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Hemispheric Processing in Object-Based Selective Attention

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Dedication

This dissertation is dedicated to my father, Dr. Arun Valsangkar, for instilling in me the belief that knowledge and education are the most prized of possessions.

Abstract

The present series of experiments investigates hemispheric processing during selective attention to objects. We found that normal subjects performed with higher accuracy when only one target object was presented as compared to when two target objects were presented (2-object cost). As well, subjects performed better when the two target objects were divided between the visual fields, 2-bilateral condition, rather than both being presented in the same visual field, 2-unilateral condition (2-bilateral advantage). This suggested that both hemispheres were capable of selectively attending to objects. These findings remained consistent despite changes in stimuli, stimulus spacing, and response task. With respect to lateralization in normal subjects, two meta-analyses revealed an overall right hemisphere advantage driven largely by the poor performance of the left hemisphere in the 2-unilateral condition, in which the same hemisphere is required to process both objects. This indicates that while both hemispheres are able to selectively attend to objects, the right hemisphere might actually be better at the task. Finally, a split-brain subject was also tested on the same object identification task, and again there was an overall right hemisphere advantage. In the 2-bilateral condition, it appears that there is actually competition or gating between the hemispheres. When rectangles were presented, the right hemisphere wins this competition and inhibits the processing of the left hemisphere. However, when letters were presented, the hemispheres seem to be more evenly matched in their processing abilities. Overall these studies indicate that while both hemispheres are capable of selectively attending to objects, it is the right hemisphere that has an advantage for this type of processing, contrary to the findings of previous research.

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First and foremost I would like to thank my co-supervisors, Dr. Michael Dawson and Dr. Alan Kingstone, without whose support and encouragement I would not be finishing my degree. I was also very lucky to be part of two wonderful labs and I would like to thank all members (past and present) of the BCP and Kingstone labs, other graduate students and old friends for enduring the journey with me. Especially important was my officemate, Leanne Willson, as she gave me many moments of courage and joy. My parents, who have always believed in me, deserve special recognition. My father is an excellent example of both a scholar and a teacher. Last but certainly not least, I would like to thank Smytty, for everything.

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Chapter 1: Hemispheric Processing and Attention

One of the central themes in psychological, particularly cognitive neuroscience research has been that of modularity. Fodor (1983) is a strong proponent of a modular theory of cognition and argues that certain psychological processes are self-contained--or modular. According to this modular theory, cognition is based upon many separate multiple systems that are each responsible for different functions, rather than having one system that serves many functions. The existence of modularity in cognition has been hotly debated and while there has been evidence for modular units of cognition, some continue to argue that all psychological processes are highly interconnected (for one particular debate see Farah, 1994; Diedrich, 1994; Glymour, 1994). If in fact there are specialized devices for cognitive functions, modularity will reveal itself in two ways. First, there must be a description of functions so that a general cognitive phenomenon, for example attention, could be broken down into a number of component functions. Second, modularity will reveal itself with claims of localization of functions to specific areas of brain. While much has been learned about the nature of different functions within cognition, including attention, and their various components, there is still not a clear picture of where many of these functions are localized in the brain (assuming that they are localizable.

For example, within the study of attention, one important distinction can be made between space-based and object-based attentional systems. In space-based attention, attention is allocated to locations in space independent of the items that occupy those locations; while in object-based attention, attention is focused on specific objects independent of their spatial positions. For example, if a stimulus such as a square was presented in the center of a computer screen, one could focus attention to that area of the screen (space-based attention) or focus on a particular dimension of the stimulus, such as its shape (object-based attention). Given these different processing abilities, each of these systems may also be subserved by separate underlying neural mechanisms.

This dissertation will explore one module within attention, object-based attention, with a particular emphasis on localizing this function to particular areas of the brain (i.e. hemispheric lateralization). It will begin by examining functional modularity of attention, or the numerous ways of subclassifying attentional phenomenon. Then modularity of attention will be considered at an anatomical level. It will be obvious that while there is substantial evidence for functional modularity in attention for an object-based system, questions remain as to how it is organized and localized within the brain.

What is attention?

Attention can be thought of as not simply one function, but rather a set of different brain processes that are important for perceptual, cognitive, and motor skills (Parasuraman, 1998). One way of subdividing these processes is by approaching attention as having three major functions: selection, vigilance and control. The focus of most of the literature to date has been on the selection process (e.g. Cherry, 1953; Broadbent, 1954; Treisman, 1960; Deutsch & Deutsch, 1963; Treisman & Gelade, 1980). It can be described as our ability to select, from a number of incoming stimuli, what to attend to, and then respond accordingly. Selection is necessary if one views the mind as a limited capacity information processing system. If all the stimuli we encounter daily were fully processed, our attentional system would quickly become overloaded. Therefore, there must be some way of only focusing on or attending to the important or relevant stimuli, and filtering out the residual information.

Functional Modularity of Attention

Overt vs. Covert Orienting of Attention

Within selective attention, there can be various ways in which we process information. One of the most basic distinctions can be made between different ways of orienting attention. We can orient our attention either overtly (with eye movements) or covertly (without eye movements). Typically, when we orient our attention, our eyes move and fixate on an object. This places the object on the fovea, which results in better resolution and therefore more information about the object can be acquired. This type of overt orienting is closely related to the saccadic eye system and its underlying neural mechanisms, including the frontal eye fields, supplementary eye fields, superior colliculus, pontine reticular formation and the mesencephalic reticular formation (Golberg, Eggers & Gouras, 1991).

We are also able to orient our attention without any eye movements, and these covert shifts of attention appear to function as a way of guiding the eyes to important areas in the visual field. Therefore there may be a shift in attention well before our eyes actually move. Posner (1995) has proposed a covert attentional system that processes information through networks of anatomical areas distributed throughout the brain. Though the entire attentional system has not been specified, there is considerable evidence for two important functions; orienting to stimuli and detecting target events.

Covert shifts of attention can be divided into three separate operations: 1) disengagement of attention from its current focus, 2) moving attention to the target, and 3) engagement of the target (Posner, Walker, Friedrich, & Rafal, 1984). Each of these operations is associated with a different brain region that has been determined by electrophysiological recordings, as well as the study of individuals with brain injury.

Posner, Walker, Friedrich, and Rafal (1984, 1987) tested patients with lesions of the parietal cortex to investigate the disengage operation. Their task was to maintain central fixation and press a button when the onset of a light was detected in either the left or right visual field. Prior to target onset a peripheral box was brightened in the left or right field, indicating where the target was likely to appear. Reaction times were faster when a target appeared in the cued field versus the uncued field. However, reaction times were extremely slow if patients were cued to expect a target in the ipsilesional field (the field on the same side as their lesion) and the target appeared in the uncued contralesional field (the field opposite their lesion). Therefore, Posner and colleagues concluded that parietal damage does not produce a difficulty in directing covert attention to the contralesional field, but it does produce an extreme difficulty in disengaging attention from the ipsilesional field. This difficulty has been coined the "disengage deficit".

Additionally, Rafal and Posner (1987) found that patients with unilateral thalamic lesions produced both ipsilesional and contralesional cueing effects that were very similar to the cueing effects found with parietal patients. The key difference between the two groups was that the thalamic patients had higher reaction times for all contralesional targets, indicating that these patients were having difficulty in engaging visual attention.

Finally, the move function has been examined in patients with progressive supranuclear palsy (PSP), a degenerative disorder affecting the nuclei in the midbrain, particularly the superior colliculus as it pertains to vertical eye movements. Rafal, Posner, Friedman, Inoff and Bernstein (1988) discovered that these patients were greatly impaired when required to covertly move their attention, especially for reflexive shifts of attention in the vertical plane. Parkinson's patients, who also have a degenerative disorder but do not have damage to the superior colliculus, do not show this vertical versus horizontal plane difference in covert orienting of attention. Therefore the superior colliculus has been implicated as critical for moving covert attention.

These findings suggest a specific anatomical circuitry for covert shifts of attention. The parietal lobe is responsible for disengaging attention, the thalamus for engaging attention onto a new target, and the midbrain for moving attention. These three brain regions work together in a network allowing us to covertly shift our attention.

Endogenous vs. Exogenous Orienting of Attention

A distinction can also be drawn between directing attention to an expected event (endogenous or voluntary orienting) and directing attention in response to an abrupt stimulus event (exogenous or reflexive orienting). For example, while you may be voluntarily attending to a specific word on a page, your attention would be reflexively grabbed if the phone happened to ring. In experimental paradigms, the typical way of producing these two different forms of orienting is by using predictive central cues for endogenous orienting and nonpredictive peripheral cues for exogenous orienting. When a central arrow points to where a target event is likely to occur, attention is oriented to the predicted location, and the orienting that results is considered voluntary. However if a peripheral box brightens, and attention is drawn to that box, even though the target is no more likely to occur there than at another location, the orienting is considered reflexive.

A number of basic differences between endogenous and exogenous orienting have been investigated, suggesting that exogenous orienting is more automatic and reflexive than endogenous orienting. For example, it is more rapid than endogenous orienting (Cheal & Lyon, 1991) and more resistant to interruption (Müller & Rabbitt, 1989).

The superior colliculus appears to be critical for reflexive shifts of both overt and covert attention. Neurophysiological evidence indicates that the superior colliculus receives direct projections from the retina and sends efferent projections to brainstem oculomotor centers. Moreover, a map of all possible saccade (or overt eye movements) vectors are represented in the superior colliculus, thus making it ideal to initiate rapid reflexive saccades toward peripheral events (see Wurtz & Munoz, 1995 for a review). With respect to covert shifts of attention, as mentioned in the previous section, Rafal, Posner, Friedman, Inoff and Bernstein (1988) discovered that PSP patients with damage to the superior colliculus were profoundly impaired at moving their attention covertly, especially for reflexive shifts of covert attention in the vertical plane.

