1981). It therefore seems reasonable to conclude that attention is not distributed symmetrically in healthy individuals, hence the current study sought to determine whether any asymmetry would be detected. Previous studies have reported different performance with stimuli displayed on either the left or the right side of space (e.g. Dallenbach, 1920; Davidoff, 1975; 1976; 1977). The asymmetry mainly depended on a combination of various features of the stimulus and type of response (e.g. verbal or non-verbal). Gorea and Sagi (2002) investigated hemifield advantage during double stimulation with five healthy volunteers. The authors observed a quite heterogeneous pattern of data, where two participants showed an advantage, in terms of higher sensitivity, for the stimulus presented on the left hemifield, one participant showed the opposite pattern of data and two participants showed a similar sensitivity across the two hemifields. Further studies with larger samples can provide further indication of possible hemifield asymmetry during a competitive attentional task.

Therefore, in Experiment 1, it was predicted that fewer correct responses in identifying pairs of items displayed on a computer screen would be made when one item was bright and the other dim, and that the ‘extinguished’ items would be those of a dim luminance. A secondary research question concerned the possibility of any attentional bias towards one or other visual field.

Method

Participants

Fourteen healthy adults took part in the study, of whom eleven were female and three male. Their ages ranged from 18 to 51 (mean age = 28.6 years, SD = 10.23). All participants were right handed and had normal or corrected vision.

Apparatus

The experiment was constructed using E-Prime software and run on a Windows 98 desktop computer, presented on a 28cm x 21cm monitor. The refresh rate was 100 Hz (i.e. the frame duration was 10 ms), thus the stimulus was displayed synchronous with the retrace events. Stimulus items were therefore set to multiples of 10 msec. Participants viewed the screen from a chin and forehead rest positioned 50cm in front of the screen. The visual angle subtended at the eye by the viewing area at this distance was 32° horizontally and 24° vertically. Testing took place in a room with no natural light; a dimmer switch on an overhead light was set half way between full on and off, and this precise light setting was maintained for all test sessions. Participants responded to stimuli via three buttons on a response box and accuracy was recorded. Exposure duration, recording of response accuracy and randomisation of the trials were controlled by the computer.

Stimuli

The stimuli are illustrated in Figure 2.1.1. A grey fixation cross, 1.15° high and wide, was displayed in the centre of the screen. Stimulus items consisted of vertical lines 1.72° long and 0.23° wide. They were green in colour and were either of a bright or dim luminance, presented against a dark grey background. In the bilateral presentations, the distance between the stimuli was 16cm. (18.18°). There were six possible stimulus displays, of which four were unilateral: a single bright line on the left (Bright/Blank); a single bright line on the right (Blank/Bright); a single dim line on the left (Dim/Blank); a single dim line on the right (Blank/Dim), and two were bilateral and of mixed luminance: a bright line on the left and a dim line on the right (Bright/Dim); a dim line on the left and a bright line on the right (Dim/Bright). Settings of the background and stimuli are presented in Table 2.1.1.

Table 2.1.1: *Settings of Background and Stimuli*

	Luminance (cd/m^2)	Saturation	Luminance	Red	Green	Blue
Background	0.15	0	59	63	63	63
Bright Stimulus	7.69	240	120	0	255	64
Dim Stimulus	0.56	240	38	0	81	40

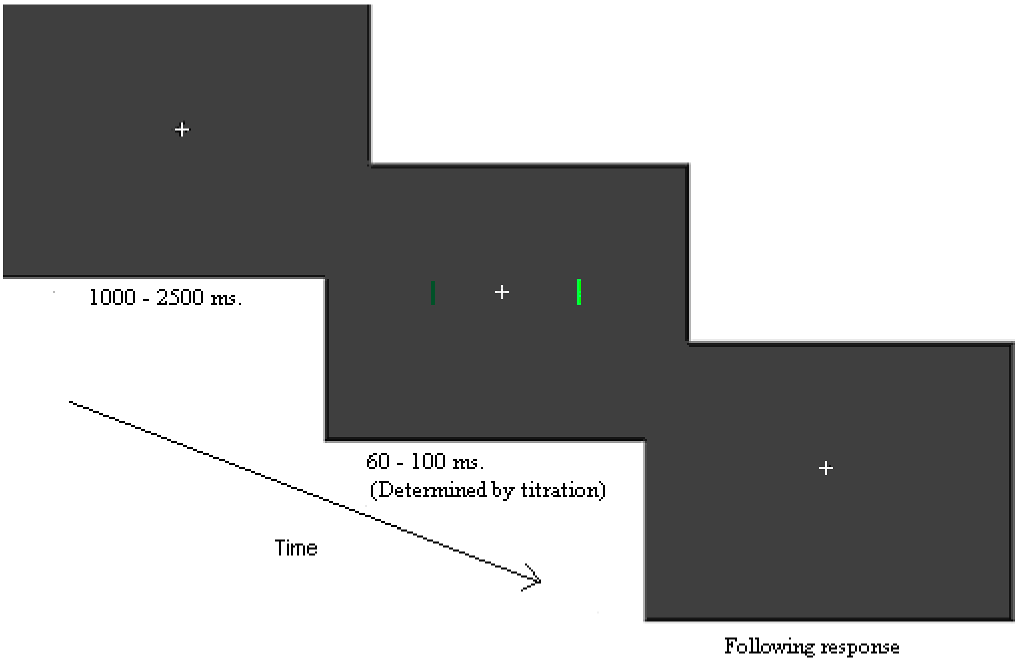


Figure 2.1.1: *A schematic representation of an experimental trial. In each trial, a central fixation cross appeared on the screen, followed after a randomized delay by a stimulus event (in this example, a bilateral trial shown with a dim stimulus on the left and a bright one on the right). Stimuli remained on the screen for the duration determined by individual titration and were followed by the words "Respond now". After a response was made the fixation cross re-appeared.*

Procedure

The procedure consisted of a short titration session, followed by the experimental session (see below). No feedback was given during either session.

Titration

In order to allow for individual differences in the ability to perceive stimuli presented for very short durations a preliminary test, a titration phase, was run prior to the experiment. The purpose of the titration phase was to determine the threshold of the shortest duration for which the stimuli could be presented on the screen and accurately perceived by the participant, whilst not at ceiling. Twelve trials were run displaying unilateral dim stimulus arrays, each with a duration of 80ms, and participants were asked to fixate on the cross in the centre of the screen, and indicate verbally on each trial whether they had noticed an item on the left of the screen, the right, or none at all (in every trial, at least one stimulus was displayed). Responses were noted on a check sheet by the experimenter and the exposure time for the experiment was set according to the criteria presented in Table 2.1.2. The range of stimulus durations was determined by a pilot study, in which stimuli were run at exposure durations ranging from 50ms to 150 ms with five participants (3 female, 2 male; age range 22 – 42, mean age = 29.2 years, SD = 7.85).

Table 2.1.2: *Criteria for stimulus duration*

% of correct responses at 80ms	0% - 60%	65% - 80%	85% - 100%
Action	Repeat titration test with 100ms duration	Run experiment with 80ms duration	Repeat titration test with 60ms duration

If between 65% and 80% of responses were correct, then the experiment was run with stimulus durations of 80msec If, on the other hand, fewer than 65% of responses were correct the titration test was repeated with longer stimulus durations; any participant who still reported 60% or fewer items correctly was excluded from the study. Similarly, if 85% or more responses were correct the titration test was repeated with briefer stimulus durations; any participant who still reported 85% or more items correctly was excluded from the study.

Experimental Session

Prior to the commencement of each experimental task the participants read a series of instructions which were presented on the display screen. Participants were instructed to fixate on the cross in the centre of the screen which would disappear after a second. Following a randomized delay ranging from 1000 to 2500 ms, a stimulus event appeared on the screen for the duration determined by the titration phase (between 60 and 100 ms). Stimulus exposure times remained constant for each participant throughout the experimental procedure. The stimuli were presented on the screen and participants were asked to indicate whether they saw a line only on the left, on both sides of the screen, or only on the right by pressing buttons labeled ‘R’, ‘L’ or ‘B’ respectively with the index finger of their dominant (right) hand. Each stimulus was followed by the words “Respond now” and the participant’s response was indicated by a button press which initiated the reappearance of the fixation point and the next stimulus event on the screen. The participant’s response hand remained positioned over the three-button response box throughout the procedure. A practice session consisting of 12 trials was run, after which Experiment 1 followed. The experiment consisted of 96 trials of randomly presented stimuli of which 32 were bilateral (dim one side and bright the other side), 32 unilateral dim (16 left and 16 right) and 32 unilateral bright (16 left and 16 right).

Results

Despite titration, one participant's data were excluded from the final analysis because her performance was too poor and at more than 3 standard deviations from the group mean on Bright/Blank and Blank/Bright trials. On the data from the remaining 13 participants, analyses were carried out on error responses in order to ascertain (1) whether an extinction effect could be observed and, if so, (2) whether there was any effect of the side (left or right) on which the dim stimuli were extinguished. Means and standard errors of participants' performance on each condition are presented in Figure 2.1.2.

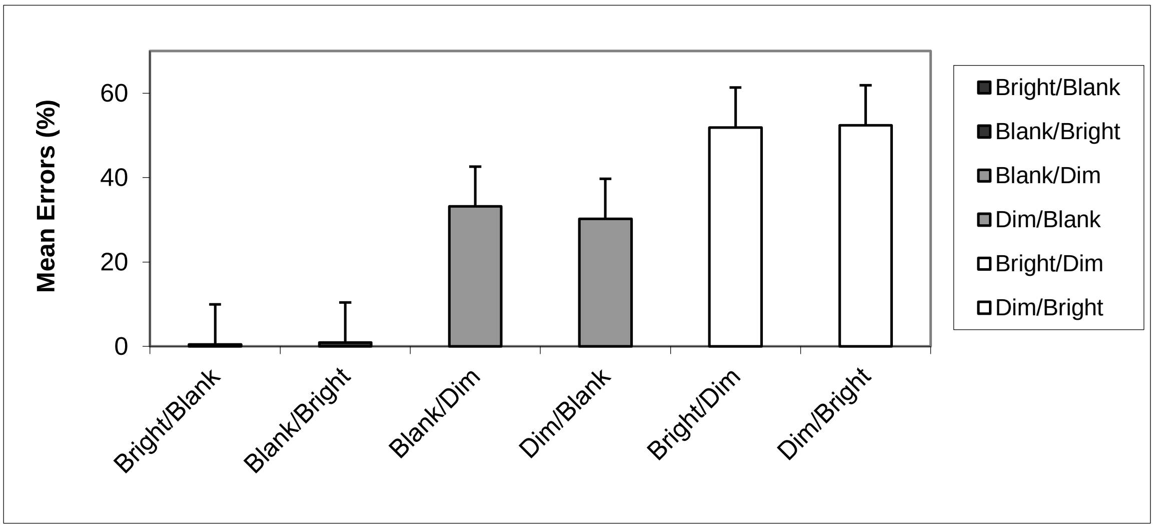


Figure 2.1.2: *Means and standard errors of errors in all conditions*

Reporting of errors in bilateral conditions always represents detection only of the bright stimulus. Only one participant indicated seeing a dim stimulus and missing a bright stimulus on a single bilateral trial; the remaining participants saw the bright stimulus and missed the dim one on bilateral trials in which detection of only one stimulus was reported.

As can be seen in Figure 2.1.2, detection of unilateral bright stimuli was at ceiling, whereas means of errors in detecting unilateral dim stimuli on the left and right were 30.2% and 33.2% respectively, suggesting that the titration phase accurately discerned the optimal threshold at which individuals could detect dim stimuli in isolation, whilst not at ceiling. The presentation of a bright stimulus had a detrimental effect on detection of the dim stimulus. Indeed, whilst errors in unilateral dim stimuli were on average 31.7%, errors increased to a mean of 52.1% in bilateral presentations, in which a bright stimulus appeared with a dim one.

An omnibus ANOVA analysed Display Type (unilateral bright, unilateral dim, bilateral) x Visual Field (bright stimulus in left field and/or dim stimulus in right field) and revealed a main effect of display type (F (2,24) = 27.51, $p < .001$, $\eta p^2 = .696$), no main effect of visual field and no interaction. Pairwise comparisons adjusted with Bonferroni correction revealed significant differences between the unilateral bright and unilateral dim conditions ($p < .05$), between the unilateral bright and bilateral conditions ($p < .001$) and between the unilateral dim and bilateral conditions ($p < .05$).

Whilst there was some value in running the initial 3 x 2 ANOVA in order to report all possible effects, there was a limitation in comparing bilateral conditions with unilateral dim *and* unilateral bright conditions. Thus, two subsequent 2 x 2 ANOVA analyses were run to compare unilateral dim and bilateral conditions, and unilateral bright and bilateral conditions. The first of these analysed display type (unilateral dim, bilateral) x visual field in which the dim stimulus appeared (left, right) and revealed a main effect of display type (F (1, 12) = 9.27, $p = .01$, $\eta p^2 = .436$). The second analysed display type (unilateral dim, bilateral) x visual field in which the bright stimulus appeared (left, right) and revealed a main effect of display type (F (1,12) = 45.85, $p < .001$, $\eta p^2 = .793$).

Discussion

It was expected that when either bright or dim stimuli were presented singly in either the left or right visual field they would be detected in most cases. When one bright stimulus appeared concurrently with a dim stimulus, it was expected that the bright stimulus would be perceived and the dim one ‘extinguished’ because attention would be drawn towards the bright stimulus and away from the dim one. In attempting to draw an analogy between extinction and an extinction-like response in healthy individuals by inducing visual impoverishment, the experimental hypothesis relied heavily on the assumption that extinction is attention-based. In line with recent studies (e.g. Gorea & Sagi, 2002) the results suggest that, in double stimulation, attention is captured by the bright stimulus, which shifts attention away from the dim stimulus. This notion is consistent with Ward, Goodrich and Driver’s (1994) account of extinction, in which the contralesional item is disadvantaged in the competition for selection.

As expected, accuracy in perceiving dim stimuli was significantly reduced when bright stimuli were presented simultaneously with a dim one, strongly suggesting that extinction can be reliably simulated in healthy participants. Unsurprisingly a ceiling effect was found in both unilateral bright conditions (Bright/Blank and Blank/Bright) and, whilst accuracy was considerably reduced in both unilateral dim conditions (Dim/Blank and Blank/Dim) there was a significant difference between accuracy in detection of stimuli in the dim unilateral and bilateral conditions. This suggests that dim stimuli can be perceived when presented alone, but are less likely to be perceived when a simultaneous bright stimulus is competing for attention. Moreover, perception of unilateral dim stimuli was relatively high, suggesting that the titration test was effective in determining individual thresholds at which dim stimuli could be perceived.

Given the known attentional biases in healthy individuals (e.g. Davidoff, 1976; 1977; Bowers & Heilman, 1980; Heilman et al., 1987; McCourt, Garlinghouse & Reuter-Lorenz, 2005; Pollatsek, Bolozky, Well & Rayner, 1981), it was expected that such a bias would show itself in the current paradigm. It was therefore surprising that no effect of visual field was found. It may be that accuracy is too rough a measure for detection of any bias towards one or other hemifield and that response times would give a more accurate account. Since participants were required to move their index finger between three buttons on a response box, response times were not measured in the current experiment. With this in mind, Experiment 2 aimed to further explore any differences in response times. In conclusion, the findings from Experiment 1 are in line with the idea that phenomena similar to those observed in extinction patients can be produced in healthy adults. A dim stimulus, whilst perceived when presented alone, becomes ‘extinguished’ when presented concurrently with a more salient stimulus. There appears not to be any effect of laterality in healthy volunteers, however methodological issues may have prevented the detection of any such effect. Experiment 2 addressed these methodological issues.