Endogenous or voluntary shifts of overt attention, on the other hand, appear to be driven by dorsolateral prefrontal cortex. Patients with lesions to the dorsolateral prefrontal cortex, including the frontal eye field, have great difficulty executing voluntary saccades away from the onset of a peripheral target and instead makc reflexive saccades towards the target. (see Henik, Rafal & Rhodes, 1994).

Space and Object Based Attentional Systems

Two other modules in selective attention are the space-based and object-based attentional systems. As previously mentioned, the main difference between these systems lies in what we orient our attention towards: either specific locations in space or specific objects.

Some theories of selective attention are referred to as space-based, as they propose that attention is allocated to specific locations in space. Therefore attention can be thought of as a 'spotlight' or 'zoom lens', with stimuli that come into this spotlight receiving attention and therefore more elaborate processing (i.e. Erikson and Hoffman, 1973; Posner, 1980; Posner, Snyder & Davidson, 1980).

Posner and colleagues (Posner, 1980; Posner, Snyder & Davidson, 1980) conducted a series of experiments to investigate space-based selective attention. Their basic paradigm is illustrated in Figure 1. Subjects were instructed to fixate on a central box, flanked by two peripheral boxes on either side of the fixation box. The trial would begin with a brightening of one of the two peripheral boxes. A target would then appear in one of the three boxes and subjects had to respond to the target as quickly as possible by making a keyboard press. It was found that subjects were significantly faster to respond to the target when it appeared in a cued peripheral box rather than the uncued box, even though the cue was not indicative of where the target would appear. This facilitation suggested that attention had been allocated to the spatial location of the peripheral box and therefore subjects were faster to respond to targets that appeared in that location.

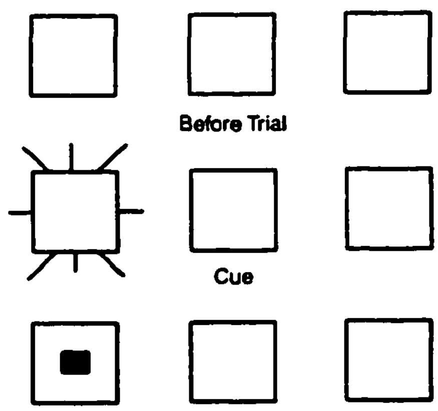

Figure 1: Posner Paradigm: Subject fixates at central box. A brightening of the outline of one peripheral box initiates a trial. A small but bright target appears in the center of one of the boxes to which a response is made.

Duncan (1984) showed that attention could also be focused on specific objects rather than on locations in space. The stimuli used in this experiment consisted if a box with a line superimposed across it. There were four dimensions that could vary in this experiment: box (size), box (gap), line (tilt) and line (texture) and for each display subjects had to judge one or two of these four properties. For example, box size and line tilt might remain constant and the subject would be required to indicate where the box gap was and whether the line going through it was dashed or dotted (Figure 2).

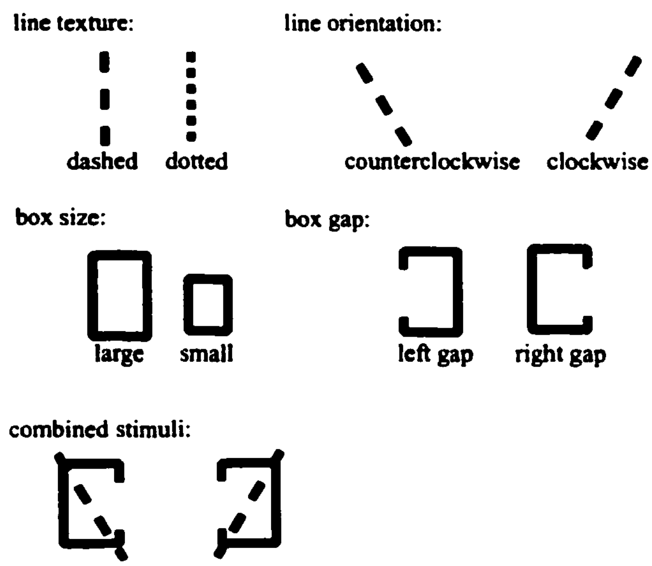

Figure 2: Duncan (1984) stimuli which consisted of a box with a superimposed line. The line varied in texture and orientation while the box varied in size and location of a gap.

These stimuli were thought to exclusively tap into object-based selection as they could be seen as two separate objects, but were found in the same location in space. Duncan found that when two judgments about the same object (line only or box only) were required, the subjects were more accurate (higher percent correct) than when two judgments about different objects (line and box) were required. This suggests a difficulty in simultaneously attending to two objects (2-object cost). A space-based theory of attention cannot explain why two judgments of two different objects should be more difficult than two judgments of one object when they share the same location in space, because both would be in the same spotlight of attention and therefore should be equally processed. The fact that there was a cost in attending to two objects at the same location demonstrated that selection could be object-based as well as space-based.

Since this study was published, other researchers have found this 2-object cost under different manipulations including using displays which could be seen as either consisting of one or two objects (Baylis & Driver, 1993), presenting objects in different hemifields (Vecera & Farah, 1994), or presenting two objects in the same hemifield (Enns & Kingstone, 1997).

All of this experimental data suggests that one of the many ways that attention can be broken down is into two separate systems devoted to either specific locations in space or specific objects. As this functional modularity has been well established, the subsequent issue concerns how and where these different functional modules might be represented in the brain.

Anatomical Modularity of Attention

Underlying Neural Mechanisms of Space-based and Object-based Attention

From the literature reviewed in the previous section, it is obvious that there are different attentional mechanisms that deal with either specific locations in space or specific objects. These attentional systems are likely to have separate underlying neural mechanisms, or in other words anatomical modularity. This principle of anatomical modularity is widespread throughout the brain. For example, there has been a great deal of anatomical and electrophysiological evidence that there are separate '<u>what</u>' and '<u>where</u>' pathways in the visual system (Ungerleider & Mishkin, 1982; Van Essen, Newsome &

Maunsell, 1985). Projections from striate cortex to extrastriate cortex in the monkey cerebral cortex can be subdivided into two 'functional' streams of processing. The ventral pathway leaves striate cortex and projects to the inferotemporal cortex and plays a special role in the identification of objects. The dorsal pathway goes from striate cortex to regions of the posterior parietal cortex and appears to be responsible for localizing objects in visual space.

These pathways were determined from lesion studies of the inferior temporal (IT) and posterior parietal (PP) cortex in monkeys. Performance on tasks requiring discrimination of visual object forms or patterns was impaired with IT lesions but this type of lesion did not affect tasks requiring visuospatial judgments. Conversely, object lesions of the PP cortex did not affect discrimination but these lesions did produce marked visuospatial deficits (Ungerleider & Mishkin, 1982).

This theory of separate visual processing streams has been expanded upon by Goodale and Milner (1992) who suggest that the two streams reflect not a difference in the processing of 'what' and 'where' but a distinction between perception and action. Specifically, they state that the difference lies in the requirements of the output systems that each stream of processing serves rather than any differences between the input stimuli. In their view the responsibility of the ventral stream is the perceptual identification of objects, while the dorsal stream is responsible for the sensorimotor transformations required for visually guided actions directed at those objects.

There is an interesting case study that seems to support this modified theory of visual processing. After suffering brain damage from carbon monoxide poisoning, a patient showed profound visual deficits but intact visuomotor abilities (Milner & Goodale, 1995). For example, she was unable to recognize faces or common objects and also unable to copy simple line drawings. However, when asked to grasp an object or open a door, she had no difficulties. The ventral (perception) stream of processing was obviously severely impaired by the brain damage while the dorsal (action) stream was left intact. It should be noted that these streams provide evidence that the brain does deal with object information and spatial information somewhat separately. However it does not speak to the issue of different types of processing in attention. Other work, including research with normal subjects, patient populations and neuroimaging techniques has attempted to address these issues within attention.

Deficits of Space and Object

As witnessed in the work Milner and Goodale, much can be gained by studying patients with specific neurological damage. In fact, historically patients have provided important insights into the brain mechanisms underlying cognitive abilities. For example, it has long been known that spatial and object deficits can occur independently of one another. Visual agnosias, or visual object recognition problems are more often seen after damage to the temporal lobes, while damage to the parietal lobes usually results in visuospatial problems (DeRenzi, 1982).

Neuropsychology provides us with many illustrations of space-based attention, including unilateral visual neglect and extinction (for a review see Rafal, 1994). Neglect typically occurs after damage to the posterior parietal lobe. This disorder results in patients failing to orient attention towards, and become aware of, objects and events in their contralesional visual field (i.e., the field that projects to the lesioned hemisphere). With severe lesions, patients fail to eat food on the contralesional side of the plate and are often unaware that half of their world is missing. The fact that the problem with these patients typically appears to be spatial in nature seems to indicate that there has been damage to attentional systems that are spatially based. A less severe deficit in patients known as extinction occurs when a signal is presented simultaneously to both the ipsilesional and contralesional fields. The contralesional signal, which would be detected on its own, is not detected when paired with the ipsilesional event (i.e. the contralesional signal is extinguished by the co-occurrence of the ipsilesional signal). Given these types of deficits, as well as the experimental data with normal subjects, there does appear to be a strong case for the existence of a specialized spatial attentional system.

There is a large amount of neuropsychological evidence for object-based systems as well (for review see Humphreys & Riddoch, 1993). For example, apperceptive agnosia is defined as any failure of object recognition in which basic visual functions are still preserved (i.e. acuity, color, or motion). This deficit usually occurs after bilateral damage to the lateral parts of the occipital lobe, including regions sending output to the ventral stream of processing. Another object-based deficit is known as associative agnosia. This is an inability to recognize objects despite an apparent perception of the object. These patients can copy a drawing but would still be unable to identify it. Associative agnosia is usually associated with damage to the regions in the ventral stream of processing (Kolb & Whishaw, 1996).

As well, patients suffering from neglect, primarily a spatial deficit, can sometimes ignore one-half of a specific object, i.e. half of a letter, even when that part of the object is presented to the ipsilesional field (Behrmann & Moscovitch, 1994). This is considered neglect in an object-based frame of reference and may hold insight as to how space-based and object-based attentional systems interact.

Finally, further evidence for specific object deficits can be found with patients who have Balint's syndrome, a disorder caused by bilateral lesions of the parietal lobe. One of their many deficits is that these patients are only able to see one object at a time, even if two or more objects in the same location in space overlap. For example, if shown a picture of a person's face that had glasses on, a Balint's patient might only be able to report seeing the face or the glasses; both of the objects could not be processed concurrently.

This object-based deficit is clearly evident in the Humpreys and Riddoch (1993) experiment in which patients with Balint's syndrome had to decide whether a number of circles were the same color. There could be black lines connecting circles of the same colour or different colours (forming dumbells), or the black lines could be randomly placed among the circles. Patients had difficulty with their decision when the circles were not connected and also when circles of the same color were connected. However, when the different colored circles were connected, patients improved significantly. This indicates that the fact that the circles were parts of an object (the dumbell) had an important effect on the patient's ability to make decision about the circles.

Therefore there is a great deal of experimental evidence with control subjects and patient populations which suggests that separate space and object attentional systems do exist and that they might be localized to different regions of the brain. As will be demonstrated in the following sections, one aspect of this localization may be systems that are lateralized asymmetrically across the two cerebral hemispheres.

Lateralization of Cognitive Abilities

From studies of both animals and humans, it has been determined that there are many anatomical and behavioural asymmetries between the left and right halves of the brain (for review see Hellige, 1993; Kolb & Whishaw, 1996). In fact, many cognitive functions can be broken down into various subcomponents that are actually distributed differently across the two hemispheres (Palmer & Tzeng, 1990).

One example of both a structural and behavioural hemispheric difference involves our language abilities. It has long been recognized that in most humans the left hemisphere is dominant for language functions (e.g. Broca, 1865; Wada & Rasmussen, 1960). A key brain area underlying our language abilities is the planum temporale, a region associated with Wernicke's speech area, which is significantly larger in the left hemisphere in both adults and human fetuses. This suggests that this anatomical asymmetry favours the left hemisphere in both the development of language functions as well as subsequent greater processing of verbal stimuli (Kandel, Schwartz, & Jessell, 1991). Another example of hemispheric specialization in attention is that the right hemisphere appears to be responsible for global visual processing (such as the overall shape of an object) while the left hemisphere is responsible for local visual processing (such as details of the object) (Ivry & Robertson, 1998). These, and other asymmetries such as those found in verbal versus nonverbal memory (e.g. Dee & Fontenot, 1973; Wingfield, Milstein & Blumberg, 1984), and the processing of faces (e.g.. Hellige, Corwin & Jonsson, 1984; Wirsen, Levander & Schalling, 1990; Nakamura et al., 1999), have led researchers to study the lateralization of the brain. That is, how the two hemispheres of the brain work together (or separately) in order to process information as efficiently as possible (e.g. Hellige, 1993; Gazzaniga, 1995; Kolb & Whishaw, 1996; Gazzaniga, 2000).

Split-Brain Patients

The lateralization of attention has been studied extensively in "split-brain" patients. These patients have had their corpus collosum surgically transected (cut) in order to control epileptic seizures. The corpus collosum is the largest commissure of the brain and connects the two cerebral hemispheres. Therefore after the transection, the two hemispheres of the brain are disconnected from each other, and stimuli and events that one hemisphere is aware of may be completely unknown to the other hemisphere. This separation of hemispheres allows researchers to study processing in a particular hemisphere without any interference from the other hemisphere.

A typical experiment with a split-brain patient involves the subject seated in front of a computer monitor. An object or a word (e.g., comb) would then appear briefly in either the right or left visual field of the monitor, and the subject would be asked to report what they saw. If the stimulus was presented to the right visual field (left hemisphere), this is not a problem and the subject says, "comb" because the left hemisphere is dominant for language production. When, however, the stimulus is presented to the left visual field (right hemisphere), the subject is unable to verbally report anything because the right hemisphere is unable to 'speak' and the left hemisphere has not 'seen' the stimulus. It is important to note that the right hemisphere still processes the stimulus, because if asked to identify that object by touch with their left hand, split brain patients are able to do the task. Another phenomenon seen with split-brain patients is the difference in control of their proximal versus distal muscles. While a disconnected hemisphere can control both arms it can only control the opposite hand. These are just a few of the many examples used to illustrate the 'disconnection syndrome' displayed by these patients (for a review see Gazzaniga, 1995). Again, these patients are an important resource for researchers investigating lateralized brain mechanisms, as they allow isolation of each hemisphere.

Lateralization of Attention

An important issue in the lateralization of attention is how our two hemispheres operate when one is attending to a stimulus. Using split-brain patients, Holtzmann, Wolpe & Gazzaniga (1984) examined whether the hemispheres have independent orienting systems. Posner's (1980) standard cueing paradigm was utilized, with two central arrow cues and a box on either side of the arrows. The arrows would point to the boxes, a number would then appear in one of the boxes and the subject had to indicate whether the number was an odd or even digit using a simple key press. There were four different types of trials included in this experiment. There was a focussed trial in which two arrows pointed to the valid box (where the target appeared), a divided trial in which the two arrows pointed in opposite directions, a neutral trial where X's replaced the arrows, and an invalid trial where the two arrows pointed to the wrong box. The researchers found that there were no significant differences in reaction times between the divided and neutral trials. This suggested that the conflicting arrows in the divided trials were interfering with the performance of both of the hemispheres. And as each hemisphere was receiving an opposite cue, there was no facilitation of response time for either hemisphere. If the hemispheres were completely independent, the conflicting arrows should not have "confused" the hemispheres and this would have resulted in the same reaction times for the focussed and divided trials. As this was not the case, the results of this study suggest that the two hemispheres are not completely independent. Therefore, Holtzmann et al. (1984) concluded from this result that split-brain patients do not have separate orienting systems that can be manipulated independently by each hemisphere, but that attention must be unifocal and the hemispheres must share an attentional pool or network.

Luck, Hillyard, Mangun & Gazzaniga (1989) propose a different view of hemispheric processing. They utilized a visual search task in which the items were rectangles made from red and blue squares. When the blue square was placed immediately above the red square, it was a distractor item and when the squares were reversed, with the red square on top, it was the target item. The stimuli were presented either unilaterally or bilaterally in sets of 2, 4, and 8. The subjects had to decide whether the target item was in the display and if so, in which visual field. With control subjects there were no significant differences between the slopes of the reaction time functions for the unilateral arrays as compared to the bilateral arrays. However with the split-brain patients, they found that the slope of the search function was twice as steep for unilateral arrays as for bilateral arrays, therefore the patients were faster when presented bilateral arrays. This seemed to indicate that each hemisphere was able to conduct an independent serial search.

Though this may be a reasonable explanation of the data, Enns and Kingstone (1997) replicated the Luck et al (1989) study using a larger set size as they felt that set sizes of 2, 4 and 8 were not sufficient for a true serial search, especially when presented bilaterally. Set sizes from 2 to 24 were tested with both intact subjects and a split-brain patient and it was found that in the larger display sizes there were no differences between the bilateral and unilateral displays (challenging the Luck et al. argument that the two hemispheres search independently. In intact subjects, there was an interaction between bilateral vs. unilateral displays and field of presentation, with the right hemisphere having an advantage a RT advantage, particularly for bilateral displays. This suggests that the hemispheres may actually be competing with each other when presented bilateral displays and for this task, the right hemisphere is dominant.

Kingstone, Enns, Mangun & Gazzaniga (1995) have also looked at hemispheric differences in attention but with a guided visual search task. This is different from a simple serial search task in that there is only a subset of items that share a target feature (i.e., colour). Therefore any items that do not share that feature can be automatically eliminated from the search, improving search efficiency. In this experiment, when a split-brain patient performed a guided visual search task (searching for a target black circle among distractor black squares, grey circles and grey squares), the reaction times for displays presented in the right visual field were much faster than for displays presented in the left visual field. This result can be interpreted as evidence that only the left hemisphere was able to take advantage of the strategy (searching only among the black items) while the right hemisphere continued to search through each item serially. This would suggest that the left hemisphere might be specialized for processing stimuli with specific shared features.

As there are so many contradictory results, especially with split-brain patients, Kingstone, Grabowecky, Mangun, Valsangkar & Gazzaniga (1997) have proposed that when disconnected, the two hemispheres may work differently depending on the type of orienting required. With exogenous (reflexive) orienting there may be independence between the left and right hemispheres and therefore they can work in parallel. With endogenous (voluntary) orienting the hemispheres may actually compete with each other, with a dominant hemisphere emerging that interferes or inhibits the performance of the non-dominant hemisphere. This theory might help to explain some of the conflicting results found for the two hemispheric roles in attention in relation to type of orienting and it also shows how they might work together to process information. There are two points to consider with this body of research. First, these results may be specific to split-brain patients and may not translate directly to intact processing of attention. Also this theory does not address how specific modules in attention, like an object-based attentional system, might be preferentially lateralized.