2.2. Experiment 2

Introduction

Mattingley and colleagues (Mattingley, Bradshaw, Nettleton & Bradshaw, 1994; Mattingley, Berborovic, Corben, Slavin, Nicholls & Bradshaw, 2004) reported that, in the greyscales task (a task more sensitive to attentional bias than the line bisection task), healthy controls showed a small but significant leftward bias, implying a subtle asymmetry favouring the right hemisphere. This finding is in line with the phenomenon of pseudoneglect (e.g. Suavansri et al., 2012) Davidoff (1975) found hemispheric differences in the perception of lightness, with right handed participants reporting coloured and grey stimuli as lighter when they were presented to the left visual field, suggesting that the role of the right hemisphere (at least in right-handed participants) is important in visual perception. Later research (Davidoff, 1976) found a similar right hemisphere superiority in the discrimination of both hue and saturation. Davidoff (1977) noted that there is also a left visual field/right hemisphere advantage for the detection of dots and suggested that the right hemisphere is responsible for the perception of simple stimuli, regardless of the visual field in which they appear. There is ample evidence to suggest that the activity of each hand is notably lateralized in the opposite hemisphere (Sperry, 1964; Springer & Deutsch, 1981). Handedness and hand used in responding can affect the attentional bias (Bradshaw et al., 1986; Brodie & Pettigrew, 1996; Suavansri et al., 2012). As a result of this, ipsilateral responses (e.g. the right hand responding to a right visual field stimulus) are always faster than contralateral responses (e.g. the right hand responding to a left visual field stimulus) by around 2-10 milliseconds (Berlucchi, Crea, Di Stefano & Tassinari, 1977; Anzola, Bertolini, Buchtel & Rizzolatti, 1977). Verfaellie and Heilman (1990) found a similar pattern with invalidly cued stimuli both in left and right hemispace and reported that cueing attention to the right side of space resulted in faster response times for the right than the left hand. In contrast, no difference between hands was found when attention was directed to the left space. Drawing on the distinction and interaction between perceptual attention and motor intention, the authors suggested that the left hand is primarily prepared for response when attention is directed towards left hemispace, while the right hand is prepared for response to stimuli in either hemispace. An alternative hypothesis is that the left hand (controlled by the right hemisphere, which is known to be more efficient in visuospatial processing than the left hemisphere) should be faster at reaction times involving spatial relationships, e.g. target detection. This notion is supported by Boulinguez and Barthelemy (2000) and Barthelemy and Boulinguez (2001 and 2002). In a simple reaction time experiment, for example, Barthelemy and Boulinguez (2001) reported shorter reaction times when the left hand was used for releasing a switch after the appearance of a target and for performing pointing movements towards the same target, suggesting right hemisphere dominance for movement planning.

There is further clear support for specialisation of the right hemisphere in attending to both left and right sides of space compared with the left hemisphere's role in attending to right space. Such evidence comes from physiological studies (e.g. Corbetta, Miezin, Shulman & Petersen, 1993; Heilman & van Den Abell, 1980; Proverbio, Zani, Gazzaniga & Mangun, 1994) and from the prevalence of unilateral neglect after right hemisphere damage (Gainotti, Messerli & Tissot, 1972; Weintraub & Mesulam, 1989). However in double stimulation paradigms, findings about asymmetry in healthy volunteers are still under debate. Gorea & Sagi (2002) reported a relatively high heterogeneous pattern of data despite the fact that all five participants were exposed to the same bilateral stimuli. In the previous Experiment the lack of asymmetry for one or the other hemifield may be attributed to a methodological issue in that response times were not collected This experiment was designed to address and extend the findings of Experiment 1 in which no bias was found towards either hemispace. It may be that measurement of accuracy alone is insufficient to detect any such bias, and an additional factor could be that the previous experiment lacked statistical power. Experiment 2 aimed to address both of these issues, the former by revising the procedure so that reaction times could be reliably collected, and the latter by increasing the number of trials.

Method

Participants

Fifteen healthy adults took part in the study, of whom thirteen were female and two male. Their ages ranged from 18 to 28 (mean age = 20.2 years, SD = 2.65). All participants were right handed and had normal or corrected vision.

Apparatus

The experiment was constructed using E-Prime software and run on a Windows 98 desktop computer, presented on a 28cm x 21cm visual display screen. Participants viewed the screen from a chin and forehead rest positioned 50cm in front of the screen. The visual angle subtended at the eye by the viewing area at this distance was 32° horizontally and 24° vertically. Testing took place in a room with no natural light; a dimmer switch was set half way between full on and off, and the precise light setting was maintained for all test sessions. Participants responded to stimuli by pressing a single button on a response box and accuracy and response times were recorded. Exposure duration, recording of response accuracy and response times and randomisation of the trials were all controlled by the computer.

Stimuli

Stimuli were identical to those in Experiment 1.

Procedure

The procedure consisted of a short titration task (identical to that employed in Experiment 1, see p.48), followed by the experimental session (see below). No feedback was given during either session.

Experimental Session

Prior to the commencement of the experimental session, participants read a series of instructions which were presented on the display screen. Participants were instructed to fixate on the cross in the centre of the screen which would disappear after a second. Following a randomized delay ranging from 1000 to 2500 ms, a stimulus event appeared on the screen for the duration determined by the titration phase (either 60, 80 or 100 ms). Stimulus exposure times remained constant for each participant throughout the experimental procedure. The stimuli were presented on the screen and participants were asked to press the button on the response box as quickly as possible only if they saw a single stimulus, but do nothing if they saw two stimuli. In this way, ‘extinction’ responses (i.e. those in which two stimuli were presented, but only one perceived) as well as responses to single stimuli were recorded. For each participant there were two blocks of trials in which they responded with the index finger of the left hand and two with the index finger of the right hand. In total, 192 trials were randomly presented in four blocks of 48 trials, each block consisting of 16 bilateral trials, 16 unilateral dim trials and 16 unilateral bright trials. Response hand was counterbalanced across participants using an ABBA design. A practice session consisting of 6 trials was run prior to the experimental data collection.

Results

Both accuracy and response times were considered in this experiment. Means and standard errors of (a) error performance and (b) response times in all conditions are presented in Figures 2.2.1 and 2.2.2 respectively.

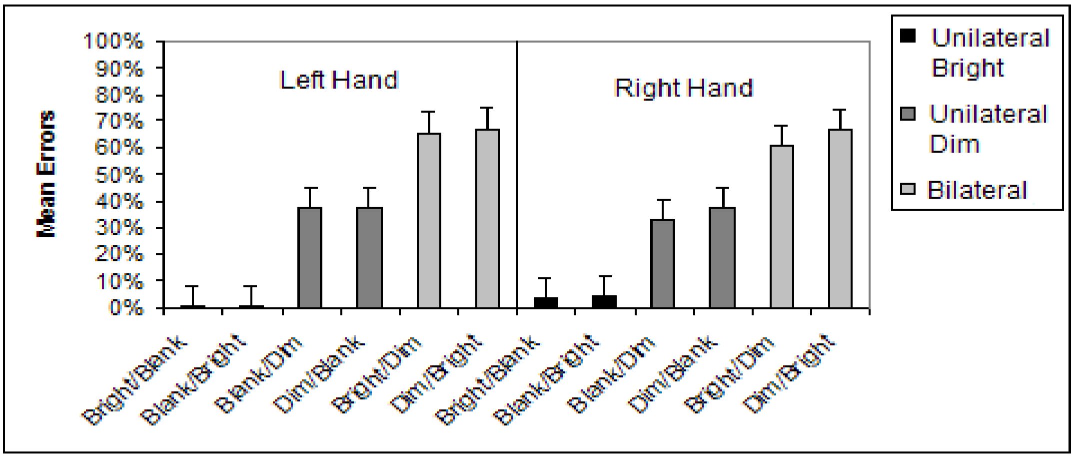


Figure 2.2.1: *Means and standard errors of errors (%) as a function of response hand in all conditions*

Inspection of the response time data revealed some extreme outlying scores, all of which represented delayed responses. Seventeen individual scores (0.6% of the data set) across all participants were more than 3 standard deviations from the means, and all were excluded from the final analysis.

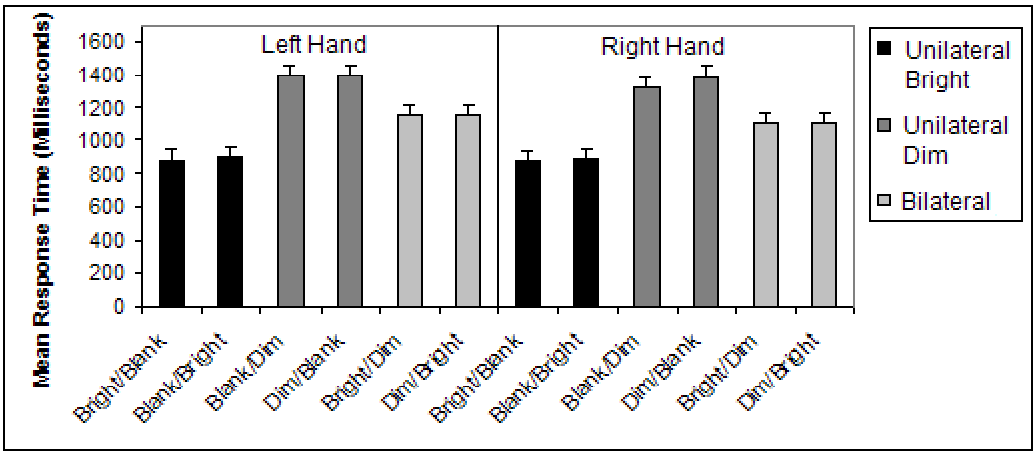


Figure 2.2.2: *Means and standard errors of response times (in milliseconds) as a function of response hand in all conditions*

Doubly multivariate repeated measures analyses with Display Type (unilateral bright, unilateral dim, bilateral), Visual Field (bright stimulus in left field and/or dim stimulus in right field) and Response Hand (left, right) as repeated measures and Errors and Response Times as dependent variables revealed a main effect of display type (Wilks' $\lambda = .132$, $F\ (4,54) = 23.67$, $p < .001$, $\eta p^2 = .637$). All other effects were non-significant.

The relationship between errors and response rates is illustrated in Figure 2.2.3.

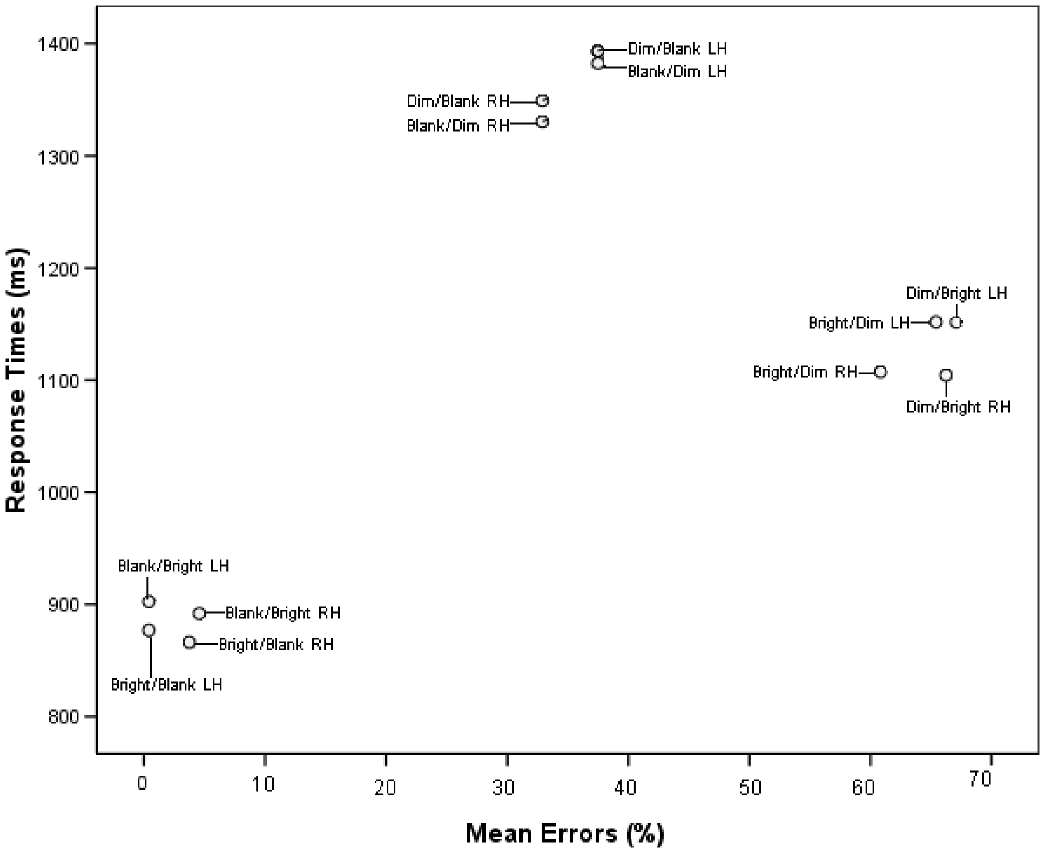


Figure 2.2.3: *Mean errors as a function of response times*

As Figure 2.2.3 shows, this relationship differs between the three display type conditions (unilateral bright, unilateral dim, bilateral). The variables in each of the three conditions are clearly clustered together, with unilateral bright displays having fast response times and no or very few errors, unilateral dim displays having the slowest response times and a moderate number of errors and bilateral displays having moderate response times and the highest number of errors. This pattern suggests a speed-accuracy trade-off between the unilateral dim and bilateral conditions. When a conflict arises between RT and error rates, as here, inverse efficiency measures can provide a method of comparing overall performance between conditions (e.g. Townsend & Ashby, 1983; Davis, Driver, Pavani & Shepherd, 2000; Goffaux, Hault, Michel, Vuong & Roisson, 2005; Falter, Arroyo & Davis, 2006; Shore, Barnes & Spence, 2006; Kiss, Driver & Eimer, 2009). The inverse efficiency score (expressed in ms) is equal to the mean RT divided by the proportion of correct responses, calculated separately for each condition. This measure was calculated for each of the twelve conditions and efficiency data were analysed in an omnibus ANOVA (Display Type (unilateral bright, unilateral dim, bilateral) x Visual Field (bright left and/or dim right) x Response Hand (left, right)) which yielded a main effect of display type (Wilks' $\lambda = .108$, $F\ (2,13) = 53.78$, $p < .001$, $\eta p^2 = .892$), no main effect of visual field (Wilks' $\lambda = .972$, $F\ (1, 14) = .41$, $p = .53$, $\eta p^2 = .028$) and no main effect of response hand, but a trend towards significance (Wilks' $\lambda = .760$, $F\ (1, 14) = 4.43$, $p = .054$, $\eta p^2 = .240$) and no interactions. Bonferroni adjusted post hoc comparisons for Display Type revealed significant differences between unilateral bright and unilateral dim ($p < .001$) and, as a relevant comparison, between unilateral bright and bilateral stimuli (i.e. when only the bright stimulus was attended) ($p < .001$), but not between unilateral dim and bilateral conditions ($p > .05$).

Discussion

As in Experiment 1, participants made more errors in bilateral displays than in unilateral dim displays, supporting the notion that there is a cost of competition in detecting a stimulus when it appears concurrently with a second, more salient stimulus. Comparison of response times between bilateral and unilateral dim conditions failed to reach significance.

The finding that there was a highly significant difference in response times between the two unilateral conditions (response times were faster in unilateral bright displays than unilateral dim displays) supports the literature on reaction times in relation to stimulus intensity. Piéron (1920) and Luce (1986), cited in Kosinsky

(2009), reported that the weaker a stimulus is, (e.g. a very faint light) the longer the response time is, but once a stimulus reaches a certain intensity, reaction time becomes constant. This can be illustrated as in Figure 2.2.4.

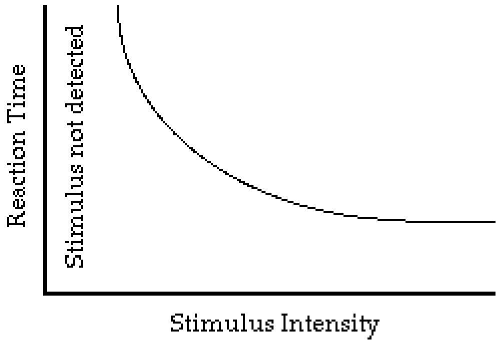


Figure 2.2.4: *Reaction time as a function of stimulus intensity (from Kosinski, 2009).*

Turning to the relationship between errors and response times, there were three distinct clusters of error/response time associations, clearly grouped according to the three display types. Unsurprisingly, unilateral bright displays evoked few errors and fast responses. Moreover, bilateral stimuli elicited more errors because participants falsely identified them as unilateral bright displays as they failed to detect the dim stimuli in bilateral trials. Interestingly, the bilateral stimuli (incorrectly perceived as unilateral bright) elicited significantly slower responses compared to unilateral bright, suggesting that the presence of the dim extinguished stimulus delayed participants' response to the simultaneous bright stimulus. This may imply a form a competition for which both stimuli (bright and dim) pay a 'cost'; the dim was not detected but the bright was detected more slowly. What is questionable, however, is whether the dim stimuli would have been detected if the arrays had been displayed for longer durations. It may be that the dim stimuli had not *yet* entered awareness. An interesting outcome showed that reaction times related to bilateral displays (i.e.

when the participants incorrectly considered that only the bright stimulus was displayed) were higher than in unilateral bright displays even when the inverted efficiency scores were considered, suggesting a ‘cost for competition’ for the detected bright stimulus even when the dim one was extinguished.