Lateralization of Space and Object Deficits

Many other patient groups have also been helpful in elucidating whether one hemisphere may have an advantage over the other for a specific attentional task. As mentioned previously, stroke patients with unilateral lesions often have problems orienting to, and being aware of, objects in their contralesional visual field. This phenomenon, known as neglect, typically occurs following lesions to the right parietal lobe. It is important to note that this deficit is not due to any type of blindness or visual system defect; it is specifically a deficit of attention. Again, even when these severe deficits resolve, subtle problems can be exposed under conditions of competing stimulation, as can be seen in the example of extinction, where the contralesional signal is extinguished by the co-occurrence of the ipsilesional signal. These deficits appear to be quite lateralized as both neglect and extinctions are more frequently observed and more severe with damage to the right hemisphere. Damage to the same area in the left hemisphere usually results in aphasia, a deficit in producing or comprehending speech. Therefore there appears to be a strong lateralization or advantage of the right hemisphere for spatial abilities.

There are different accounts for this asymmetry of deficits including one proposal that suggests the right parietal lobe is dominant for spatial attention and is able to orient attention to both the right and left visual fields, while the left parietal lobe is only able to orient attention to the right visual field (Posner, 1995). If this hypothesis is correct then damage to the left parietal lobe would not have as large an impact on attentional processes as would damage to the right parietal lobe. Support for this proposal has come from a PET study conducted by Corbetta, Miezin, Shulman and Petersen (1993). They found that the right parietal lobe is active when attention is shifted to either the right or the left visual field whereas the left parietal lobe was only active during shifts to the right visual field. These types of evidence point to the conclusion that the right hemisphere, specifically the right parietal lobe, does play an especially important role in spatial attention.

Work with Balint's syndrome patients has also added to our knowledge of lateralization in spatial attention. As mentioned earlier in this chapter, Balint's syndrome is a disorder characterized by bilateral damage to the occipito-parietal lobes. Its visuo-spatial deficits include a reduced ability to track moving objects, report the location of an object, or reach for an object; while its most striking object-based deficit is the inability to see more than one object at a time. Though Balint's syndrome is usually associated with bilateral damage, it is important to consider with respect to lateralization of attention since the bilateral damage to the parietal lobes results in visuo-spatial deficits that are much worse than those deficits that emerge with unilateral damage. If spatial attention was completely lateralized to the right hemisphere, as could be interpreted by the stroke patients' data, then the deficits should not be greater when there is also damage to the left hemisphere. The fact that the deficits are more severe with bilateral damage suggests that lateralization of these functions is not complete. Therefore even though the right hemisphere may be more dominant or active during attentional tasks, Balint's syndrome patients demonstrate that the left hemisphere must also play a role in spatial attention.

Lateralization of Space-based vs. Object-based Attentional Systems

As is evidenced in the preceding section, much of the research to date has focussed on the neural mechanisms and lateralization of function underlying spatial attention, and not as much research has been devoted to uncovering the neural mechanisms and lateralization of function underlying object attention. Therefore, while there is a relatively clear idea of the anatomical modularity of the space-based attentional system, many questions remain as to the underlying neural mechanisms of the object-based attentional system. Recently, however, investigators have tried to expand the knowledge of the anatomical modules in object-based attention. For example, a group of researchers has undertaken to distinguish the relationship between the hemispheres with respect to space-based and object-based attention. Egly, Driver and Rafal (1994a) measured both space and object components of covert attention in a single paradigm (Figure 3).

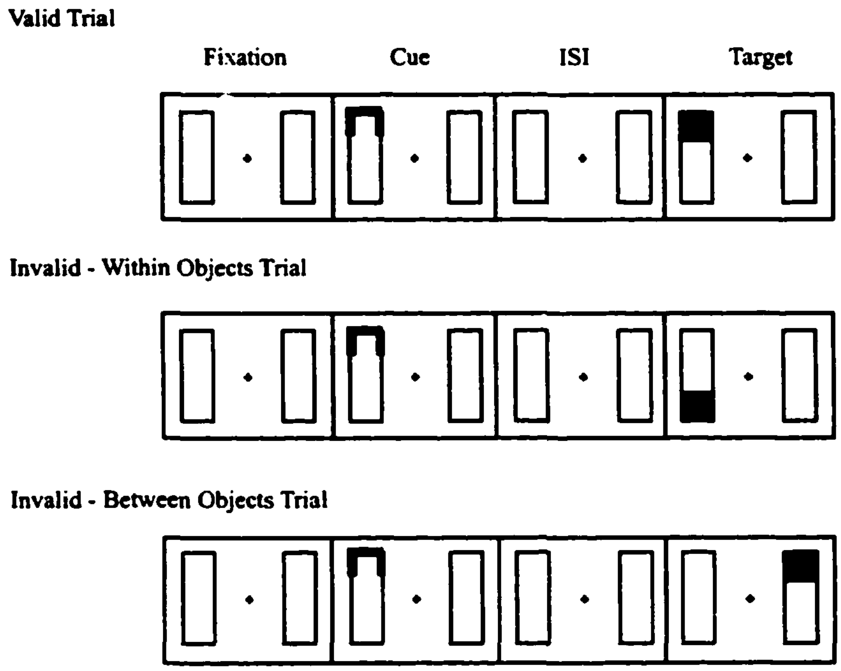

Figure 3: Egly, Driver & Rafal (1994a) Experimental Paradigm. A trial begins with a central fixation cross and two rectangles. Either the top or the bottom of one these rectangles brightens as the cue. After a interstimulus interval, the target (either the top or bottom of one of the rectangles filled in) is presented. In a valid trial, the cue and target match in both location (top/bottom) as well as rectangle (left/right). In a invalid within object trial, the cue and the target appear in the same rectangle but at opposite ends. In a invalid between objects trial, the cue and target appear in different rectangles.

Subjects were presented displays that consisted of two outline rectangles either above and below a central fixation point or to the right and left of a central fixation point. One end of one of these two rectangles would be cued by a change in line colour. A target would then appear either in the previously cued end of the rectangle (valid), the other end of that same rectangle (invalid-within object) or it could appear at either end of the other rectangle (invalid-between objects). When the target appeared in the same rectangle but at a different end (invalid-within object), space-based attention was thought to be required because the subject had to shift attention but only within the confines of a single object. When the target appeared in a different rectangle, shifts of attention between objects were required, thus implicating object-based selection. The subject's task was simply to press a key as soon as the target was detected.

With normal subjects they found evidence of both space-based and object-based components of attention. Subjects were significantly slower to respond to invalid-within object trials (spatial component) than valid trials. There was also an additional increase in reaction time on the invalid-between object's trials, when attention had to be shifted to the other previously uncued rectangle (object component).

With parietal lobe damaged patients, Egly et al. (1994) again found evidence of both components. Right hemisphere damaged patients were significantly slower to respond to invalid cueing for contralesional targets than for ipsilesional targets. This finding is known as a spatial disengage deficit, in which there is a deficit in disengaging attention from an ipsilateral cue (Posner, Walker, Friedrich, & Rafal, 1984). However these same patients did not show any greater cost with shifts of attention between objects than normals. The left hemisphere damaged patients showed a similar spatial disengage deficit as the right hemisphere damaged patients for shifts of attention within an object but also showed additional costs. When shifting attention between the two rectangles, these subjects were significantly slower to respond to contralesional targets than ipsilesional targets. This indicated that left parietal damage results in additional problems with the object based component of shifting attention. Therefore, Egly et al.'s (1994a) data with both normal and stroke patients suggests that space-based and object-based attentional systems can coexist and they may be represented differently across the cerebral hemispheres.

Egly, Rafal, Driver & Starrveld (1994b) again looked at both space and object-based components of attention, however this time they tested split-brain patients. The paradigm of this study was similar to the one used by Egly et al. (1994a) except that there were always four rectangles presented to the subject, two in each visual field. When the targets were presented in the left visual field (right hemisphere), there were no significant differences in reaction time between shifts of attention within an object and between objects. However when targets were presented in the right visual field (left hemisphere) the subjects were much slower to respond when shifts of attention between objects were required than when shifts of attention within an object were required. This indicated that shifts of attention by the right hemisphere were spatially modulated while the left hemisphere seemed responsible for shifts of attention between objects.

It is very important that Vecera (1994) takes issue with Egly et al.'s (1994a, 1994b) use of the term 'object-based' attention, and argues that it is actually referring to a modified location based representation in which locations are grouped according to whether the locations belong to an object. Therefore he argued that 'object-based' attention should actually be called a grouped array representation. To demonstrate this point, Vecera repeated the Egly et al. (1994a) study but added a spatial manipulation, so that distances between the rectangles were varied by a few degrees of visual angle. The results replicated the within objects and between objects effects, namely that subjects were faster to respond to a cued vs. uncued location in the same object but they were slower to respond when attention had to be shifted between two objects. However the between-object effect was modulated with variations in the distance between objects, such that subjects were faster when two objects were closer together (approximately 4°) than when they were farther apart (approximately 6°). This suggests that Egly et al.'s (1994a, 1994b) 'object-based' effect had an intrinsic spatial component. This does not negate the idea of object-based attention in general, but does bring into question whether the results of Egly et al. were due to object-based attention. The implication of Vecera's finding should not be underestimated. If the object-based attention effects reported by Egly et al. are sensitive to spatial manipulations, than the hemispheric differences reported in Egly et al.'s patient studies may merely reflect differences in space-based attentional orienting and have little to do with object-based attentional orienting. Thus, the question remains open as to whether the brain mechanisms subserving object-based attention are represented differentially between the cerebral hemispheres.

If the answer to this question is to be determined, more testing needs to be conducted with normal subjects and patient populations. This suggestion is reminiscent of the approach endorsed by Marr's tri-level hypothesis (1982), which proposes that to achieve a greater understanding of a processing system, the problem under investigation should be examined at different levels of analysis and with different techniques.

Conclusion

This chapter has presented some of the evidence for separate space-based and object-based attentional systems. The main difference between the two systems is what we orient our attention towards: locations in space or objects. From patient populations and neuroimaging techniques, we have some idea that these systems, though they may interact, are localized in different areas of the brain. However the details of some of the evidence for anatomical modularity of object-based attention has been called into question. Consequently we still do not know exactly how the object-based system is organized throughout the brain and whether there is any lateralization of this function. Therefore the remaining chapters of this dissertation will focus on experiments with normal subjects and patient populations to help clarify the nature of the object-based attentional system and its underlying neural mechanisms.

Chapter 2: Hemispheric Processing in Object-Based Selective Attention

The first chapter of this dissertation introduced some basic issues within the attentional literature, including the existence of separate modules for space-based and object-based selective attention. While object-based selective attention has been well established (Duncan, 1984; Baylis & Driver, 1993; Duncan, 1993; Vecera & Farah, 1994; Enns & Kingstone, 1997), questions remain as to where this module might be localized in the brain. In particular, there is debate as to how each of the hemispheres might be processing this type of attentional information. While Egly et al. (1994a, 1994b) concluded from both normal and patient populations, that the left hemisphere plays an important role in object-based attention, Vecera (1994) has questioned whether their studies taps into the mechanisms of object-based attention. As the question of lateralization in object-based selective attention has not been answered convincingly, the present goal will be to resolve this issue. Like the Egly work, various methodologies will have to be employed to gain a better understanding of the underlying organization of this attentional system, including research with normal subjects as well as patient populations. This chapter will concentrate on object-based selective attention in normal subjects, with a focus on determining whether objects are processed differently by the two cerebral hemispheres.

The idea of differences in functioning between the hemispheres is a recurring organizational theme within the brain (Hellige, 1993). There are actually a number of cognitive functions whose functional modules are divided between the hemispheres. For example, within memory there lies a distinction between verbal memory, that is processed mainly in the left hemisphere and nonverbal memory that is predominantly processed in the right hemisphere. Some illustrations of how the hemispheres might differentially process attentional information were presented in the previous chapter (i.e. Holtzmann et al., 1984; Luck et al., 1994; Kingstone et al., 1997) and it was demonstrated that at times the hemispheres are interdependent while in other circumstances they process information independently. Certain types of attentional processing also appear to be lateralized, for example the left hemisphere having an advantage when performing strategic visual search (Kingstone, Enns, Mangun & Gazzaniga, 1995). With respect to object-based selective attention, the issue must continue to be investigated.

The research of Egly et al. (1994a, 1994b) with normal subjects, stroke patients and split-brain patients suggested that object-based attention is preferentially lateralized to the left hemisphere and space-based attention to the right hemisphere. There has been other evidence (Corbetta et al., 1993; Posner, 1995) that supports a bias of the right hemisphere for space-based attention, but the evidence for the left hemisphere playing a special role in object-based attention has not been compelling. Therefore the first issue explored in this dissertation is how each of the hemispheres perform during object-based selective attention. The aim was to use a relatively simple object-based attention paradigm that could also be used to test patients. As a result the object identification task originally employed by Enns & Kingstone (1997) was utilized.

Enns and Kingstone (1997) began investigating lateralization in object-based selection of attention by looking at hemifield competition in a task that produced a 2-object cost (cf. Duncan, 1984), i.e., response accuracy that is lower when two objects are presented in a display as compared to when only one object is presented. In this task, a series of four displays are presented to the subject (see Figure 4).

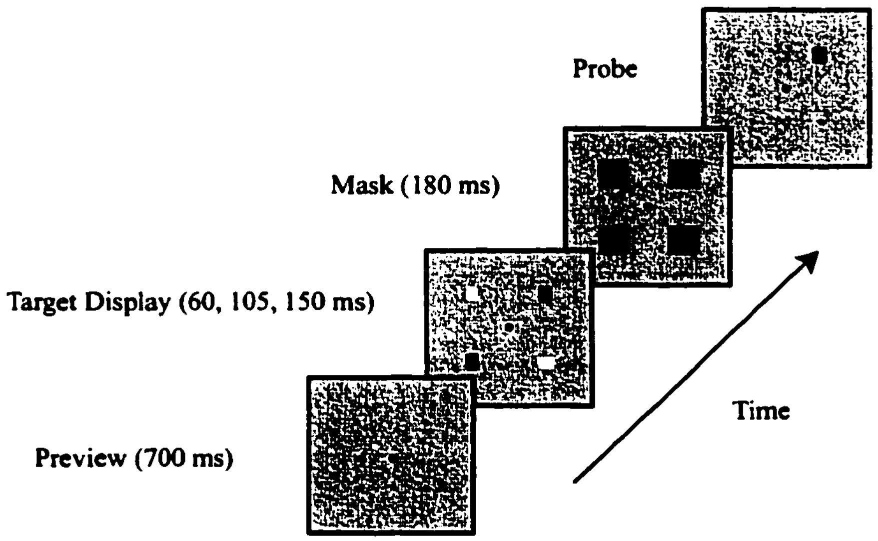

Figure 4: Enns and Kingstone (1997) Paradigm. A trial consisted of four displays. A central fixation dot and 4 location markers were presented in the preview. In the target display black target or white distractor rectangles (oriented vertically or horizontally) were presented at the location markers. After a brief mask, a probe rectangle was presented in one of the black target locations. The subject's task was to indicate whether the probe and target rectangles matched on orientation.

The stimuli in the target display consisted of four long rectangles, placed around a central fixation point. Each object could be oriented vertically or horizontally, and coloured black or white. Subjects were instructed to attend to only the black rectangles. A mask was then briefly flashed and a probe display presented. This probe display consisted of one black rectangle in the same location where a black rectangle in the target display had been. The subject's task was to decide whether the orientation of the probe rectangle matched the orientation of the black rectangle from the target display. There could be either one or two black rectangles in the target display and when there were two objects, they could be presented either unilaterally (two objects presented on the same side and therefore they both projected to the same hemisphere) or bilaterally (two objects presented on different sides and therefore the objects projected to different hemispheres).

Enns and Kingstone (1997) found a 2-object cost for both unilateral and bilateral displays. And though the data for 2-objects presented unilaterally and for 2-objects presented bilaterally were not significantly different, they did tend towards an advantage for the bilateral displays. This performance in the 2-bilateral condition might indicate that in some cases the hemispheres are able to work relatively independently. That is, each hemisphere may process the object that has been presented to it with relatively little interference in object processing by the other hemisphere. The present series of experiments seeks to investigate further hemispheric performance during an object identification task by utilizing the experimental paradigm of Enns and Kingstone (1997). It is postulated that there may be an advantage for objects presented bilaterally and also that there may be differences in the ability of each of the hemispheres to selectively attend to these objects. The results of these studies should help clarify the role of the hemispheres in object-based selective attention.

Experiment #1

As questions remain about the lateralization of object-based selective attention, the purpose of this first experiment was simply to examine how the hemispheres perform on an object identification task. The task consisted of subjects judging whether objects in two different displays were the same or different. In the first display one or two objects were presented briefly and then masked. For two-object displays the items could both be in the same visual field (2-object unilateral display) or the two objects could be in different visual fields (2-object bilateral display). After a brief mask, the final display had a probe item, which was always presented at the location of one of the objects (Figure 5). Half the time the probe matched the previous object and half the time it differed. From previous research (e.g., Duncan, 1984; Baylis & Driver, 1993; Duncan, 1993; Vecera & Farah, 1994; Enns & Kingstone, 1997), we expected that response accuracy would be reduced when subjects were required to attend to two objects in the initial display compared to when they only had to attend to a single object, i.e., there should be a 2-object cost. From Enns and Kingstone (1997) we also expected that when two objects were presented in one field, accuracy might be lower than when the objects were divided between two fields. This would suggest that both hemispheres were capable of selectively attending to objects. Another critical question was whether these object-based attentional effects would differ across the hemispheres.

Method

Subjects

Sixteen undergraduate psychology students at the University of Alberta were tested. All had normal or corrected-to-normal vision and all received course credit for their participation in the study.

Apparatus

This experiment was conducted on a Macintosh 66 computer. The stimuli were presented on a 14-inch Apple color monitor (set to black and white) at a viewing distance of approximately 57 cm. Responses were collected from keyboard button presses.

Stimuli and Procedure

Figure 5 illustrates the sequence of stimulus events presented in a given trial. The initial display signaled the start of a trial and consisted of a black central fixation point with four black location markers (in the shape of diamonds) on a gray background. These markers were located 6° from central fixation and were positioned on the four corners of an imaginary square centered on fixation. The subjects were instructed to keep their eyes on the fixation point at the start of each trial, and to withhold any eye movements until the end of the trial. The duration of this initial display was 700 ms. The next display (which will be called the "target display") was composed of either one or two horizontal or vertical black ovals being presented within the location markers. The ovals subtended 0.9° x 0.7° visual angle, and were presented for 100, 150 or 200 ms (each duration was equiprobable and randomly selected). Immediately following this display was a 180 ms display consisting of four squares with a pattern of thick white and black oblique lines. These pattern masks subtended 2.6° x 2.3° visual angle and were centered on each of the four location markers. The final display (which will be called the "probe display") was similar to the second display except that only one black oval was presented. This probe always appeared in the same location as a black oval in the target display. Half the time the probe matched, and half the time the probe mismatched, the orientation of the target black oval that had preceded it.