There was no evidence of an advantage in terms of accuracy or in response times to either visual field, regardless of the hand used to make the response despite claims in the literature that response times to stimuli appearing in the field ipsilateral to the response hand are generally faster (Berlucchi et al., 1977; Anzola et al., 1977). Given the negligible difference in response times (2–10 milliseconds) reported in these studies, one could argue that the failure to find such an effect in this experiment may be due to a lack of statistical power. Nevertheless, in a similar task, Verfaellie and Heilman (1990) reported larger differences (in the order of 35-50 milliseconds) between responses with the ipsilateral and contralateral hands to invalid stimuli in both hemispaces, with a relatively small sample (24 participants) so this explanation seems unlikely. However, unlike paradigms used in the first two experiments reported herein, Verfaellie and Heilman (1990) used a top-down paradigm, that may have induce a different distribution of attention and that will be considered Chapter 3 of this thesis.

In conclusion, the data supported the extinction interpretation made in Experiment 1 and also revealed a significant effect of display type with faster response times to bright stimuli in unilateral than bilateral conditions, suggesting a cost of competition also for the ‘strong’ stimulus. No significant lateral biases were found however, either in terms of faster responses to one visual field *per se*, or in terms of faster responses to the field ipsilateral to the response hand, although there was one anomalous finding that is hard to explain.

The experiments reported thus far have relied on detection of simple lines that appeared as either bright or dim. The literature suggests that detection or absence of individual stimuli relies on very early visual processing mechanism, in which features are encoded in parallel, but that the more demanding task of identification of features draws on more limited resources where features are encoded serially (Treisman & Gelade, 1980; Broadbent & Broadbent, 1987). With this in mind, it may be that a new experiment designed to test identification of features might be a more useful measure of investigating other aspects of attention competition between visual stimuli in healthy participants.

2.3. Experiment 3

Introduction

Experiments 1 and 2 employed a simple detection task paradigm, in which participants had only to note the presence or absence of a stimulus in one or other visual field. There is evidence to suggest that whether or not extinction occurs in brain-damaged patients is influenced by task demands (Volpe et al., 1979; Bisiach et al., 1989; Smania et al., 1996; Vuilleumier and Rafal, 2000). With this in mind, Experiment 3 was designed to investigate whether extinction-type errors could be seen in healthy volunteers using a bottom-up paradigm in a test that requires identification of stimuli, rather than simple detection as used in Experiments 1 and 2. Identification may recruit more complex cognitive processes, being a more complex and demanding task than simple detection. With this in mind, the participants' task in the current study was to identify characteristic shapes that comprised circles, triangles and squares (a task that would presumably entail the recruitment of enhanced attentional processing, as compared to the simple discrimination task employed in Experiments 1 and 2). Two of these shapes appeared simultaneously on the screen, one with higher contrast values than the other. It was proposed that the shape with higher contrast would be perceived as more salient than the other and therefore spatial attention would be directed towards the more salient shape and, because of the complexity of the identification task, this would reduce the amount of available resources for processing the shape outside of the locus of attention. A strength of the design and one that increased task demands was the degree of difficulty in discriminating between shapes; the shapes used in the current study were overall less prototypical than the geometric patterns usually assigned to circles, triangles and squares as their corners and edges were reshaped to form a more homogenous overall set (see Figure 2.3.1 for examples of stimuli used). It would be expected that participants would be required to expend extra resources because the three shapes were very similar exemplars. In order to perform the task, participants had to make fine-grained discriminations, as in the case of a within-category discrimination task where exemplars have a highly similar overall shape (e.g. the identification of individual faces), as compared to basic-level identification where participants discriminate between shapes that differ in their overall characteristics (e.g. a car as compared to a dog). Evidence for such a finding is usually based on differences in reaction time for within- versus basic-level categorization tasks. For a discussion of this issue, see Mack and Palmeri (2011). In order to increase statistical power, more trials than in Experiment 2 were presented.

Whilst in Experiments 1 and 2, extinction was found in a simple detection task, the current study is employing a more demanding identification task, and therefore it would be expected that extinction would still occur, but perhaps to a greater degree in line with the predictions made by Lavie's perceptual load theory (1995). For this reason, it was predicted that, in line with the results of Experiments 1 and 2, when participants made a simple task detection there will be greater accuracy for a unilateral non-salient stimulus as compared to a non-salient stimulus presented simultaneously with a salient shape when participants perform an identification task.

Saliency models predict that a spatial contrast can enhance visual inputs so that items become more salient in certain background contexts. Accordingly, in a bottom-up paradigm, when shapes are presented with a more intense colour it is expected that participants' attention will be directed based on bottom-up saliency-driven mechanisms (e.g., Itti, Koch & Niebur, 1998).

Method

Participants

Twenty healthy adults took part in the study, of whom thirteen were female and seven male. Their ages ranged from 20 to 32 (mean age = 24.63 years, SD = 2.77). All had normal or corrected vision.

Apparatus

The experiment was constructed using E-Prime software and run on a Windows 98 desktop computer, presented on a 40.5 x 30.3 monitor. Participants viewed the screen from a chin and forehead rest positioned 40.5cm from the monitor. The centre of each shape was 4^o from the mid-point of the screen. A grey fixation cross was used to focus participants' attention on the centre of the screen. Testing took place in a room with no natural light; a dimmer switch on an overhead light was set half way between on and off and this precise light setting was maintained for all test sessions. Participants responded verbally to stimuli and responses were recorded via a keyboard by the experimenter. Exposure duration, randomisation of the trials were controlled by the computer,

Stimuli

Three shapes were used as target stimuli; a circle, square and triangle. The corners and edges of the square and triangle were slightly rounded in order to make discrimination between the three shapes more difficult. The shape of stimuli was controlled so that each was of approximately the same size ($0.8cm^2$). Shapes appeared as light grey with a luminance of 181 (dim) or dark grey with a luminance of 89 (bright) against a white background. The dim or less salient stimuli are illustrated in Figure 2.3.1. Shapes and saliency appeared randomly and with equal probability to the left or right side of fixation. There were 168 trials, as shown in Table 2.3.1. These consisted of 72 unilateral displays and 96 bilateral displays.

The less salient stimuli are illustrated in Figure 2.3.1.

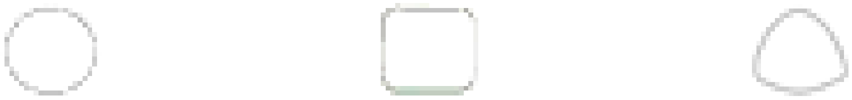


Figure 2.3.1: *Examples of stimulus items*

Table 2.3.1: *Stimulus displays*

	Left	**Right**
	Stimulus Strength (Luminance)	
Unilateral (18 trials)	Bright	
Unilateral (18 trials)	Dim	
Unilateral (18 trials)		Bright
Unilateral (18 trials)		Dim
Bilateral (48 trials)	Bright	Dim
Bilateral (48 trials)	Dim	Bright

Procedure

The procedure consisted of a short titration task (identical to that employed in Experiments 1 and 2), followed by the experimental phase (see below). No feedback was given during the testing session.

Experimental Session

At the start of the experiment, participants received a set of instructions that appeared on the computer monitor, informing the participants about the sequence of events during each trial. A fixation appeared in the centre of the screen. After this, either a single shape would appear on one side of fixation or two shapes for a fixed duration based on individual performance on the titration task. For example, if participants' accuracy was over 90% on the titration task the standard duration was set to 53 msec. for both unilateral and bilateral displays. If response accuracy was under 65% duration was set to 97 msec. For any performance between 65 and 90%, duration was set at 75 msec. as this indicated no floor or ceiling effects. Immediately after each presentation participants were required to make a verbal response indicating the identity and location of the shape or shapes seen. Responses were recorded on a keyboard by the experimenter, with specific keys assigned to each of the shapes and locations. Keys ‘A’, ‘S’ and ‘D’ indicated responses to shapes on the left and ‘J’, ‘K’ and ‘L’ to shapes on the right. In cases where participants did not perceive anything on a particular side of space they were instructed to say the word “nothing”, in which case the experimenter would press the spacebar. If they perceived something but could not identify the shape explicitly, they were instructed to say “I don’t know”, and the experimenter would press ‘E’ (left) or ‘U’ (right). In this way, a response was always recorded for left and right. Half of the participants reported the left stimulus first; the other half followed the opposite order. There was no time limit and participants were advised to take as long as necessary and focus on accuracy. Participants were offered a short break after approximately every 50 trials. No feedback was given during the test sessions.

Results

One participant's overall score (<20%) was significantly below the overall group mean so it was excluded from further analysis. Figure 2.3.2 shows mean accuracy for each condition.

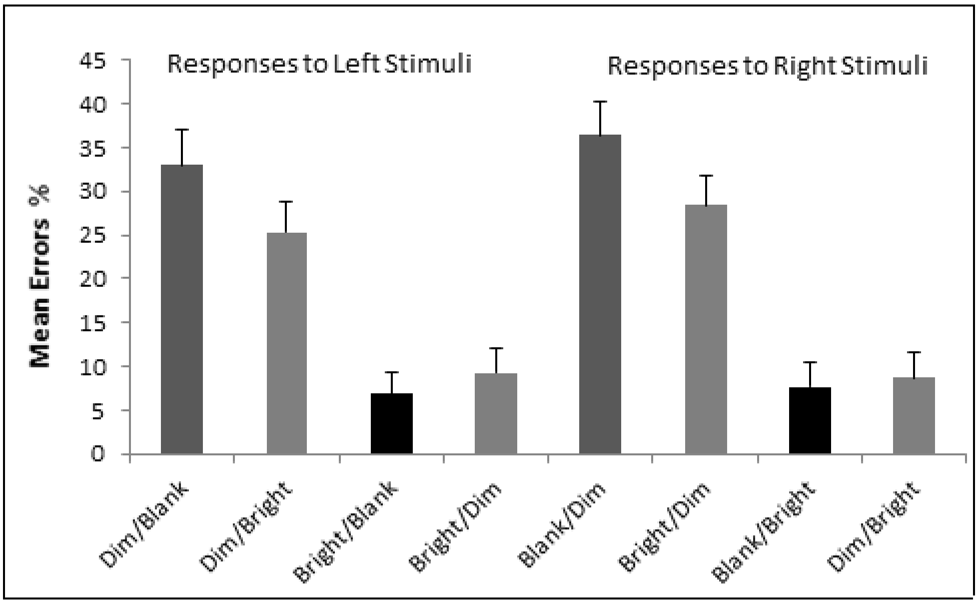


Figure 2.3.2*: Mean (%) errors and standard error. Dark grey, light grey and black bars indicate errors in unilateral dim, bilateral and unilateral bright displays respectively.*

Average percentage of error for bright stimuli was lower than average error for dim stimuli. Participants' performance with dim stimuli was worse in unilateral than bilateral conditions.

A 2 x 2 x 2 repeated measures ANOVA was run with location on screen (left/right) x condition (unilateral/bilateral) x strength (dim/bright). A main effect was found for the strength of the target shape (*F* (1, 17) = 170.04, *p* < .001) with less accuracy for dim stimuli. There was also a main effect of condition (*F* (1, 17) = 6.08, *p* < .05). The location in which a target shape appeared had no significant effect on performance. There was an interaction between condition and strength (*F* (1, 17) = 22.02, *p* < .001).

Corrected pairwise comparisons revealed that performance with dim stimuli in unilateral trials was significantly worse than in bilateral trials (t (18) = 4.12, p = .001).

Discussion

Interestingly, an extinction pattern of errors was not found; indeed significantly more errors were made in identifying dim stimuli when they appeared alone than when they were accompanied by a bright stimulus in the opposite field. The finding that processing of a stimulus can be enhanced rather than suppressed by a second stimulus has been reported (albeit rarely) in the literature and has been termed the ‘anti-extinction’ effect (Goodrich & Ward, 1997; Humphreys, Riddoch, Nys and Heinke, 2002). Anti-extinction is defined as “poor report of a single stimulus presented on the contralesional side of space, but better report of the same item when it occurs concurrently with a stimulus on the ipsilesional side” (Humphreys et al., 2002, p. 361). This pattern of errors is particularly interesting because it seems to contradict the assumption that stimuli compete for attention in a limited capacity system (Broadbent, 1958; Neisser, 1967; Desimone & Duncan, 1995; Ward, Goodrich & Driver, 1994).

It would be hard to explain this apparent anti-extinction effect in healthy participants in terms of a biased competition model; if it were the case that a stimulus loses out in the competition for attention in the presence of a second stimulus, one would expect identification of a dim stimulus to be worse when there was a concurrent bright stimulus in the opposite field. A number of alternative explanations are discussed with reference to the anti-extinction literature with a clinical population.

The idea that processing of a contralesional stimulus is primed by a concurrent ipsilesional stimulus is proposed by Goodrich and Ward (1997) in their report of patient VH. The authors suggested that for VH, a contralesional stimulus on its own is not sufficiently strong to activate the response mechanisms required for overt detection and identification. When these same response mechanisms are activated by the ipsilesional target, however, they are ‘primed’ for subsequent engagement. In such a way, it is the primed response mechanisms that act to ‘pull out’ [*sic.*] a contralesional target that would otherwise be ignored. This model suggests that task demands are crucial in whether or not an ipsilesional stimulus is detected in the presence of a contralesional one. VH showed reliable anti-extinction when performing a simple detection task in both fields and also when performing an identification task in both fields, but not when he was asked to detect the stimulus in one field and identify the stimulus in the other field. According to the authors, if common task requirements are shared (i.e. either to detect or identify both stimuli), then a priming benefit will emerge. Indeed, the authors suggest that extinction studies of unilateral parietal patients which, traditionally, use the same task in both fields would find more pronounced extinction if different tasks (e.g. identification of one stimulus and detection of the other) were used.

Humphreys et al. (2002) reported a study that investigated anti-extinction in a patient, GK, with bilateral parietal lesions and a strong spatial bias with more impaired identification of left visual field stimuli. A series of experiments examined a number of factors that may have led to anti-extinction including temporal onset and offset of stimuli, response priming (as was suggested by Goodrich & Ward, 1997), eye movements, stimulus masking and temporal binding. GK showed reliable anti-extinction when stimuli were presented briefly (for less than 450 msec.) but when stimuli were presented for longer durations (between 450 and 900 msec.) the pattern changed to one of extinction. The authors suggested that this pattern is consistent with a temporal binding model: when stimuli remain on screen for relatively long durations GK's spatial bias dictated that he selected the stimulus on the right before the one on the left, resulting in extinction. However, when stimuli were presented relatively briefly, with common onsets, they were bound by temporal synchronization and both were selected.

Since the two studies discussed here both reported single cases of brain damaged patients it is difficult to extrapolate any firm conclusions from their evidence. It may be that what holds as an explanation in patient VH might not be applicable to GK, who had a number of different neurological complications. Nevertheless, it is still valuable to consider their explanations in relation to the current findings with non-brain damaged participants. The suggestion that anti-extinction is dependent on response priming and occurs when the task requirements are the same for both stimuli (either detection or identification), but is mediated when the task requirements are different would support the findings of the current experiment in which the task was always one of identification. The notion that it is transient temporal binding in brief exposure that accounts for the anti-extinction effect would be harder to reconcile with the current findings. Since no temporal binding is likely to have occurred in the current experiment (exposure durations were the same as in Experiments 1 and 2 where this effect was not found), an alternative explanation based on the relative strength/weakness of stimuli is possible. The studies reported in this thesis thus far have relied upon manipulating the relative strength of stimuli in order to simulate in healthy participants the condition in which an ipsilesional stimulus is far more salient than a concurrent contralesional one in patients with extinction. Experiments 1, 2 and 3 achieved this by weakening the relative luminance of stimuli, thus attention was directed towards the stronger (brighter) stimulus in a bottom-up manner. However since identification requires retrieval of semantic information of stimuli and then previous exposure to similar targets, it might be that identification of stimuli relies more on top-down mechanisms than does detection. Accordingly, a further experiments was devised which relied on manipulation of stimulus strength in a top-down manner and this is reported in Chapter 3.

Finally, in addressing the question of any possible bias towards one or other visual field in the current experiment, performance in identifying dim stimuli (regardless of whether they appeared alone or were accompanied by a bright stimulus in the opposite visual field) was slightly worse in the left visual field than the right, but this difference failed to reach statistical significance.

2.3 Summary and General Discussion

Using a bottom-up paradigm, Experiments 1, 2 and 3 sought to reproduce an extinction-like pattern of errors in healthy volunteers by presenting stimuli of different conspicuity. Stimulus salience was manipulated in all three experiments, thus inducing visual impoverishment. In Experiment 1 accuracy rates showed that performance in bright unilateral trials was at ceiling, and few errors were made in dim unilateral trials. On bilateral trials the bright stimuli were perceived whilst the dim stimuli were missed, consequently an extinction pattern of errors was reliably simulated. A secondary aim of the experiment was to determine whether there was any evidence of an attentional bias towards one side of space, in line with some studies reported in the literature. No such effect was found, but it was thought that accuracy may be too rough a measure to detect it. Experiment 2 explored further the possibility of a difference in response times. More errors were still made in bilateral than in unilateral dim displays, lending support to the notion of a competition effect but no difference in response times was found between left and right visual fields, nor was there a difference in response times between left and right hand responses. Interestingly, some cost of competition was also found for the ‘stronger' stimulus when presented with a weak extinguished one. However detection relies on very early visual processing mechanism, in which features are encoded in parallel. Experiment 3 therefore investigated competition of visual attention with the more demanding task of identification of features where attentional selection is deployed and features are encoded serially (Treisman & Gelade, 1980; Broadbent & Broadbent, 1987). Results from Experiment 3 revealed an unexpected pattern of responses, in which accuracy for a weak stimulus was *improved* when it was accompanied by a strong stimulus, compared with when it appeared alone. This was consistent with the notion of ‘anti-extinction' as reported by Goodrich and Ward (1997) and Humphreys et al. (2002) in studies carried out with brain damaged patients. The finding of anti-extinction in Experiment 3 may have been a result of the identification task used in that study. For example, perhaps identification requires different processes that include more top-down elements. It is interesting to note that the only two reported cases of anti-extinction (Goodrich and Ward, 1997 and Humphreys et al., 2002) reported experimental tasks that relied on identification tasks.

In light of these considerations, the next phase of this series of studies used a top-down paradigm to investigate the primary research question of whether an extinction-like pattern of responses can be induced in healthy volunteers, and whether the finding of anti-extinction would be reproduced using a task that directs attention in a top-down manner.

Chapter 3

Extinction and anti-extinction in healthy volunteers using a top-down paradigm

Thus far, this thesis has investigated the effects on attention by manipulating the luminance of stimuli using a bottom-up paradigm observing an extinction-like pattern of errors with detection tasks and anti-extinction pattern of errors when identification of stimuli was required. Changing the task from one of simple detection to one of identification may have invoked retrieval of semantic information about a stimulus and may have guided attention distribution in a qualitative different way. The added complexity of the identification task may have enlisted some top-down cortical processes in addition to bottom-up mechanisms modulated by strength of stimuli.

There is evidence in the literature that attention in extinction patients may be biased towards ipsilesional space not only by bottom-up factors, but also by top-down factors. Vuilleumier and Rafal (2000), for example, investigated mechanisms of visual extinction by presenting patients with tasks in which they had to attend to the location, number and shape of stimuli presented in both visual fields. They found marked contralesional extinction when the location had to be reported, but not when stimuli had to be enumerated. Identifying distractors amongst shapes revealed an inability to detect two similar targets between and within hemifields. It was concluded that spatial attention is not drawn to ipsilesional stimuli in a purely bottom-up manner in extinction patients. Kastner and Ungerleider (2000) published a review of mechanisms of visual attention. Drawing on the neglect literature (e.g. Driver, Baylis & Rafal, 1992; Marshall & Halligan, 1994; Mattingley, Davis & Driver, 1997) they noted that the competition between multiple stimuli can be biased equally across the visual field by bottom-up processes; top-down mechanisms, on the other hand (e.g. directing attention towards a particular location) are biased towards the intact hemifield.

Covert attentional orienting has been the subject of much research. As long ago as 1894, von Helmholtz observed from a series of experiments that “by a voluntary kind of intention, even without eye movements, and without changes of accommodation, one can concentrate attention on the sensation from a particular part of our peripheral nervous system and at the same time exclude attention from all other parts”. Posner’s spotlight metaphor (1980) likened visual attention to a spotlight that facilitates detection of events within its beam. Posner, Snyder and Davidson (1980) developed an endogenous cueing paradigm in which a central cue is presented at fixation and indicates whether the target will appear on the left or the right. A peripheral stimulus item is then presented tachiscopically in either the left or right visual field and on control trials no cue is given. This endogenous (controlled by the observer) approach is distinct from exogenous cueing, which relies on a change in the visual environment which will capture attention, for example, a flicker or occlusion that signals the appearance of a target stimulus. There is no doubt that endogenous cueing effectively facilitates detection of the item and discrimination of its properties (Lupiáñez et al., 2004) and this method has been used extensively (e.g. Müller & Rabbitt, 1989; Theeuwes, 1994; Abrams & Dobkin, 1994; Caputo & Guerra, 1998) but not in an extinction paradigm. The predictive value of the cue results in increased performance for targets at the cued location than for targets at uncued locations and is therefore a suitable paradigm for manipulating attention towards one visual field and away from another.

Previous studies have, as a rule, employed endogenous cueing to orient attention towards a unilateral object in a simple detection task in which the stimulus item has been a shape or a flash of light. In an extinction paradigm, however, there must be a bilateral condition in which two items appear concurrently. Experiment 4 will eliminate the bottom-up component led by the difference on stimuli strength and employ a top-down attentional cueing paradigm, in which stimuli of equal strength are cued by an arrow, in order to investigate whether anti-extinction effect could be reproduced and extended using a cued attention paradigm that engages top-down attentional mechanisms.

3.1. Experiment 4

Thus far, this thesis has investigated the effects on attention of manipulating the strength of stimuli using a bottom-up paradigm in which the luminance of stimuli varied. Bottom-up processing may cause our visual attention to be ‘pulled’ towards one object at the expense of another. Alternatively, top-down factors can ‘push’ our attention towards a particular object regardless of its physical properties. The analogy of the strong/weak stimuli from Experiments 1, 2 and 3 becomes a question of whether the stimulus is validly or invalidly cued in a top-down paradigm.

In Experiment 4 the cue was an arrow that pointed either left or right and of particular interest was whether or not the anti-extinction effect seen in a bottom-up identification task (Experiment 3) would emerge in a top-down identification task.

Method

Participants

The same twenty right-handed participants who took part in Experiment 3 were recruited for this experiment.

Apparatus

The apparatus was the same as reported in Experiment 3.

Stimuli

Stimuli were similar to those used in Experiment 3, however in Experiment 4 all stimuli were dim (i.e., luminance for all shapes was fixed at 181), which correspond to the dim condition for Experiment 3. A black horizontal arrow (60*40 pixels) pointing left or right appeared in the centre of the screen. There was a randomized delay of 1000-2500 ms between each cue and display. All displays lasted for a fixed duration that was based upon individual performance on the titration conducted. In Experiment 4 there were 126 individual trials (see Table 3.1.1). Valid and invalid cued stimuli were defined by whether or not a stimulus was correctly cued by the central arrow.

Table 3.1.1*: Stimulus displays*

Number of targets	**Left**	**Right**
Unilateral (18)	Valid	
Unilateral (9)	Invalid	
Unilateral (18)		Valid
Unilateral (9)		Invalid
Bilateral (36)	Valid	Invalid
Bilateral (36)	Invalid	Valid

Circle, square and triangle targets each appeared on the left in 50% of the trials and on the right in 50%. A higher number of valid unilateral trials *vs.* invalid unilateral trials was necessary in order for the arrow cue to be effective. For this reason, the arrow cue was valid in 67% of unilateral trials and invalid in 33% of unilateral trials.

Procedure

The procedure consisted of a short titration task (identical to that employed in Experiments 1, 2 and 3), followed by the experimental phase (see below). No feedback was given during the testing session.

Experimental Session

Participants read a set of instructions presented on the screen. They were asked to maintain fixation on the centre of the screen where the arrow would appear and to identify shapes appearing on one or both sides; examples of the three shapes were displayed. Participants were informed that a shape was more likely (67% of the time) to appear on the side where the arrow was pointing, i.e. the cued side. A short practice block of twenty trials followed, in which every trial displayed a unilateral validly cued shape. Immediately after each presentation participants were required to make a verbal response indicating the identity and location of the shape or shapes seen. Responses were recorded on a keyboard by the experimenter, with specific keys assigned to each of the shapes and locations. Keys ‘A’, ‘S’ and ‘D’ indicated responses to shapes on the left and ‘J’, ‘K’ and ‘L’ to shapes on the right. In cases where participants did not perceive anything on a particular side of space they were instructed to say the word “nothing”, in which case the experimenter would press the spacebar. If they perceived something but could not identify the shape explicitly, they were instructed to say “I don’t know”, and the experimenter would press ‘E’ (left) or ‘U’ (right). In this way, a response was always recorded for left and right. Half of the participants reported the left target first and the other half followed the opposite order. There was no time limit and participants were advised to take as long as necessary and focus on accuracy. Participants were offered a short break after approximately every 50 trials. No feedback was given during the test sessions.

Results

One participant's overall score (<20%) was far below the overall group mean so it was excluded from further analysis.

Percentage of error responses was higher for invalid than valid targets. Figure 3.1.1 shows percentage of error responses for each individual condition. Moreover, invalid targets were better reported in bilateral than in unilateral trials.

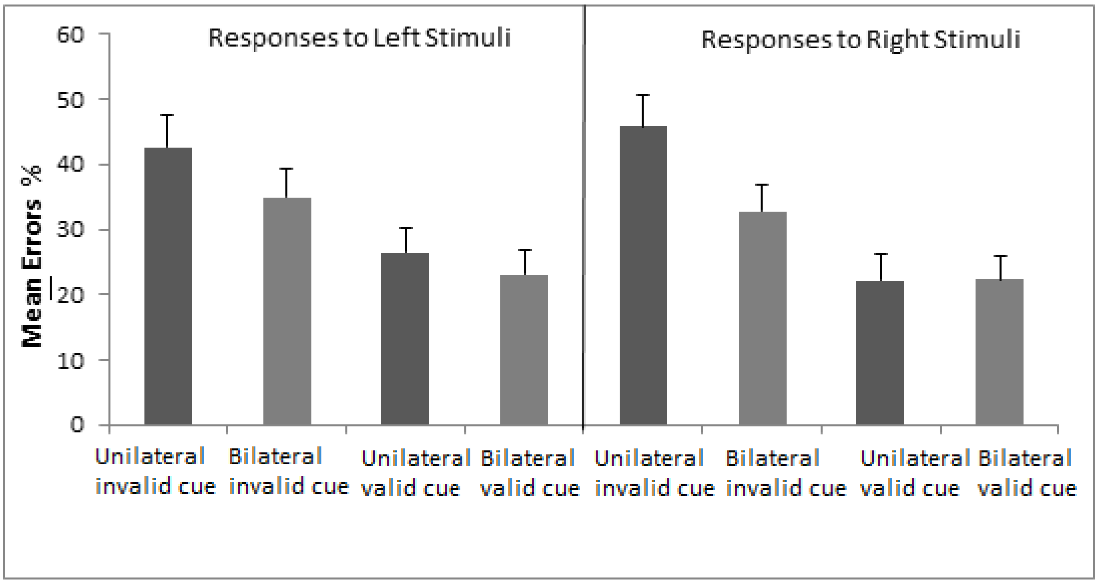


Figure 3.1.1*: Mean (%) errors and standard errors in all conditions*

An omnibus ANOVA analysed side (left/right) x condition (unilateral/bilateral) x cue (valid/invalid) x order of report (left/right). ANOVA revealed a main effect for cue *F* (1, 17) = 11.29, *p* <.01, of condition *F* (1, 17) = 7.28, *p* <.05, but side and order of report were not significant. There was a significant interaction between the cue and condition *F* (1, 17) = 5.53, *p* <.05. Post-hoc pairwise comparisons mainly revealed that invalid targets were significantly better identified in bilateral than in unilateral condition *t* (18) = -2.9, *p*=.009 (See Figure 3.1.2).

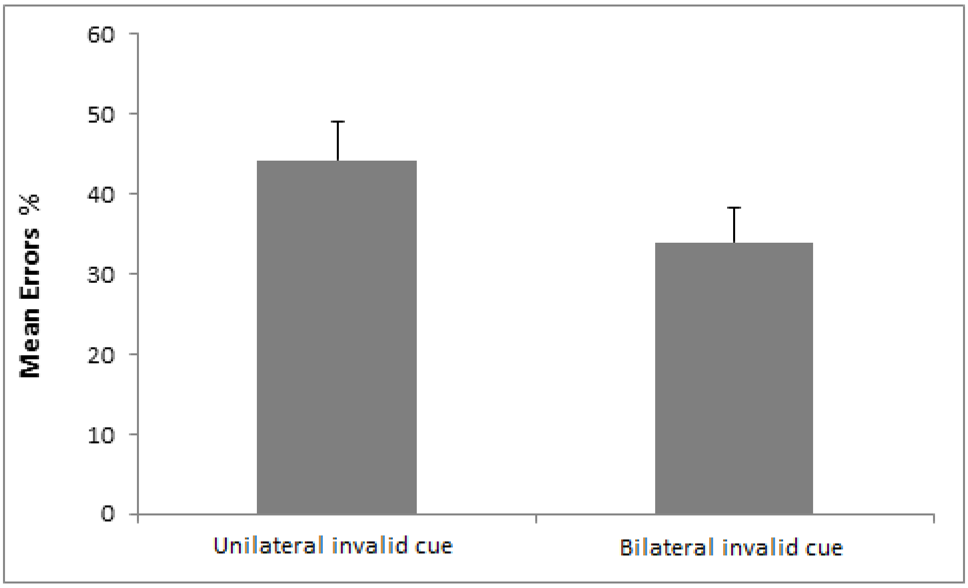


Figure 3.1.2: *Mean (%) errors and standard errors of invalid targets in unilateral and bilateral conditions*

Discussion

There was still no significant effect of laterality but the ‘anti-extinction’ pattern of errors was observed; if an invalid target was presented on its own, there was less chance of it being identified than when it was presented bilaterally beside a valid target. Thus, an anti-extinction effect was observed when the task was one of identification.

This effect, found in Experiments 3 and 4, is difficult to explain since it has never before been reported in a non-clinical sample. One can only make an analogy between the contralesional stimulus in patients and the less salient, or weaker, stimulus in the current studies, that is the dim stimulus in Experiment 3 and the invalid stimulus in the current experiment. Similarly, or course, the ipsilesional stimulus for patients may be seen as the stronger of the two stimuli here, i.e. the bright, or validly cued, stimulus. The explanations proposed by Goodrich and Ward (1997) and Humphreys et al. (2002) to account for anti-extinction would, perhaps, be best applied to clinical participants with contralesional and ipsilesional visual fields and, as such, cannot fully explain the results herein. It may be that whether extinction or anti-extinction emerges depends not just on temporal binding (as suggested by Humphreys et al., 2001) but on an imbalanced competition between stimuli that is determined by the relative strength of stimulus in the left and right visual fields.

In the current study's invalid unilateral conditions, attention was directed by the cue towards an empty space. Meanwhile, the stimulus in the other field remains unattended while the participant waits for a target that never arrives. By the time attention is disengaged, the display has disappeared and no stimulus is detected. However, in bilateral trials there is no 'waiting': two targets appear, the cued one is perceived and reported immediately, leaving time for the uncued side of space to be scanned and reported. Thus it may be that the relative strength and weakness of stimuli is important in understanding anti-extinction (at least in healthy individuals), perhaps more so than task requirements.

It would be of interest to carry out further studies to test this assumption as well as the temporal binding account. Humphreys et al. (2002) reported that their patient GK's pattern of errors changed from anti-extinction to extinction when stimulus durations were lengthened to more than 450 msec. In healthy volunteers, longer exposure durations would likely result in a ceiling effect in all conditions, so in order for this finding to be supported or refuted it is necessary to test extinction patients. Thus far, other than the studies by Goodrich and Ward (1997) and Humphreys et al. (2002), the incidence of anti-extinction in brain damaged patients is unknown since it may have gone unreported. It remains to be discovered, therefore, how commonly extinction and anti-extinction co-occur in patients and under what conditions each of the two phenomena occur.

Chapter 4 describes a series of experiments with extinction patients that partially replicated Humphreys et al.'s first experiment.