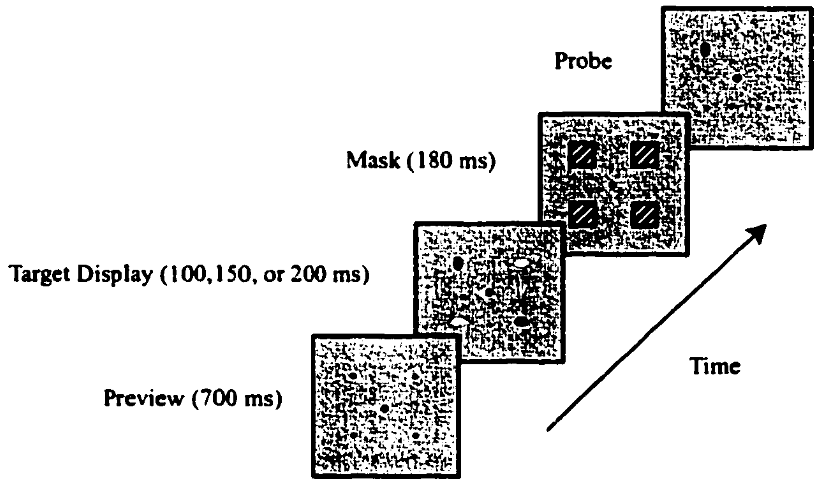

Figure 5: Experiment #1 Paradigm. A trial consisted of four displays. A central fixation dot and 4 location markers were presented in the preview. In the target display black target or white distractor ovals (oriented vertically or horizontally) were presented at the location markers. After a brief mask a probe oval was presented in one of the black target oval locations. The subject's task was to indicate whether the probe and target ovals matched on orientation.

The subject's task was to decide whether the probe matched or mismatched the target. If the probe matched the target, and the probe was in the left visual field, then the subject pressed the "z" keyboard key with the left hand. If the probe matched the target, and the probe was in the right visual field, then the subject pressed the "/" keyboard key with the right hand. When a response was executed the probe was extinguished and following an intertrial interval of 1350 ms the next trial began. If the probe did not match the target, no response was to be made. On these trials the probe was extinguished after 1995 ms, and following an intertrial interval of 1350 ms, the next trial began.

A single object, two objects in the same visual field (2-object unilateral display), and two objects in different visual fields (2-object bilateral display) were equally likely and were selected randomly from trial to trial. On single object displays the position of the target occurred at random and with equal probability in each of the four possible locations. For 2-object unilateral displays, left and right visual field presentations were equiprobable and randomly selected. For 2-object bilateral displays, top, bottom and diagonal field presentations were equiprobable and randomly selected. For two object displays the probe item appeared randomly and with equal probability at one of the target locations. On single object displays the probe always occurred at the location of the target. In all cases target and probe orientations were equiprobable and randomly selected, and whether the probe orientation was the same or different from the target orientation was equiprobable and varied randomly from trial to trial.

Each subject received 20 practice trials followed by 9 blocks of 64 trials. Approximately one hour was required for the subject to complete the 696 trials (20 practice trials plus 576 test trials).

Results and Discussion

Response accuracy (percent correct) was subjected to an analysis of variance (ANOVA) with object display (1-object, 2-object unilateral, 2-object bilateral), display time (100, 150, 200 ms), and target visual field (left or right) as within-subject factors (Table 1).

The main effect of field was non-significant, $F(1,15)=0.268$, $p>0.5$, therefore there was no difference in accuracy if the probe was presented in the right or left visual field. The interval was significant, as accuracy increased with an increase in the duration of the target display, $F(2,30)=35.43$, $p<0.001$. This is not surprising since longer display durations would result in more time for processing, and therefore more accurate object identification. As predicted, there was also a highly significant effect of object, $F(2,30)=82.96$, $p<0.001$ (Figure 6). As can be seen from the graph, the largest difference in accuracy was between the one object condition and the 2-unilateral condition. Subjects were more accurate when only one black target was in the target display than when 2 potential target objects were presented, i.e. there was a 2-object cost.

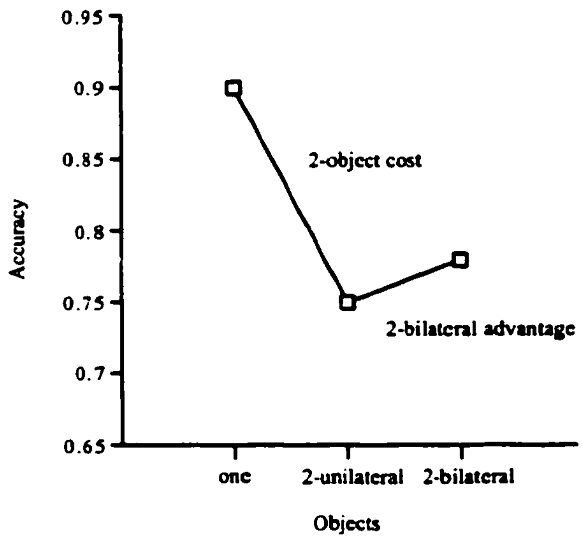

Figure 6: Experiment #1 - Object Effect. There is a decrease in accuracy from the one object condition to the 2-unilateral condition (2-object cost) and an increase in accuracy from the 2-unilateral condition to the 2-bilateral condition (2-bilateral advantage).

From the results of Enns and Kingstone (1997), we also expected a difference in accuracy between the 2-unilateral and 2-bilateral conditions. A planned means comparisons found that there was a significant increase in accuracy for the 2-bilateral condition as compared to the 2-unilateral condition, which can be referred to as a 2-bilateral advantage, $F(1,15)=6.78$, $p<0.05$. With respect to hemispheric processing, this suggests that for an object identification task the two hemispheres are able to work somewhat independently. This would explain the 2-bilateral advantage because in that condition each hemisphere has only one object to attend to, whereas in the 2-unilateral condition, one hemisphere must attend to both objects. If each hemisphere is able, to some degree, attend independently to objects, then the 2-bilateral condition should result in higher response accuracy, which it does.

There was a non-significant field x interval interaction, $F(2,30)=0.209$, $p>0.5$. However there was a significant field x object interaction, $F(2,30)= 7.024$, $p<0.005$ (Figure 7), which is very interesting as it appears that the 2-bilateral advantage only arises when the target is presented in the right visual field (left hemisphere). This interaction reflects the fact that there was no difference between visual fields for 1-object displays, $F(1,15)=0.399$ $p>0.5$, but there were differences in both the 2-unilateral and 2-bilateral conditions. Planned contrasts showed that there was a significant right hemisphere advantage for the 2-object unilateral display, $F(1,15)=5.163$, $p<0.05$, but there was a significant left hemisphere advantage for the 2-bilateral condition, $F(1,15)=5.57$, $p<.05$.

Planned contrasts also showed that there was no significant difference between the 2-unilateral and 2-bilateral conditions for objects presented in the left visual field, $F(1,15) = 0.0025$, $p<1$, but the difference was significant for objects presented in the right visual field, $F(1,15) = 28.55$, $p<0.001$. These present contrasts demonstrate that the left hemisphere (right visual field) performed better when two objects were divided between the visual fields, whereas the right hemisphere (left visual field) performed better when required to process both objects. It should be noted that Egly et al. (1994a, 1994b) concluded that the processing of objects was lateralized to the left hemisphere, and the results of this first experiment indicate that while there may be some hemispheric differences in attentional processing of objects, it is unclear whether the left hemisphere has an advantage for this type of processing. From Figure 7 and the planned means comparisons, it is clear that the right hemisphere does better than the left hemisphere when it is given 2 objects (2-unilateral condition). This suggests that the right hemisphere is better at object processing, when there is a heavier object load. However, when each hemisphere gets only one object (2-bilateral condition), the left hemisphere performs better, suggesting that if the two hemispheres are competing for resources the left hemisphere may be winning.

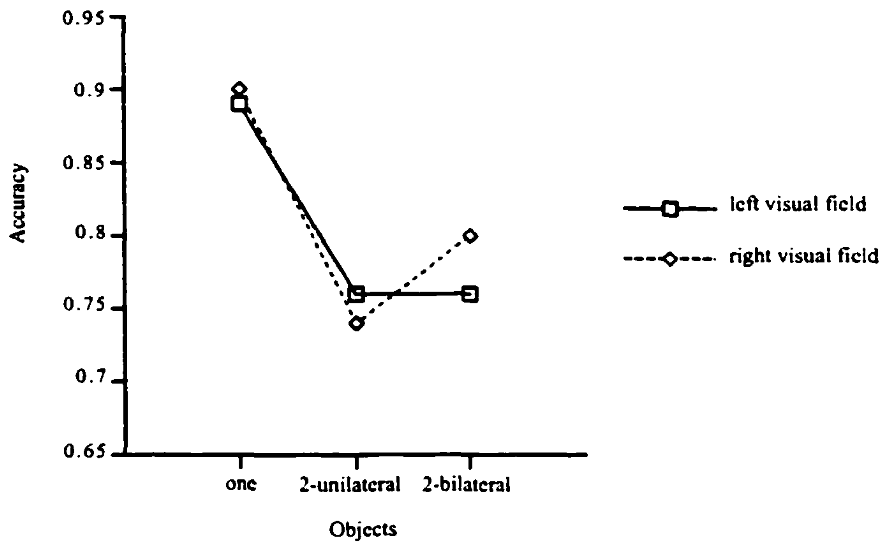

Figure 7: Experiment #1 - Field x Object Interaction. In the 2-unilateral condition the right hemisphere outperforms the left hemisphere, however at the 2-bilateral condition the opposite pattern emerges.

There was a non-significant interval x object interaction, $F(4,60)=0.820$, $p>0.5$. Finally there was a significant 3-way interaction between field, interval and object, $F(4,60)= 2.773$, $p<0.05$ (Figure 8). The 2-bilateral advantage is significant at all three intervals for objects presented in the right visual field, [100 ms: $F(1,15)= 8.350$, $p<0.05$; 150 ms: $F(1,15)= 19.628$, $p<0.0005$; 200 ms: $F(1,15)= 9.649$, $p<0.005$] but not for objects presented in the left visual field, [100 ms: $F(1,15)= 1.791$, $p>0.05$; 150 ms: $F(1,15)= 0.048$, $p>0.5$; 200 ms: $F(1,15)= 1.4839$, $p>0.1$]. From Figure 8, one can see that at 100 ms, though not significant, there is actually a 2-bilateral disadvantage for objects presented in the left visual field, which moves closer to an advantage as display duration increases.