Chapter 4

Extinction and anti-extinction in brain damaged patients

4.1 Assessment of extinction in 9 brain damaged patients

Anti-extinction is a rarely reported phenomenon that is surprising because it seems to contradict theories of normal attentional function in which attention is considered to be of limited capacity. Performance declines when two stimuli are attended relative to one (Broadbent, 1958; Duncan, 1980; Treisman, 1969) and the ‘stronger’ stimulus receives more attention at the expenses of the ‘weaker’ one. However, anti-extinction may have been underestimated for methodological issues, and it may be more common than is reported; there may be an assumption by researchers that patients with right hemisphere damage who show poor report of single contralesional stimuli would perform worse still in double stimulation trials. In such cases performance on double stimulus trials may not be examined and cases of anti-extinction may go unreported. Di Pellegrino, Basso and Frassinetti (1997), for example, reported a patient with right parietal damage who showed a marked impairment in processing a single stimulus (when it occurred within a period of several hundred milliseconds before or after the onset of an ipsilesional one). Olson, Stark and Chatterjee (2003) described a patient with right parietal damage whose ability to discriminate items in contralesional (as well as ipsilesional) space was marginally better with than without competing items. In a study by Baylis, Driver and Rafal (1993), five extinction patients were reported to display more pronounced extinction when stimuli shared the same dimension (colour or shape). The authors present a table of raw data that clearly shows this to be the case; however, it can also be noted from their data that all five patients showed poorer performance on single left trials than on left stimuli in double trials in either or both dimensions (colour/shape). Whilst differences were small and may not reach statistical significance, there is a clear and unequivocal trend that has gone unreported, seemingly because the authors were addressing the question of the differences in errors between the two dimensions. To date, only two studies in the literature have clearly referred to this pattern of data as anti-extinction and the authors have offered a number of suggestions to explain the phenomenon; both of these studies will be described here and discussed in relation to the findings here of anti-extinction in healthy volunteers.

Goodrich and Ward (1997) were surprised to find that their patient, VH, showed better performance on detection of contralesional stimuli when they were accompanied by ipsilesional stimuli than when they were presented alone. Over ten sessions, VH participated in a number of computerised tasks involving the detection and identification of stimuli in which the features of the target items were manipulated to test a number of hypotheses concerning the anti-extinction effect. In all sessions there were four display types: Single Left, Single Right, Double and Blank displays and the participant responded verbally by indicating “left”, “right”, “both” or “nothing”. As is standard in tasks for extinction patients, central fixation was maintained by means of a fixation point in the centre of the screen, which appeared briefly and was followed by stimulus displays. In all of the experiments reported by Goodrich and Ward (1997), stimuli appeared for less than 50 msec Stimuli in the first two sessions consisted of letters ‘*X’* and ‘*O’* and a reliable pattern of anti-extinction emerged. In the following session, the letter stimuli were replaced with circles and triangles and the same pattern of errors was observed. Next, drawing on previous research that showed ‘good’ objects are less likely than ‘scrambled’ objects to be extinguished (Ward & Goodrich, 1996), simple line drawings of common items (e.g. a house, heart, pipe, envelope, cup, crocodile, newt, camel) that were either complete or ‘scrambled’ by fragmenting the outlines and scattering them randomly within the outlines of the original pictures, were presented. It seemed to be the case that, for VH, contralesional items benefited from the simultaneous appearance of ipsilesional ones and it was speculated that if ‘good’ contralesional items are less likely than scrambled ones to be extinguished, then maybe, in the case of VH, good contralesional items might benefit *less* from ipsilesional stimuli, eradicating the anti-extinction effect. This was not the case and VH continued to show a significant anti-extinction pattern of errors. Following the finding by Ward et al. (1994) that perceptual grouping reduces extinction (described briefly here in Section 1.3.2), two further sessions explored the effect of grouped versus ungrouped stimuli. It was thought that since a contralesional stimulus is less likely to be extinguished when it is perceptually grouped with an ipsilesional one than when the two items do not form a perceptual group, then grouping may actually improve detection of contralesional items in bilateral conditions. Indeed, Goodrich and Ward (1997) conjectured that anti-extinction could be an extreme form of this perceptual grouping benefit. This would seem a reasonable supposition; it might be that, if there were good perceptual grouping between two simultaneously presented stimuli, then the anti-extinction effect could be even more evident in the case of VH. However, the grouping or non-grouping of stimuli was found to have no effect; a large anti-extinction effect was still found, but there was no significant effect of perceptual grouping. In two subsequent testing sessions the horizontal alignment of the stimuli was manipulated. The letter *X* was presented either in horizontal alignment or above or below fixation, creating a diagonal alignment, with the speculation that the spatial relationship between the two simultaneous items could be the basis of VH’s anti-extinction; perhaps when the stimuli were presented in line with one another the presence of an ipsilesional item could serve as a cue to the contralesional item, and if this spatial symmetry were disrupted then anti-extinction might not occur. Two possible outcomes were anticipated: either the trials in which the stimuli were horizontally aligned would result in higher detection of contralesional stimuli, or (since aligned and non-aligned stimuli were randomly presented in a block), reducing the predictability of the spatial relationship would disrupt the effect of alignment and eliminate the anti-extinction effect across all conditions. It was found, however, that neither of these predictions held true; anti-extinction was slightly reduced but not eliminated, and still statistically significant in all conditions and there was no effect of the alignment of the items. The alignment of stimuli, though diagonal and not horizontal, was still symmetrical so, in a final session, stimuli were presented in random asymmetrical spatial arrays on the left or right of the screen. Eliminating the remaining spatial predictability still did not eliminate the anti-extinction effect, and it was concluded that the spatial arrangement of items was not an important factor in VH's anti-extinction. A second set of studies reported by Goodrich and Ward (1997) showed that, in the case of VH, anti-extinction was dependent on the types of tasks performed and on whether or not the same task was performed in both visual fields. In the studies described thus far, the task always consisted of detection of stimuli. For the subsequent two testing sessions the task requirement was varied so that VH was asked to *identify* both targets in double simultaneous presentation ('Same Task') or to *identify* the contralesional target and simply to *detect* the ipsilesional one ('Different Task'). In the 'Same Task', VH continued to show anti-extinction, even though the task was perceptually different (one of identification, rather than detection). In the 'Different Task' however, the presence or absence of an ipsilesional item had no significant effect on identification of a contralesional one, thus the anti-extinction effect was negated. In these 'Different Task' conditions VH correctly identified 45% of contralesional items in double displays and 39% of contralesional items in single displays, so it cannot be said that he displayed the opposite pattern of extinction, merely that significant anti-extinction was no longer found. It should be noted, however, that this pattern of errors still resembles one of anti-extinction (i.e. better report of contralesional items in double displays than in single displays) and, although the difference failed to reach significance it can still be considered a trend towards significance. It seemed that, for VH, anti-extinction was influenced by the influence of ipsilesional processing on contralesional identification. The authors suggested that their findings might be generalised to other right hemisphere-damaged patients; since previous extinction studies had always used the same task in both fields they may have missed important differences in the extinction effect that would become apparent if different tasks were used. It was speculated that if patients were to be tested in both Same and Different tasks, extinction would be more pronounced in the latter. Goodrich and Ward (1997) put forward a number of possible explanations for their findings. The results could not be attributed to general visual processing capacity limitations, since stimulus identification places a higher demand on processing performance than does detection – resource limitations alone would predict poorer performance in the Same Task (in which identification of both stimuli was required) than the Different Task (in which only one stimulus had to be identified and the other simply detected). Nor could the results be due to the cognitive effort of switching tasks, which are known to reduce performance (Allport, Styles, & Hsieh, 1994), because this would not account for the improved contralesional performance on Double compared to Single left displays. The authors suggested that the presence of a contralesional stimulus alone is insufficient to trigger appropriate response mechanisms (i.e. the mechanisms necessary for detection and identification) in VH, but when these mechanisms are activated by the ipsilesional stimulus they are primed for subsequent engagement by the less salient contralesional stimulus. In other words, the presence of an ipsilesional item primes a response to the contralesional item, and this response priming benefit occurs when the contra- and ipsilesional tasks are the same, and not different, and when the same response mechanisms are shared. They refer to the contralesional stimulus, which might otherwise be ignored, being ‘pulled out’ by the primed task-specific response mechanism.

Humphreys et al. (2002) reported six experiments conducted on GK, a patient with *bilateral* parietal lesions following two strokes, but who exhibited a strong rightward spatial bias, showing neglect on a number of clinical tasks. It should be noted that GK also had a number of additional neurological symptoms, including Balint’s syndrome (incoordination of hand and eye movement and the inability to perceive more than one object at a time; Cooper & Humphreys, 2000; Humphreys, Romani, Olson, Riddoch & Duncan, 1994) and attentional dyslexia (Hall, Humphreys & Cooper, 2001). Experiment 1 examined the time course of extinction and anti-extinction effects by varying the exposure duration of stimuli in a task in which GK was required to identify letters (*A*, *B*, *C* or *D*) that appeared randomly to the left or right of central fixation, and were displayed either unilaterally or bilaterally with some blank trials included. The letters appeared for seven different stimulus durations (75, 150, 450, 600, 750 and 900 msec), randomly displayed in six blocks of trials. GK showed clear anti-extinction on trials with brief exposures (up to 300 msec) however, as the stimulus duration increased, then the pattern of anti-extinction changed to one of extinction. With regard to the findings of Goodrich and Ward (1997), this change from extinction to anti-extinction at longer stimulus durations was not explored; patient VH showed consistent anti-extinction in a variety of tests, but one variable that was not manipulated by Goodrich and Ward was the duration for which stimuli were displayed. Their stimulus durations were all less than 50 msec and, whilst they did find that the anti-extinction effect was modulated when task demands differed between contra- and ipsilesional items, it would be interesting to know whether VH might have shown extinction at longer stimulus durations. Since studies have shown that, in normal observers, abrupt onsets in visual displays can be strong cues for the capture of visual attention (Yantis, 1998; Yantis & Jonides, 1984; 1990), Humphreys et al. (2002) examined the effects of onsets by presenting the stimuli as offsets rather than onsets (by initially presenting masks, which disappeared from the screen to reveal stimuli (Experiment 2a) and by having the stimuli onset abruptly, but following them with masks designed to that the stimuli did not offset (Experiment 2b). The latter task was one of detection, rather than identification, because the post-display masks that were used made performance more difficult. Interestingly, in Experiment 2a the anti-extinction effect was not found at shorter durations, as in the previous experiment, rather an extinction effect was observed at longer stimulus durations (450 msec and over). In Experiment 2b anti-extinction was found, but only for shorter durations as in Experiment 1. Thus so far anti-extinction had been found for brief stimulus durations both in identification task (Experiment 1) and a detection task (Experiment 2b). Since the effect had been observed when target letters onset but do not offset together, it was concluded that common offsets are not necessary for anti-extinction. In contrast, Experiment 2a showed that there was no anti-extinction effect when stimuli were defined by offsets, suggesting that common onsets are crucial. This factor had not been considered by Goodrich and Ward (1997), who instead explained anti-extinction as the result of response priming: report of contralesional items was supported by the same response being made to ipsilesional items. To test this in Experiment 3a GK was asked to identify both letters on some double stimulation trials and to identify the letter on the contralesional side but simply detect the letter on the ipsilesional side in others. Similarly, Experiment 3b was identical to Experiment 3a, except that on double stimulation trials the letters were the same (*00* or *XX*) on half the trials and different (*OX* or *XO*) on the others. According to the response-priming account suggested by Goodrich and Ward (2002), anti-extinction should occur when the letters were the same, but not when they were different because for response priming to occur, the responses to both stimuli must be the same. Anti-extinction was found both in Experiments 3A and 3B, but in all conditions so this could not be attributed to response-priming. Another factor that Humphreys et al. considered might be important in inducing anti-extinction was whether GK's unusual pattern of anti-extinction at brief exposures and extinction at longer ones might be due to eye movements in longer exposure durations. If, for example, GK moved his eyes in an ipsilateral direction during longer stimulus displays this could cause him to miss the contralesional stimulus, resulting in extinction. To test this, GK's eye movements were monitored in Experiment 4 in which the method was identical to Experiment 1. The anti-extinction effect prevailed even when eye movements were made towards ipsilesional space, showing that the change in the error pattern from anti-extinction to extinction was not due to eye movements in longer stimulus exposure trials. Thus far, anti-extinction had been found in response to brief stimuli when stimuli in both fields onset together and three possible explanations were considered: a) cueing attention to a common spatial region as suggested by Goodrich and Ward (1997); b) increased arousal (which could occur when more than one stimulus appears and the observer tries to pay more attention to all stimuli that are present, possibly resulting in the anti-extinction effect in GK's case) and c) temporal binding of the stimuli (which could explain the fact that anti-extinction occurred for brief stimuli but the pattern changed to one of extinction when the stimuli remained for longer in the visual field). These three possibilities were tested in Humphries et al.'s Experiments 5a and 5b, in which a central masked offset letter appeared, flanked on either side by two similar masked onset letters. In two blocks the onset letters were red and the offset letters and pre-masks were in black, to highlight grouping differences between the onset and offset items. In another two blocks the onset and offset letters were all black. In Experiment 5a, GK was asked to report all the letters. If the cueing account held true, then GK would be expected to perform well in reporting the central letter on trials where he first reported a left-side letter created by an onset because the central letter should be selected before the leftward one since it falls relatively to the right, within the attended area of space; the more ipsilesional of the two stimuli (the central one) should prime a response to the contralesional one. The arousal account would predict that GK would be able to report all three stimuli; furthermore, that report of the central letter on trials with two onsets should be better than on trials with one onset. Finally, the binding account would predict accurate report of the left and right items, but not necessarily of the central item since the central letter was created by an offset rather than an onset. It was found that GK was able to identify the central letter on all one-item trials in which the left letter was also identified, the central letter being selected first. In contrast, he performed poorly in identifying the central offset letter on two-item trials even when the left offset letter was identified. These findings are consistent with the binding account and not the attentional cueing or arousal accounts. According to this account the left and right stimuli are grouped by common onset, resulting in an anti-extinction effect. This would appear to account for GK's responses; his spatial bias dictated that the rightmost stimulus was selected first and this was grouped by common onset with the leftmost stimulus, which was reported prior to the central offset letter. This pattern of responses might partly be explained by the fact that stimulus onsets are more salient than offsets (Yantis, 1998) but one would expect this to affect GK's responses to all onset stimuli, and this was not the case. Since, on one-item trials, central offset letters were identified prior to left onset letters it was speculated that a single left onset may not generate a strong enough masking effect, enabling selection of the central letter prior to the left flanker. To test this, Experiment 5b required GK to report only the central letter, which was presented in a different colour to the flanking onset letters. If poor report of the central letter was because GK selected the two flankers, then the effect should have been mediated in this experiment. Data showed better report of the central letter here than when flanker letters had to be reported, suggesting that poor report of the central item in two-item displays of Experiment 5a was not due to lateral masking. As a result of Experiments 1 – 5b it was concluded that GK's anti-extinction was due to temporal binding based on common (and simultaneous) onset of the stimuli. A final experiment was run to explore GK's reaction to stimuli that did not occur simultaneously. One red and one green letter were presented on each trial and GK was required to judge which colour appeared first. The letters were presented either simultaneously or separated in time by 450 msec or 720 msec An anti-extinction effect was found when the letters were presented simultaneously. However, when they were staggered in time GK consistently judged that the right item appeared prior to the left. It was concluded that the effects of time on anti-extinction dissociated from the effects on conscious temporal order judgment. In summary, the authors suggested that for GK anti-extinction occurred when stimuli that have a common onset are briefly presented, and that the effect is due to temporal binding of the stimuli. This is interpreted as indicating that there is unconscious and transient temporal binding in vision.

The diverse explanations offered by Goodrich and Ward (1997) and Humphreys et al. (2002) to account for anti-extinction do share the notion that report of a contralesional stimulus is triggered by report of an ipsilesional stimulus; by response priming according to the former authors, and by temporal binding by the latter. A new explanation is suggested for the findings in the current experiments that also share this underlying assumption, though with yet another interpretation. It is proposed that the right- or left bias, induced by bottom-up or top-down mechanisms found in healthy participants, dictates that the right, or left, visual field is attended initially, and that If no stimulus appears in the firstly attended visual field, attention remains there ‘waiting’ for its appearance. If, however, a stimulus does appear there, then the stimulus is promptly processed, freeing attentional resources to shift to the other visual field, where a second stimulus may occur and be processed. This account depends on the relative strength of stimuli in both fields and would explain anti-extinction both in patients and healthy individuals. In patients with right hemisphere damage, attention is drawn strongly towards ipsilesional space, thus the ipsilesional (right) stimulus is accorded more strength than the weaker contralesional one. Thus, report of the stronger ipsilesional item may trigger report of the weaker contralesional one by freeing attentional resources to shift to the more poorly attended contralesional space.

The dearth of reporting of anti-extinction in the literature does not necessarily indicate its rarity. Indeed, it may be possible that anti-extinction has passed unnoticed as poor performance in reporting single contralesional items is interpreted as evidence of hemianopia thus rendering assessment with double presentation simply irrelevant. However, findings with healthy volunteers in Experiments 3 and 4 of this thesis and evidence from Goodrich and Ward (1997) and Humphreys et al. (2002) patients suggested that better performance with double trials may be observed if specifically investigated, for example increasing duration of stimuli presentation. Since, it would not be possible to present stimuli for very long durations (e.g. > 450 ms, as reported by Humphreys et al., 2002) to healthy volunteers without a resulting ceiling effect, a sample of brain damaged patients was sought.

Method

Participants

The University of Waterloo in Ontario, Canada maintains a database of brain damaged patients who have indicated that they are willing to take part in research[2] and nine of these patients were selected for participation in the experiments reported here. The study received institutional ethics approval from both Goldsmiths and Waterloo Universities and all nine patients gave informed consent to participate.

Initial assessment of extinction is reported in these patients. Nine right handed adult patients with right hemisphere vascular lesions were recruited via the University of Waterloo's Neurological Patient Database and gave informed consent to participate in this study. Neglect was investigated by means of the Star Cancellation test (Albert, 1973), Bell Cancellation test (Gauthier, Dehaut, & Joanette, 1989), the Drawing task involving copying of three different simple figures (e.g., a flower; Wilson, Cockburn, & Halligan, 1987), and the Line Bisection test (Wilson et al., 1987). For the Line Bisection test deviations from the true centre greater than 10% of line length were considered evidence of neglect. All but one of the patients had previously shown left neglect. Demographic and clinical data, as well as neglect diagnosis for all nine patients are presented in Table 4.1.1. All patients were well oriented in time and place and had good comprehension. They were paid for their participation and signed informed consent statements.

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[2] The Neurological Patient Database is maintained under the direction of Dr James Danckert with the assistance of Project Co-ordinator Nadine Quehl. Further information is available at http://npd.uwaterloo.ca/

Table 4.1.1: *Patients' demographic and clinical data*

Patient	**Sex**	**Age**	**Months post infarct**	**Demonstrated signs of neglect ***	**Lesion nature and site**
HH	F	47	11	Left neglect	Nature: Ischaemic and heamorrhagic stroke. Site: Right frontal and parietal cortex/right middle cerebral artery/right internal carotid artery.
WW	M	63	1	Left neglect	Nature : Ischaemic stroke. Site: Right temporal lobe cortical sulci.
JJ	M	72	16	Left neglect	Nature: Subdural haematoma Site: Right frontoparietal cortex.
CP	M	60	5	Left neglect	Nature: Ischaemic stroke Site: Right fronto-parietal and occipital cortex and subcortical structures; corpus callosum and splenium
RB	M	62	2	Left neglect	Nature: Ischaemic stroke. Site: Right parietal lobe, including subcortical structures.
CS	F	73	10	No neglect	Nature: Ischaemic stroke. Site: Right parietal cortex.
LG	M	41	10	Left neglect	Nature: Ischaemic and heamorrhagic stroke. Site: Right temporal and parietal cortex.
OP	M	56	4	Left neglect (figure drawing)	Nature: Ischaemic stroke. Site: Right frontal and parietal cortex.
DF	M	80	4	Left neglect	Nature: Ischaemic stroke. Site: Right parietal subcortical structures.

* Neglect was established by a series of routine tests (i.e., Star and Bell Cancellation tests, copying of drawings and Line Bisection).

Visual extinction was assessed by means of two tests: first clinically with the Visual Confrontation Test (Bender, 1952), and then with a computer task.

Visual Confrontation Test: The examiner held both hands at shoulder height and moved two fingers of either the left, right or both hands simultaneously. The patient's task was to maintain central fixation (by looking at the examiner's nose) and to report whether a stimulus (a movement of the fingers) was detected on their left, right, or on both sides. Six unilateral left, six unilateral right and six bilateral stimuli were presented in random order. According to Geeraerts, Lafosse, Vandenbussche and Verfaillie (2005), responses indicating detection of unilateral stimuli in both fields (at least 80%), but failure to detect a stimulus in the patient's contralesional field in bilateral trials (more than 30%) would indicate extinction.

Computer Task: Following Cocchini, Cubelli, Della Sala and Beschin's (1999) procedure, a computerised test (described below) was devised to assess patients' ability to detect stimuli presented very briefly. The test also enabled accurate control of spatio-temporal parameters.

Apparatus

The computerised experiment was constructed using E-Prime software and run on a Dell Inspiron laptop computer with a 39.1 cm screen (31.29cm wide x 23.47cm high) and a screen resolution of 1680 x 1050 pixels. Participants were seated centrally in front of the laptop, which was placed on a table at a viewing distance of approximately 50 cm. Thus, the visual angle subtended to the eye by the viewing area at this distance was approximately 34° horizontally and 26° vertically.

An additional, external keyboard was connected to the laptop computer, enabling the experimenter (seated beside the patient) to make keyboard responses.

Stimuli

The stimuli are illustrated in Figure 4.1.1. Stimuli were based on those used by Cocchini et al. (1999) in an assessment of visual extinction. A white fixation cross, 1.15° high and wide, was displayed in the centre of the screen against a dark grey background, followed 150ms later by stimulus onset. Stimulus items consisted of white dots 0.58° in diameter, presented for 100ms at about 14° from the point of fixation. Stimuli appeared randomly, either unilaterally to the left or right of fixation, or bilaterally in both fields. Precise luminance (cd/m^2) and settings for the background and the stimuli are presented in Table 4.1.2.

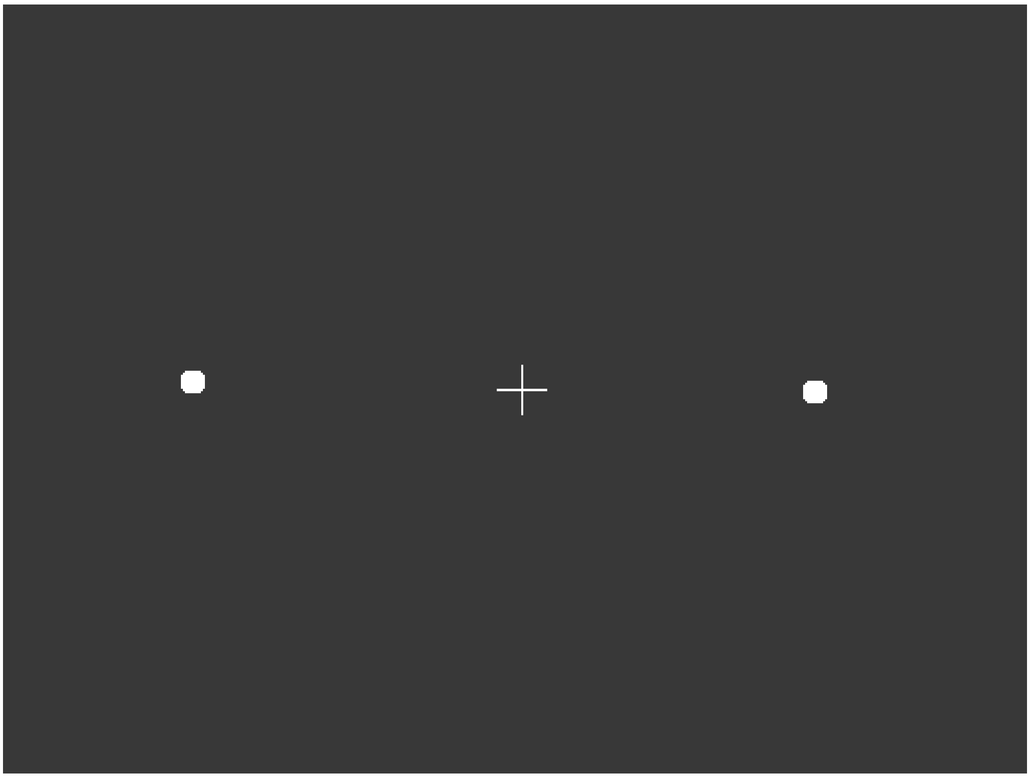

Figure 4.1.1: *A schematic representation of an experimental trial. In each trial, a central fixation cross appeared on the screen, followed after 150ms by a stimulus event (in this example stimuli appear in both left and right visual fields). Stimuli remained on the screen for100msec*

Table 4.1.2: *Settings of Background and Stimuli*

	Luminance (cd/m^2)	Saturation	Luminance	Red	Green	Blue
Background	.15	0	53	56	56	56
Stimuli and Fixation Cross	10.8	0	240	255	255	255

Procedure

Eye movements were monitored by an assistant seated behind the computer screen. The patient was aware that his/her eye movements were being monitored, and he/she was instructed to fixate centrally whenever an eye shift occurred. If eye movements deviated from the centre of the screen on a trial, then that trial was excluded from the final analysis. There were 32 trials (16 bilateral, 8 unilateral left and 8 unilateral right) presented in a randomised order. Each trial began with the onset of the central fixation cross. There followed a blank interval of 150ms and then the stimulus display. Patients made verbal responses reporting how many dots (one or two) appeared, and on which side of the screen. Keyboard responses were made by the experimenter and the entry of each response initiated the next trial.

Results

Visual Confrontation test

Results for all nine patients of the visual confrontation test are presented in Table 4.1.3.

Table 4.1.3: *Errors in identifying movements in clinical confrontation test* [3]

Patient	Single (unilateral) trials		Double (bilateral) trials	
	Left Errors (%)	Right Errors (%)	**Left Errors (%)**	Right Errors (%)
CP	0	0	**16**	0
HH	0	0	**81.25**	0
WW	0	0	**50.00**	0
JJ	0	0	**0**	0
RB	0	0	**0**	0
CS	0	0	**0**	0
LG	0	0	**0**	0
OP	0	0	**31.25**	0
DF	0	0	**0**	0

As can be seen from Table 4.1.3, all nine patients correctly detected all single stimuli (both left and right) and all stimuli in ipsilesional space in double trials. If extinction were to take place, one would expect to see a high percentage of errors in the highlighted column for contralesional stimuli in double trials, and a low percentage of errors in single trial columns. Previous studies employing this test (e.g. Geeraerts et al., 2005) have classified patients as showing extinction if they correctly detected more that 80% of unilateral left and right stimuli, but failed to perceive more than 30% of stimuli in bilateral trials. According to these criteria, only three patients (HH, WW and OP) showed extinction, missing 81.25%, 50% and 31.25%, respectively of contralesional stimuli on double trials. However, it was noted that OP found it difficult to maintain central fixation and was hesitant in making responses to the stimuli. Patient CP showed a slight trend towards extinction, his only errors being on 16% of contralesional stimuli in double trials. Five of the nine patients showed no extinction on the visual confrontation test, scoring at ceiling in all trials (Patients JJ, RB, CS, LG and DF).

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[3] Errors are defined as trials on which no stimulus was reported

Computer Task

Results of the computer task for all nine patients are presented in Table 4.1.4.

Table 4.1.4: *Errors in computerized detection task* [4]

Patient	Single (unilateral) trials		Double (bilateral) trials	
	Left (% errors)	Right (% errors)	**Left (% errors)**	Right (% errors)
CP	62.50	0	**0**	0
HH	12.50	12.50	**81.25**	0
WW	0	0	**100.00**	0
JJ	12.50	0	**81.25**	0
RB	0	0	**6.25**	0
CS	12.50	0	**0**	0
LG	0	0	**12.50**	6.25
OP	75.00	0	**62.50**	31.25
DF	0	0	**0**	0

As Table 4.1.3 shows, there was a more complex pattern of results than was found in the visual confrontation test. Interestingly, patient CP showed anti-extinction with a high error rate in left single trials and accuracy at ceiling in left double trials. Following previous criterion by Geeraerts et al. (2005) for extinction, three patients (HH, WW and JJ) showed extinction with few errors in left single trials, and high percentages of errors in left double trials. Patients RB, CS, LG and DF scored at or almost at ceiling in all conditions, whilst patient OP had poor accuracy in all conditions with left stimuli in line with a possible visual hemianopia.

Patient CP showed mild extinction on the visual confrontation test and anti-extinction on the computerized test. In order to explore whether an extinction pattern of errors would emerge with longer exposure durations (as was the case with Humphreys et al.'s patient GK), a number of further tests were devised for CP; these are described in Experiments 5 A and B.

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[4] Errors are defined as trials on which no stimulus was reported

Patients HH, WW and JJ all showed reliable extinction either on the visual confrontation test, the computerised test, or both. Further tests with these patients are described in Experiment 6.

4.2 Experiment 5A

Patient CP showed a pattern of anti-extinction in the assessment tests described earlier so Experiment 5 was devised to explore these responses further in this patient, in particular to determine whether a pattern of extinction would emerge with longer stimulus durations in a simple detection task. Stimulus durations were manipulated in a simple detection task similar to the preliminary task in which anti-extinction had been observed in this patient.

Method

Participant

Demographic and clinical data for Patient CP may be found in Table 4.1.1. Lesion sites had previously been identified by a computerised tomography (CT) scan, which is presented in Figure 4.2.1.

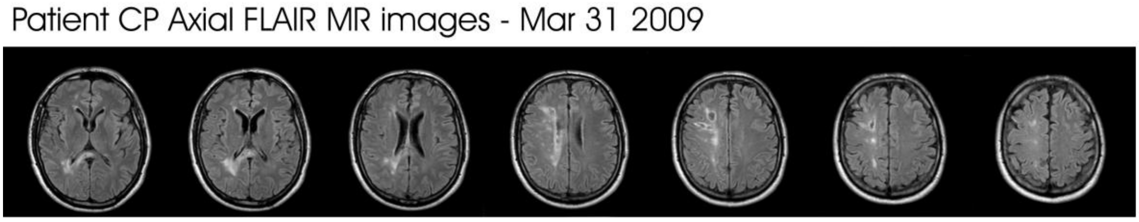

Figure 4.2.1: *MRI scans for Patient CP showing damage to the post right occipital region extending to the corpus callosum and the right fronto-parietal region. Scans are in radiological convention, i.e. right hemisphere is represented on the left side of the image.*

Apparatus

Apparatus was identical to that reported in the previous experiment for the computerised test. Testing took place in a room with no natural light; an overhead light with a constant brightness remained on for all testing sessions.

Stimuli

Stimuli were identical to those in the previous experiment for the computerised test, but were presented for four different durations (150, 300, 450 and 600 msec) at about 5 degrees from point of fixation. There were 33 trials for each stimulus duration, presented in a randomised order. Stimuli appeared randomly, either unilaterally to the left or right of fixation, or bilaterally in both fields.

Procedure

Eye movements were monitored by an assistant seated behind the computer screen. The patient was aware that his eye movements were being monitored, and he was instructed to fixate whenever an eye shift occurred. If eye movements deviated from the centre of the screen that trial was excluded from the final analysis. Each trial began with the onset of the central fixation cross. There followed a blank interval of 150ms and then the stimulus display. CP made verbal responses and keyboard responses were made by a second experimenter (the author). The entry of each response initiated the next trial.

Results

As can be seen, when exposure time of stimuli increased CP's performance was at or almost at ceiling across all single left trials. Data are presented in Table 4.2.1.

Table 4.2.1: *Mean errors in single left and double trials*

Stimulus Duration	% Errors Single Left Trials	% Left Errors in Double Trials	p-value
150 msec	7%	0	ns
300 msec	0	0	ns
450 msec	0	0	ns
600 msec	7%	0	ns

Discussion

According to Humphreys et al. (2002), longer stimulus durations are more likely to result in an extinction, rather than an anti-extinction pattern of data, but CP's anti-extinction did not reverse to extinction with longer stimulus durations, as he scored at ceiling in all conditions. However, Humphreys et al. had used a paradigm of identification rather than one of simple detection. It was speculated that this difference in error patterns might become apparent in an identification task, either because it may be more sensitive, or because of the nature of the task. It has been shown that identification can be more sensitive than detection in revealing contralesional deficits (Baylis, Gore, Rodriguez & Shisler, 2001; Rafal, Danziger, Grossi, Machado & Ward, 2002; Olson, Stark & Chatterjee, 2003; Ricci, Genero, Colombatti, Zampieri & Chatterjee, 2005) and that there is a difference in responses by extinction patients when the two competing objects are different than when they are identical (Rafal, 1994). With this in mind, CP's responses to an identification task were explored in Experiment 5B. The task was a partial replication of the first experiment reported by Humphreys et al. (2002) employing identical stimuli and exposure durations. In order to reduce the length of testing sessions and minimise tiredness of the participant, the number of trials was reduced and there were no blank trials (i.e. trials in which a blank screen appeared with no stimuli displayed).