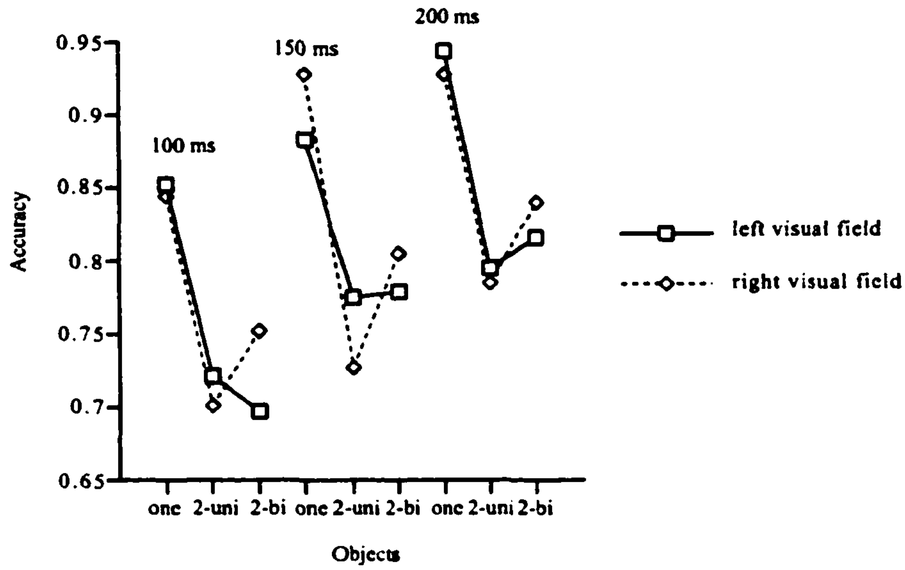

Figure 8: Experiment #1 - Field x Interval x Object Interaction. At 100 ms, a 2-bilateral advantage is not seen however at 200 ms the advantage emerges.

This first experiment resulted in some important data emerging. One finding was that subjects were more accurate when only one object was presented in the target display than when two objects were presented. The second was that there was a 2-bilateral advantage, with higher accuracy for two objects presented bilaterally than unilaterally. This indicates that for this object-based selective attention task, each hemisphere was able to orient attention towards objects. However the ability of each hemisphere may not be equal and unlike the conclusions of Egly et al. (1994a, 1994b), it is unclear whether there is a left hemisphere advantage. The left hemisphere may actually have a disadvantage in processing objects, rather than an advantage, when it has more than one object to process. However in the 2-bilateral condition in which the hemispheres are competing for resources, it is the left hemisphere that performs better. Further tests were obviously needed to elucidate the hemispheres' performance in object-based attention.

Experiment #2

Two main findings of Experiment 1 were a 2-object cost (lower accuracy when two objects are presented) as well as an increase in accuracy when two objects were presented bilaterally as compared to when they were presented unilaterally. These findings are consistent with previous attentional phenomena (Duncan, 1984; Enns & Kingstone, 1997), but alternative explanations should be considered. It is possible that the 2-bilateral advantage or independence in hemispheric processing may have emerged because the response to the task was actually lateralized (left-hand key press for left field stimuli, right hand key press for right field stimuli). As both the stimuli and the response were separated by field, it may have resulted in some artificial independence of processing by the two hemispheres for bilateral stimuli. Therefore this second experiment investigates a possible non-attentional explanation for the 2-bilateral advantage and field effect by manipulating the response demands to reduce any possible effects of lateralization.

Method

Methodological details were the same as in Experiment 1 except where indicated. Sixteen new subjects were recruited for this experiment with the same profiles as the previous experiments. The stimuli were the same as in Experiment 1, but the response demands differed. When the ovals matched, the subjects had to respond with a specific keyboard press ("z" for half of the subjects and "/" for the other half), regardless of the field. If the ovals did not match, the subjects had to respond with the opposite keyboard press ("z" or "/"). Therefore subjects made a right hand key press half of the time and a left-hand key press the other half of the time.

Results and Discussion

Again a three-way analysis of variance (ANOVA) was conducted (Table 2). As in Experiment 1 there was not a significant field effect, $F(1,15) = 0.061$, $p>0.5$. The main effect of interval was significant, $F(2,30) = 31.82$, $p<0.001$, with accuracy increasing as display duration increased. As well the analysis showed a highly significant effect of object, $F(2,30) = 69.904$, $p<0.001$ with the same pattern of the 2-object cost and 2-bilateral advantage seen in Experiment 1 (Figure 9). Planned means comparisons were again conducted between the 2-unilateral and 2-bilateral conditions, with a significant difference, $F(1,15) = 5.347$, $p<0.05$. Therefore it does not appear that the 2-bilateral advantage is due to the lateralization of responses.

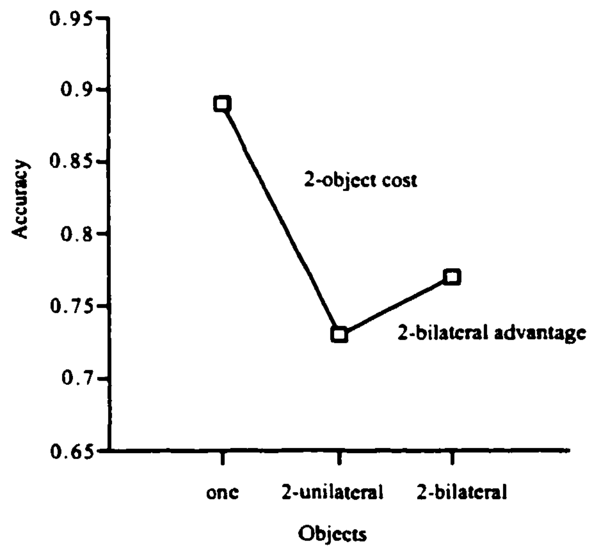

Figure 9: Experiment #2 - Object Effect. Both the 2-object cost and the 2-bilateral advantage emerge.

There was also a significant interaction between visual field and interval, $F(2,30) = 4.085$, $p<0.05$ (Figure 10). This field by interval effect appears to be caused by accuracy in the left visual field being lower at the 100 ms interval than the right visual field, and then higher than the right visual field at 150 ms. They both finish at the same accuracy for the 200 ms interval, therefore it is difficult to surmise anything from this result except that perhaps for this task, the right hemisphere is at a disadvantage when a display is presented briefly, but at later intervals is able to perform as well or even better than the left hemisphere.

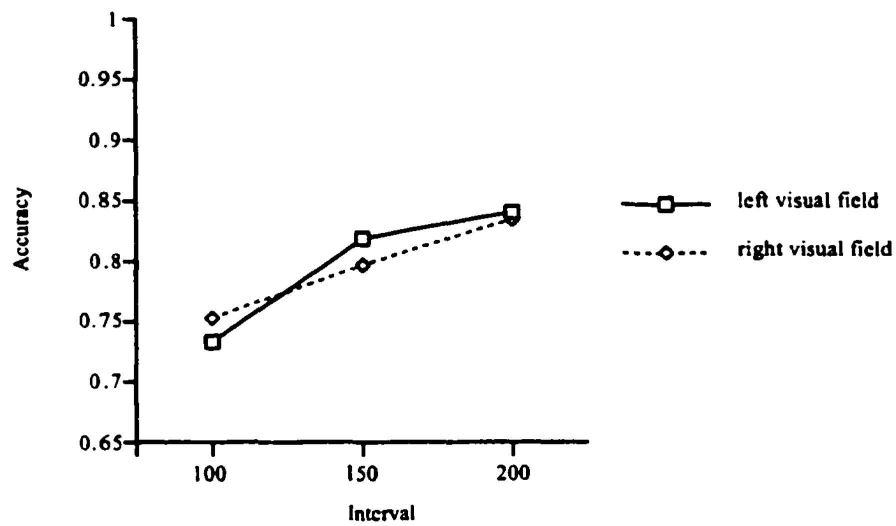

Figure 10: Experiment #2 - Field by Interval Interaction. At 100 ms the left hemisphere performs better than the right hemisphere but at 150 ms the right hemisphere outperforms the left hemisphere.

The field x object interaction was not significant in this experiment, $F(2,30) = 0.172$, $p>0.5$ (Figure 11), nor was the interval x object interaction, $F(4,60) = 0.187$, $p>0.5$. Lastly, the field x interval x object interaction was not significant for this experiment, $F(4,60) = 1.09$, $p>0.05$ (Figure12).

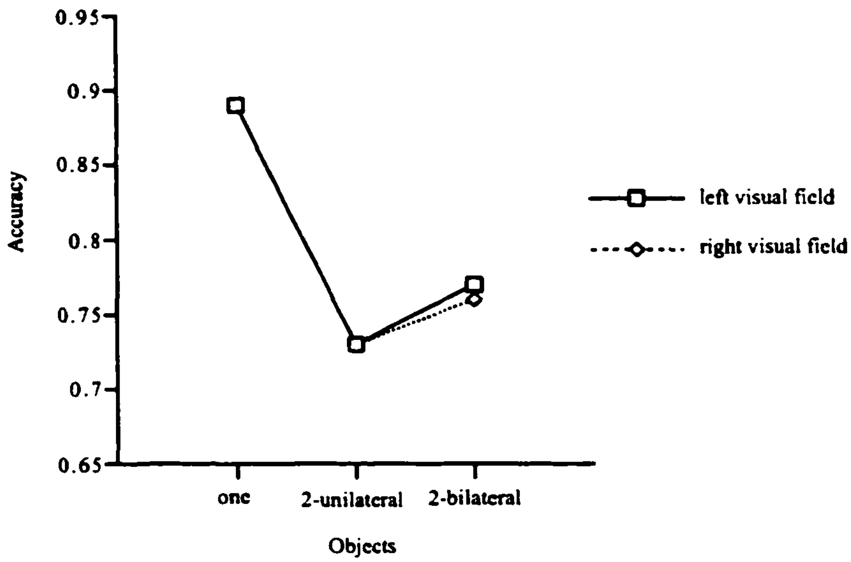

Figure 11: Experiment #2 - Field x Object Interaction. There are no significant field differences in any of the object conditions.