4.3 Experiment 5B

Participant

Demographic and clinical data for Patient CP may be found in Table 4.1.1.

Apparatus

Apparatus was identical to that reported in Experiment 5A. Testing took place in a room with no natural light; an overhead light with a constant brightness remained on for all testing sessions.

Stimuli

A grey fixation cross, 1cm high and wide, was displayed in the centre of the screen against a white background, followed 150ms later by stimulus onset. Stimuli were grey against a white background and an example of an experimental trial is depicted in Figure 4.2.2. Luminance (cd/m^2) and settings of the background and stimuli can be found in Table 4.2.2. Partially replicating a study by Humphreys et al. (2002), stimuli consisted of letters drawn from the set *A*, *B*, *C* and *D*, presented at about 5° from point of fixation. Each letter was in Times New Roman font and measured 0.69° wide x 0.69° high. Letters appeared randomly, either unilaterally to the left or right of fixation, or bilaterally (one left and one right). In bilateral displays, the two letters were never the same. Letters remained on the screen for four different durations: 150, 300, 450 and 600 msec. The different stimulus durations were presented in separate trial blocks. In line with the study reported by Humphreys et al. (2002), there were more trials displayed for 150msec than for the other three stimulus durations: there two blocks of 48 trials (24 two-stimulus, 12 one-left and 12 one-right trials) with stimulus durations of 150 msec and one block of 48 trials with each of the remaining three stimulus durations (a total of 240 trials). The order of the blocks was randomised. Prior to the experimental trials there was a short practice session consisting of 12 trials with stimulus durations of 150 msec.

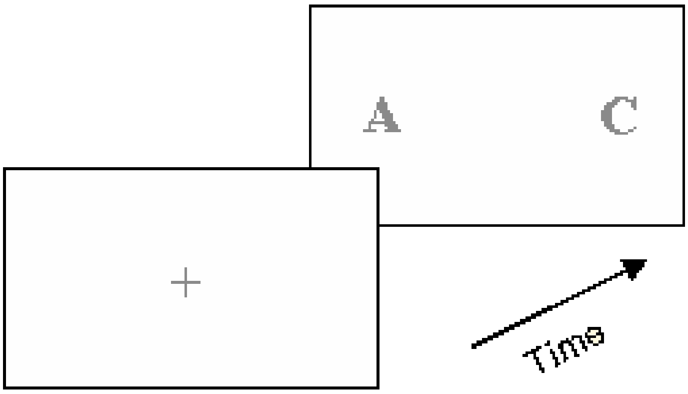

Figure 4.2.2: *A schematic representation of an experimental trial. In each trial, a central fixation cross appeared on the screen, followed after 150ms by a stimulus event (in this example stimuli appear in both left and right visual fields).*

Procedure

Eye movements were monitored by an assistant seated behind the computer screen. The patient was aware that his eye movements were being monitored, and he was instructed to re-fixate whenever an eye shift occurred. If fixation deviated from the centre of the screen that trial was excluded from the final analysis. Each trial began with the onset of the central fixation cross. There followed a blank interval of 150ms and then the stimulus display. The patient made verbal responses, reporting the letter on the left and the letter on the right of the screen and keyboard responses were made by the experimenter. A response of “A on the left and B on the right”, for example, would be entered by a second experimenter (the author) as ‘AB’; a response of “Nothing on the left and B on the right” would be entered as ‘0B’. The entry of each response initiated the next trial.

Results

Data are presented in Table 4.2.2.

Table 4.2.2: *Mean errors in single left and double trials*

Stimulus Duration	**% Errors Single Left Trials**	**% Left Errors in Double Trials**	**Error Trend**	**p-value**
150 msec	25%	50%	Extinction	ns
300 msec	13%	50%	Extinction	ns <.05 combined
450 msec	13%	38%	Extinction	ns
600 msec	13%	25%	Extinction	ns

There was a trend towards extinction, which failed to reach significance in any of the individual stimulus durations. However, when the three shorter stimulus durations were combined a significant pattern of extinction emerged (χ^2 (1) = 4.95, p = .026). Data are presented in Figure 4.2.3.

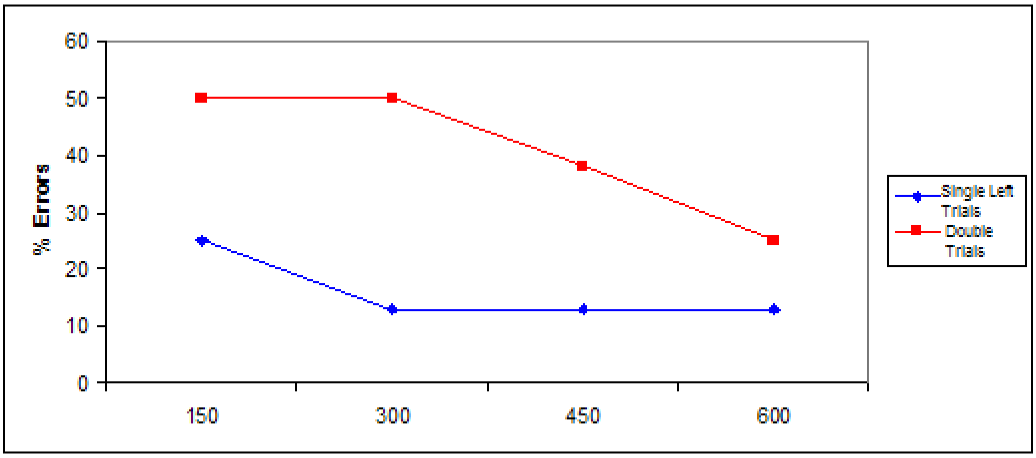

Figure 4.2.3: *The percentage of left errors made by CP in the identification task at stimulus durations of 150, 300, 450 and 600 msec.*

Discussion

CP showed clear anti-extinction in a simple detection task when exposures were brief, but performed at ceiling in longer stimulus durations trials. The anti-extinction pattern of errors found at 100 msec in the detection task can be explained by the suggestion made earlier in relation to healthy individuals, which is that attention was initially focused in ipsilesional space awaiting a stimulus event. If one appeared then it was processed and attention was free to be shifted to contralesional space. If no ipsilesional stimulus appeared, then attention remained in the ipsilesional field awaiting a stimulus, only to be shifted to contralesional space too late for a brief contralesional event to be detected. When an identification task was performed, probably requiring more top-down processes, he showed a trend towards extinction at all stimulus durations which, when the three shorter durations were combined, did reach significance.

Interestingly, Figure 4.2.3 shows that leftward errors in double trials decreased as exposure durations increased, whilst errors in single left trials, despite being low, remained constant. It might be that, had there been longer exposure durations, the anticipated switch from extinction to anti-extinction could have occurred, resulting in a crossover of the data lines in Figure 4.2.3. It was, unfortunately, not possible to retest CP to explore this possibility.

CP’s performance seems in line with Goodrich and Ward’s account of their patient VH, who showed anti-extinction on both detection and identification tasks; however it is clearly in contrast with Humphreys et al.’s patient GK, whose performance with bilateral stimuli worsen while exposure of stimuli increased.

In order to explore further the responses of the three patients identified as showing extinction in the simple detection task, the same identification task used with CP was undertaken.

4.4 Experiment 6

Introduction

Experiments 5A and B tested a patient who had shown anti-extinction on the initial detection task and a trend towards extinction on the identification task. Crucially, his error pattern was not seen to change from extinction to anti-extinction with longer exposure durations on the identification task. However, data suggested that this may have been the case if there had been trials with durations longer than 600msec.With this in mind, the current experiment sought to explore with a similar task the error patterns of three patients who had shown extinction on initial tests, but the range of stimulus durations was broadened to include briefer (75 msec) and longer (750 msec and 900 msec) durations.

Method

Participants

Patients HH, WW and JJ took part in Experiment 6; their clinical and demographic details are reported in Table 4.1.1, and reconstructions of their brain lesions have been also added in Figure 4.3.1. All three patients showed evidence of visual extinction on previous extinction tasks (see Experiment 4). Additional data from prior assessments on a number of tests are reported below:

HH performed well on the Mini Mental State Exam (MMSE) obtaining 30 out of 30. She showed evidence of neglect on the Bell Cancellation tests (omitting 5 left targets) and on the Copying task (missing the left side of 2 figures).

WW performed well on the MMSE obtaining 28 out of 30. He showed only very mild neglect on the Bell Cancellation test (omitting 5 left and 2 right targets) and mild neglect on the Copying task for one figure.

JJ showed neglect on the Star Cancellation test (omitting 26 left targets and 9 right targets) and on copying of all 3 figures.

Stimuli

Identification task: The apparatus and viewing conditions were identical to those reported for the previous test used with CP; however, as in Humphreys et al.'s (2002) study, stimulus duration ranged from 75 msec to 900 msec with seven durations in total (75, 150, 300, 450, 600, 750 and 900 msec) and with the different stimulus durations presented in separate trial blocks. Also in line with Humphreys et al.'s (2002) study, there were more trials displayed for the 150 msec duration than for the other six stimulus durations: there were two blocks of 48 trials (24 bilateral, 12 unilateral left; 12 unilateral right trials) with stimulus durations of 150 msec and one block of 48 trials with each of the remaining six stimulus durations, giving a total of 384 stimuli. The order of the resulting 8 blocks was randomised. Prior to the experimental trials there was a short practice session consisting of 12 trials with stimulus durations of 150 msec.

Procedure

Patients made verbal responses (for example, “A on the left and C on the right”). The entry, by the examiner, of each response initiated the next trial.

Results

All three patients performed at ceiling or close to ceiling in identification of right visual stimuli on unilateral (error rate ranging from 0 to 3% for all patients) and bilateral trials (error rate ranging from 0 to 8% for HH and WW, and from 0% to 25% for JJ), whereas identification of left visual stimuli on unilateral and bilateral trials was poorer (Table 4.3.1). The vast majority of errors consisted of errors of omission. Individual Fisher’s exact tests analyses were carried out for each patient and each duration on identification error rates for left stimuli on unilateral trials (‘left unilateral’) and bilateral trials (‘left bilateral’). Results from all three patients are reported in Figure 4.3.1.

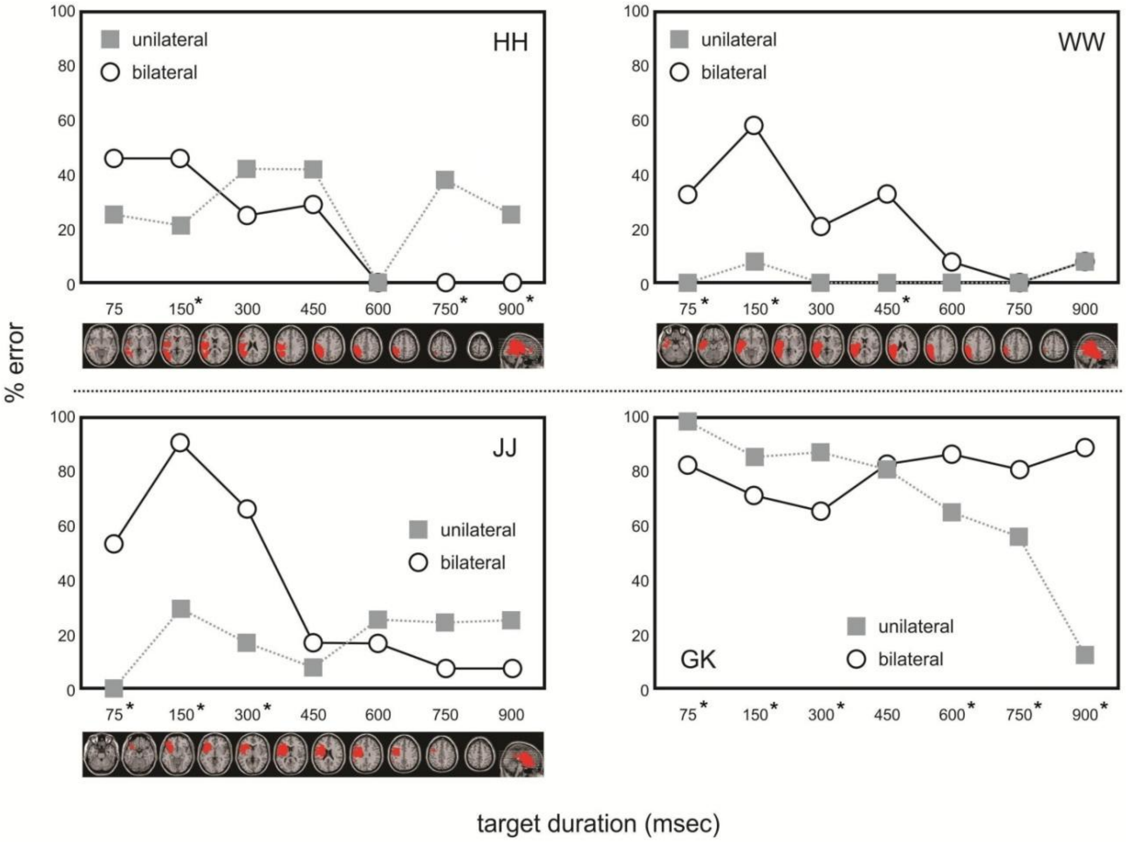

Figure 4.3.1: *Errors (%) of HH, WW and JJ and GK (Humphreys et al., 2002) on unilateral and bilateral trials; CT scans of HH, WW and JJ. [From Watling et al., in press)*

Patient HH showed extinction at shorter stimulus durations, reaching significance on a Fisher’s exact test at 150 msec (p <.05) and anti-extinction for stimulus durations of 300 msec and longer (with the exception of 600 msec; Figure 4.3.1). At 750 msec and 900 msec this pattern of anti-extinction reached significance (p < .005 and p< .05, respectively).

The changeover from extinction at short exposure durations to anti-extinction at longer durations appears to have been driven by a decrease in left bilateral identification errors with increasing exposure duration, whereas performance on unilateral left trials remained relatively constant across all durations (Figure 4.3.1).

Indeed, Spearman's correlations between duration of stimuli and error rate indicated a significant negative correlation for bilateral stimuli (r = -.917; p <.005), but only a weak, non-significant, correlation with unilateral stimuli (r = .018; p= .919; ns).

Patient WW's identification of left stimuli was close to ceiling for unilateral left trials, therefore a changeover from extinction to anti-extinction could not be observed even though the patient's identification of left stimuli in in bilateral trials improved with longer stimulus durations (Figure 4.3.1). In bilateral trials, he showed a significant pattern of extinction for shorter stimulus durations (reaching significance on a Fisher's exact test at 75, 150 and 450 msec), while no extinction was found with stimulus durations longer than 600 msec. Spearman's correlations between duration of stimuli and error rate with bilateral stimuli indicated a significant negative correlation (r = -.818; p<.05).

Patient JJ showed a very similar pattern to that of HH. Indeed, JJ showed extinction with shorter stimulus durations and anti-extinction with longer stimulus durations (Figure 4.3.1). JJ's error rate for identification of left stimuli on bilateral and unilateral trials was significantly different on a Fisher's exact test different at 75, 150 and 300 msec, showing clear evidence of extinction for these stimulus durations. For stimulus durations of 600 msec and greater, he performed better with bilateral than unilateral displays. Despite the fact that differences between single and bilateral trials did not reach significance for any individual longer stimulus duration, a difference approaching significance was found when longer (i.e., 600, 750 and 900 msec) exposures durations were considered together ($\chi^2 = 3.491$; 2-tailed p=.062).

As was the case for HH, increasing the stimulus duration mainly reduced JJ's error rate for the left bilateral condition, whereas it had a negligible effect on left unilateral trials. In other words, the trend for a change from extinction to anti-extinction was mainly due to an improvement of performance in bilateral trials. Indeed, Spearman's correlations between stimulus duration and error rate indicated a significant negative correlation for bilateral trials (r = -.873; p <.01) and a weak, non-significant, correlation for unilateral trials (r = .371; p = .413; ns).

Discussion

All three patients showed an extinction pattern of errors at shorter exposure durations and two patients (HH and JJ) also showed an anti-extinction pattern for longer exposure durations. For all three patients, performance on bilateral trials showed significant improvement as exposure duration increased (Figure 4.3.1).

In contrast with Goodrich and Ward's (1997) prediction, these patients showed both extinction and anti-extinction when the same task was required. The current findings suggest that anti-extinction may not be as rare a phenomenon as previously thought when temporal-exposure duration is taken into account. Indeed, like Humphreys and colleagues' (2002) patient GK, patients JJ and HH showed both extinction and anti-extinction depending on exposure duration. Humphreys and colleagues (2002) suggested that binding occurs when stimuli have common onsets, but that this binding effect is transient and only enhances performance for briefly presented stimuli. When stimuli remain in the field for longer durations the authors suggested that there is a decay in the tag that binds the stimuli, resulting in poorer performance. Within this theoretical framework, one would predict that anti-extinction should occur with brief stimulus durations, whereas extinction should occur at longer durations. However, two patients (JJ and HH) reported here showed better performance in detecting contralesional stimuli on bilateral trials when the stimulus duration was longer, and all three patients showed extinction (not anti-extinction) for shorter durations.

Thus, a novel ‘attentional waiting’ hypothesis is suggested. Due to brain damage, patients’ spatial bias dictated that attention was mainly drawn to the ipsilesional side. Despite this bias, on a proportion of unilateral trials the contralesional stimuli were able to capture sufficient attentional resources to be identified; on the remaining trials, however, attention waited indefinitely on the unilateral side. Therefore, longer duration of the contralesional stimulus should not have a great impact on patients’ performance on unilateral trials but only on bilateral trials. Indeed, on bilateral trials with longer exposure durations, the prompt identification of the ipsilesional stimulus allowed attention to shift to the contralesional side in time to permit the identification of the contralesional target before it disappeared. Taking all these considerations into account, patients’ performance expressed itself as better identification of contralesional stimuli on bilateral than unilateral trials, that is anti-extinction, but only for longer durations.

According to the ‘attentional waiting’ hypothesis, anti-extinction would, however, be replaced with extinction when shorter exposure durations are used. In such cases, there would be insufficient time before stimuli are removed to disengage from an ipsilesional stimulus and shift attention towards a contralesional target. Consistent with the notion of attention being firmly rooted in ipsilesional space and the difficulty in releasing attention from ipsilesional space, Karnath (1988) reported that contralesional errors in extinction patients are reduced when there is a requirement to report the contralesional item first, or to report only the contralesional item.

Additionally, according to the ‘attentional waiting’ hypothesis, exposure duration should exert a strong effect on bilateral trials but have much less, if any, effect on correct detection of contralesional unilateral trials. Interestingly, careful inspection of HH’s and JJ’s error rates showed just this. In contrast, Humphreys et al.’s patient GK showed the opposite pattern, with a stronger beneficial effect of stimulus duration for contralesional unilateral trials than for bilateral trials (Figure 4.3.1). Indeed, analysing GK's data for the current study, a strongly significant correlation (Spearman’s correlation) was found between duration of stimuli and errors in contralesional unilateral trials ($r = -.964$; $p < .001$), whereas the correlation between duration of stimuli and bilateral trials was very weak ($r = .571$; $p = .180$; ns). Considering data from the patients reported here and from GK, it is suggested that different mechanisms underlie the anti-extinction in the patients reported here and GK’s anti-extinction. HH, WW and JJ mainly showed a rightward attentional bias (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005), whereas GK is known to be simultanagnosic (Boutsen & Humphreys, 1999). It is therefore likely that while GK might eventually, with increasing exposure duration, have been able to shift his attention from an empty location, he would have remained engaged on an occupied location. As a result, for GK longer exposure durations would result in better performance for single stimuli but would have little effect on bilateral presentations where one stimulus would monopolise attention. Therefore, while different patients may show a better performance in processing contralesional stimuli when displayed simultaneously with an ipsilesional one, the underlying causes may be very different and may lead to further fractionation of anti-extinction in different phenomena. A novel ‘attentional waiting’ hypothesis is proposed, which implies a main underlying rightward bias in spatial processing and we propose that anti-extinction with longer exposure durations may be observed in larger proportion of patients showing extinction if duration of stimuli is increased.

4.5 Summary and General Discussion

Of the nine patients initially tested, three showed extinction and one showed anti-extinction on a preliminary detection task. A further two patients showed evidence of anti-extinction on identification tasks. Experiments with clinical population suggest that visual attention may be distributed across the visual field in quite different ways depending on the type of task and underlying cognitive processes required. A novel hypothesis, the ‘attentional waiting’ hypothesis has been proposed to explain occurrence of extinction and anti-extinction. The hypothesis proposes that because of the shift of attention towards ipsilesional space in brain damaged patients, a stimulus in the right visual field is awaited and attention remains rooted there until the appearance of one. Despite the fact that the contralesional target may be able to still capture sufficient attentional resources to be identified occasionally, in most cases attention waits indefinitely on the unilateral side if no stimulus appears. Therefore, longer duration of the contralesional stimulus should not affect patients’ performance on unilateral trials but only on bilateral trials. Indeed, on bilateral trials with longer exposure durations, the appearance of an ipsilesional stimulus allows attention to shift to the contralesional side in time to permit the identification of the contralesional target before it disappears. Thus, in the study reported herein, anti-extinction (better identification of contralesional stimuli on bilateral than unilateral trials) was observed, but only for longer durations. According to the ‘attentional waiting’ hypothesis, anti-extinction would be replaced with extinction in shorter exposure durations. In bilateral displays with short exposure durations, there would not be enough time to disengage attention from an ipsilesional stimulus and shift attention towards a contralesional one.

Finally, it seems that anti-extinction may be a less rare phenomenon than thought; indeed it may well have escaped report by a large number of researchers due to an assumption that if performance on single contralesional stimuli is poor, it would necessarily follow that performance on double simultaneous stimuli would be poorer still.

Chapter 5

Summary, conclusions and suggestions for future research

5.1 Summary and conclusions

Many theories of attention (e.g. Broadbent, 1958; Duncan, 1980; Treisman, 1969, Desimone & Duncan, 1995) share the assumption that the myriad of visual stimuli that surround us compete for perceptual attention in a limited capacity cognitive system. As a result of this competition the winning stimuli are processed and the losing items fail to reach conscious awareness. The competitive nature of this process is aptly demonstrated in the neurological condition of visual extinction. This thesis has focused on the competitive nature of visual stimuli and its effects on early visual processing. In recreating in healthy volunteers an extinction-like pattern of errors similar to that observed in patients who show extinction and anti-extinction some insights have been gained into the conditions that mediate these error patterns.

The experiments reported in the present thesis fall into three categories: Chapter 2 reports three experiments that simulated extinction in healthy volunteers using a bottom-up, stimulus driven paradigm. Of these, the first two experiments employed a simple detection task and the third a more demanding identification task. The experiment reported in Chapter 3 employed a top-down, cueing paradigm using an identification task and Chapter 4 reports findings with extinction patients. The fact that extinction can reliably be simulated by manipulation of stimulus events provides support for the notion of the competitive aspect of visual processing in healthy individuals, indeed it has been suggested that extinction is simply an exaggerated form of a normal attentional limitation (de Haan & Rorden, 2004; Ptak & Schnider, 2005). Whilst extinction has been temporarily induced in healthy volunteers with transcranial magnetic stimulation (e.g. Pascual-Leone et al., 1994), only a few papers have attempted to investigate this phenomenon in healthy volunteers (e.g. Gorea & Sagi, 2002).

In Chapter 2 it was found that, in experiments where participants simply had to *detect* the presence of a stimulus, extinction-like errors ensue when the two stimuli in bilateral presentation differ in luminance, the brighter one extinguishing its less bright counterpart resulting in more errors in bilateral than in unilateral displays. Moreover, despite several attempts to uncover any possible bias towards one or other visual field none was found. However, when the task was a more demanding one of *identification*, an interesting pattern of anti-extinction emerged. This apparent advantage in reporting a weaker stimulus when it appeared in a bilateral display with a stronger item rather than when it appeared alone directly opposes what might be expected in extinction.

The qualitative different performance observed following identification and detection tasks may be debatable as it cannot be excluded that these two tasks may be at the extreme of one attentional *continuum*, where different types of responses may be recorded depending on various aspects of the task. For example, Goodrich and Ward (1997) observed anti-extinction also in detection tasks, whereas patient CP reported in this thesis, showed anti-extinction on detection tasks where duration of stimuli was higher than those in the identification tasks. Finally, Humphreys et al.'s (2002) patient GK showed both extinction and anti-extinction by means of identification tasks and this patient's pattern of data were more easily explained in terms of binding process and associated simultagnosia. It seems therefore difficult to reconcile all observations of extinction and anti-extinction in the literature to the same explanation and to a parallel with a distinction between detection and identification. However, it must be considered that identification requires retrieval of semantic information of stimuli, and identification of stimuli may indeed rely more on top-down mechanisms than does detection. With this in mind, Experiment 4 (Chapter 3) was designed to test whether a pattern of extinction or one of anti-extinction would be observed in healthy volunteers in an experiment which employed a cueing paradigm, and which presented the same stimuli used in Experiment 3 (shapes that had to be identified). Again, a pattern of anti-extinction was observed, in which detection of an invalidly cued stimulus was more likely when it appeared simultaneously with a validly cued one than when it appeared alone.

Scrutiny of the literature revealed that this pattern had been found in two patients with right hemisphere damage and reported in two articles (Goodrich & Ward, 1997; Humphreys et al., 2002, see also Riddoch, Rappaport & Humphreys, 2009 for a review). These authors suggested that anti-extinction is either triggered by similar task demands (Goodrich & Ward, 1997) or by temporal binding between pairs of stimuli over a short period of time, but not with more prolonged stimulus durations (Humphreys et al., 2002). Goodrich and Ward’s interpretation may account for the healthy volunteers’ extinction and anti-extinction pattern of errors; indeed, extinction-like responses were found with detection task whereas anti-extinction pattern was found with identification task. However, the type of task was the same within the same experiment and for both stimuli. Alternatively, a novel ‘waiting’ hypothesis, could be considered (Watling, Danckert, Linnell & Cocchini., in press). It suggests that when a stimulus appears in the cued location, attention is directed to it and then immediately transferred to the opposite field where a simultaneous item can be processed. If, however, no stimulus appears in the cued space, then attentional resources remain there for longer and disengage to the opposite field too late for a brief stimulus to be attended. Some supporting evidence can be found in a series of studies on temporal order judgments (TOJs; e.g., Stelmach & Herdman, 1991). These studies show that stimuli are perceived as simultaneous if the unattended stimulus precedes the attended one by up to 40 msec in healthy volunteers. Similar effects have been found in brain damaged patients, who tend to perceive ipsilesional stimuli as preceding the contralesional ones by up to 250 msec (Rorden, Mattingley, Karnath & Driver, 1997; Geeraerts, Lafosse, Vandenbussche & Verfaillie, 2010).

In order to explore this phenomenon further, Chapter 4 reports two experiments (Experiments 5a and b and 6) with patients who have right hemisphere damage and have shown clinical evidence of neglect and extinction, thus their attention was drawn towards stronger targets due to a cognitive deficit, rather than an external cue. In Experiment 6 two of them, JJ and HH, are reported to have shown better performance in detecting contralesional stimuli in double trials when stimulus duration was longer. Despite a clear role of exposure of stimuli, these finding are in clear contrast with Humphreys et al.'s temporal binding hypothesis with the opposite pattern of performance. Following the 'waiting' hypothesis previously proposed to account for healthy volunteers' pattern of data, a similar account could explain anti-extinction in patients HH and JJ. When stimulus duration was brief there was insufficient time on bilateral trials to disengage attention from the ipsilesional stimulus and shift it towards the contralesional one, but when stimuli remained in view for longer, attention was freed to shift to the contralesional field in time to process a second stimulus. This interpretation is particularly interesting if one considers that previous studies have reported that patients tend to perceive contralesional stimuli much later than ipsilesional stimuli (as in TOJ studies) and that difficulty in disengagement of attention from ipsilesional stimuli has also been reported (e.g. Karnath, 1988). But how can this explanation account also for extinction with brief stimulus durations and within the same task? It is possible that, despite the bias towards the ipsilesional side dictated by the brain lesion, in a proportion of unilateral trials, the single contralesional stimuli were still able to capture sufficient attentional resources to be identified. On remaining trials, however, attention waited for an indefinite time on the ipsilesional side. Longer duration of the contralesional stimulus did have no great impact on patients' performance on unilateral trials but only on bilateral trials. Indeed, on bilateral trials with longer exposure durations, the prompt identification of the ipsilesional stimulus allowed attention to shift to the contralesional side in time to permit the identification of the contralesional target before it disappeared. Taking all these considerations into account, patients' performance expressed itself as better identification of contralesional stimuli on bilateral than unilateral trials, that is anti-extinction, but only for longer durations (Watling et al., 2013).

5.2 Future Directions

The experimental work in this thesis successfully addressed a number of issues relating to attentional competition, extinction and anti-extinction. Moreover, several interesting questions for future research have arisen from the results herein.

Firstly, it would seem reasonable to conclude that anti-extinction is more prevalent than is currently reported in the literature. As an attentional phenomenon that seems to be determined by stimulus properties, much can be learned from patients who show anti-extinction and further research would be of interest. Three conflicting accounts have now been proposed to account for the particular pattern of errors which, at first sight, seems at odds with the notion that multiple stimuli compete for attention in a limited capacity system. Goodrich and Ward (1997) suggested that task demands play a role in extinction and anti-extinction; their patient showed anti-extinction on tasks of simple detection and in identification tasks, but not when required to identify stimuli in one field and to detect stimuli in the other. They suggest that a priming effect is triggered by a task-specific response mechanism, which results in the processing of a contralesional stimulus and that, if a patient showing extinction were to carry out a task requiring both detection and identification, the extinction pattern of errors would become more pronounced. It seems not to be the case that there are some patients who show extinction and others who show anti-extinction, but that patients with right hemisphere damage may well show both patterns of errors in different tasks, and it would be interesting to test Goodrich and Ward’s interpretation with more patients. Certainly there is evidence in the literature to suggest that tasks of simple detection and those requiring identification elicit different responses because they place different levels of demand on the cognitive system. Kanwisher’s token individuation hypothesis (Kanwisher, 1987; 1991) accounted for the phenomenon of repetition blindness (the inability to report the identity of a visual stimulus that is repeated shortly after an earlier presentation of the same stimulus) by making a distinction between type recognition (recognition of a single property such as colour) and token individuation (assigning an identity); type recognition is less cognitively demanding and therefore possible under conditions of rapid serial visual presentation, whereas token individuation is not. Baylis, Driver and Rafal (1993) used the token individuation hypothesis to explain the finding that stimulus similarity leads to increased extinction in identification tasks (Baylis et al, 1993; Vuilleumier & Rafal, 1999; 2000), but not in detection tasks (Gilchrist, Humphreys & Riddoch, 1996; Humphreys, 1998; Pavlovskaya et al., 1997; Ward et al., 1994). Moreover, the current study found differences in performance of patients in these two types of tasks, with patient CP, for example, showing anti-extinction in a detection task on brief stimulus exposure, and a trend towards extinction in a detection task in all exposure durations. There is therefore much evidence to suggest that manipulation of task demands and exposure durations influence competition between stimuli and many further studies with patients could be undertaken to explore the interplay between these factors.

The visual confrontation test (Bender & Teuber, 1946) is still commonly reported as a tool for the assessment of extinction. The findings in Experiment 5 suggest that this task is less effective in assessing visual extinction than a computerised detection task. Both tasks were administered to nine patients and, whilst four patients did not show extinction in either task, the visual confrontation task failed to detect extinction in one patient and, importantly in the context of the current findings, also failed to detect anti-extinction in a second patient; the error patterns became apparent in the more sensitive computerised detection task. It is acknowledged that the sample of patients was small and a larger scale study would be essential in determining the usefulness of both tests and possibly in designing an improved version of the computerised test that could be more widely used with, or instead of, the visual confrontation test. This may lead to a better understanding of the actual incidence of anti-extinction in right hemisphere damage patients which, in turn, could lead to new interpretations of attentional processes.

Finally, future studies may address the ‘waiting’ hypothesis by means of asynchronous presentation of bilateral stimuli to closely monitor the relationship between attention shift and duration of stimuli.

The work in this thesis has shown that it is possible to create a reliable pattern of extinction errors in healthy participants by creating an imbalance of strength between the stimuli in both visual fields, either by bottom-up or top-down processes. When the complexity of task demands, and duration of stimuli, is increased from detection to identification, a pattern of anti-extinction can be seen. Anti-extinction was also observed in brain damaged patients and a novel ‘attentional waiting hypothesis’ was proposed to account for these findings. Despite extensive progress in understanding the mechanisms that underlie extinction and related attentional disorders, much still remains to be learned about the processes of attentional competition and selection. It is hoped that the work in this thesis has added to the evolving body of knowledge in the area and that it has also raised some interesting possibilities for future research.

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