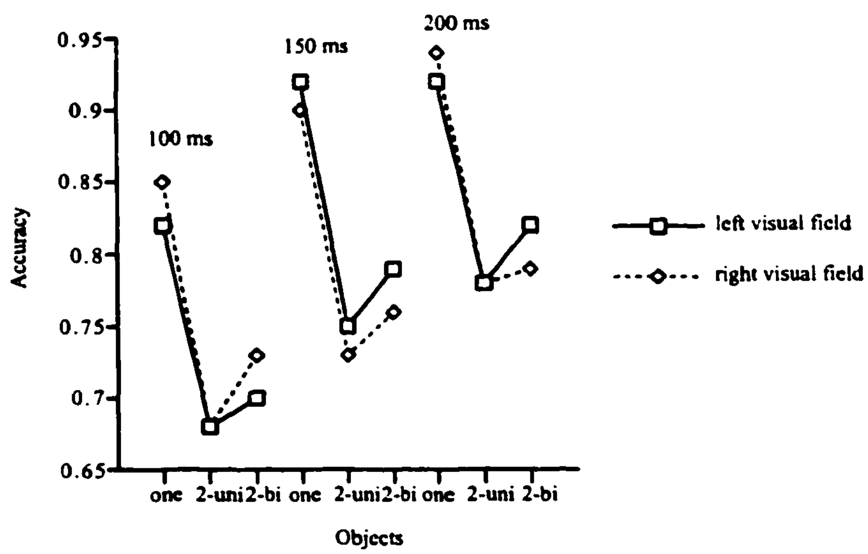

Figure 12: Experiment #2 - Field by Interval by Object Interaction. This three way interaction was not significant.

The focus of this experiment was to ensure that the pattern of hemispheric processing seen in Experiment 1 was not a by-product of response demands. Though not all the same effects emerged in this experiment as did in Experiment 1, the main effects remained consistent and this indicates that the 2-bilateral advantage is not simply due to lateralization of response demands, but does appear to be the result of attentional processing. The lack of a significant field by object interaction with the manipulation of the response task was surprising and therefore this rather important finding from Experiment 1, namely that the left hemisphere outperformed the right hemisphere in the 2-bilateral condition but the right hemisphere outperformed the left hemisphere in the 2-unilateral condition, may have simply been an artifact of the response demands used in Experiment 1. Therefore it will be important to utilize the original response demands in further experiments to determine what, if any, impact it has on the field x object interaction.

Experiment #3

In Experiment 1 both a 2-object cost and a 2-bilateral advantage were evident. The fact these effects were due to attentional processing and not simply a by-product of response demands was established in Experiment 2. While that much has been confirmed, the type of attentional orienting, either endogenous or exogenous, producing these effects has not been established. In the previous two experiments, white distractor ovals were presented along with the black target ovals. The subjects were instructed to attend to only the black ovals, and this implies endogenous or voluntary orienting of attention. The evidence for object-based attention has predominantly been demonstrated with endogenous orienting of attention (i.e. the judgments required in Duncan (1984) as well as the first two experiments of this dissertation). The goal of the present experiment was to investigate whether exogenous or reflexive orienting would also produce the 2-object bilateral advantage. Therefore the influence of the distractors on the previous results was examined. The white distractors were simply removed from the displays in this paradigm (Figure 13). As only the black target ovals were presented, this resulted in a reflexive 'pop-out' effect of the stimuli (exogenous orienting). If we continued to see the object effects seen in the two previous experiments, it could be concluded that the phenomena could be produced by exogenous orienting of attention as well as endogenous orienting of attention (which is engaged when the distractors are present). However, if by removing the distractors the effects disappeared, one could conclude that the 2-bilateral advantage was a product of the endogenous attentional system. As endogenous and exogenous orienting of attention may be processed differently in the brain (Kingstone et al., 1997), this could be an important factor in determining the underlying neural mechanisms of object-based attention.

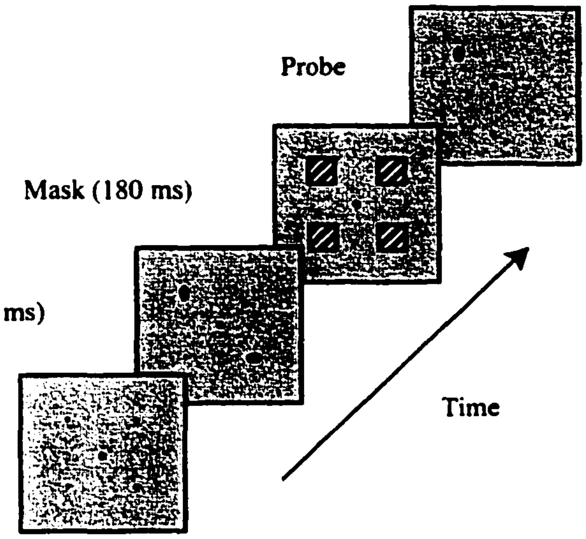

Figure 13: Experiment #3 Paradigm. This paradigm is identical to the one utilized in Experiment 1 except that the white distractors were removed to examine the issue of endogenous vs exogenous orienting of attention.

Method

Methodological details were the same as in Experiment 1 except where indicated. Sixteen new subjects were brought in for this experiment with the same profiles as the previous experiments. The only difference between this study and Experiment 1 was the removal of all of the white ovals. The subjects were still required to attend to the black ovals and respond accordingly.

Results and Discussion

A three-way analysis of variance (ANOVA) was again conducted (Table 3). As in the previous experiments there was not a significant field effect, $F(1,15) = 0.054$, $p>0.5$. However, the main effect of interval was significant, $F(2,30)=38.89$, $p<0.001$, with accuracy increasing as display duration increased. Also, the analysis showed a highly significant effect of object, F (2,30)=81.29, p<0.001 with the same pattern of the 2-object cost and 2-bilateral advantage seen in Experiments 1 and 2 (Figure 14) emerging. Planned means comparisons were again conducted between the 2-unilateral and 2-bilateral conditions, and showed a significant increase in accuracy for the 2-bilateral condition, F (1,15)=5.347, p<0.05.

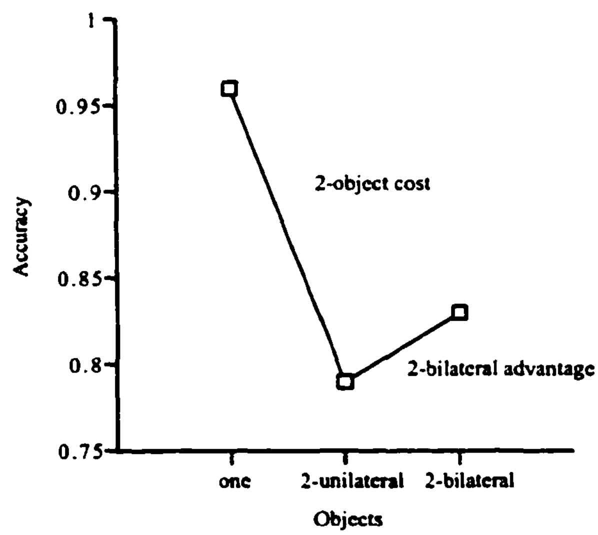

Figure 14: Experiment #3- Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge.

There was no significant interaction between visual field and interval, F (2,30) = 1.314, p>0.05. The field x object interaction was also not significant, F (2,30)=1.971, p>0.05 (Figure 15). However the interval x object interaction was significant, F (4,60)=5.712, p<0.001 (Figure 16).

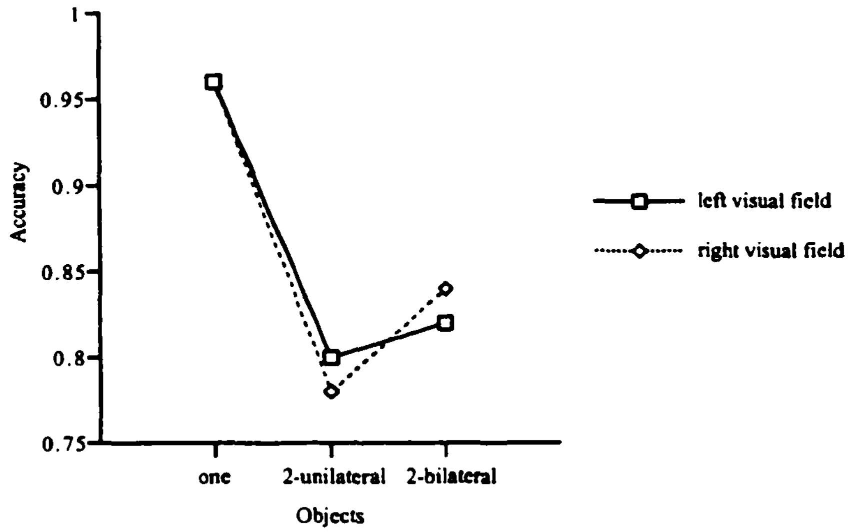

Figure 15: Experiment #3 - Field by Object Interaction. This interaction was not significant.

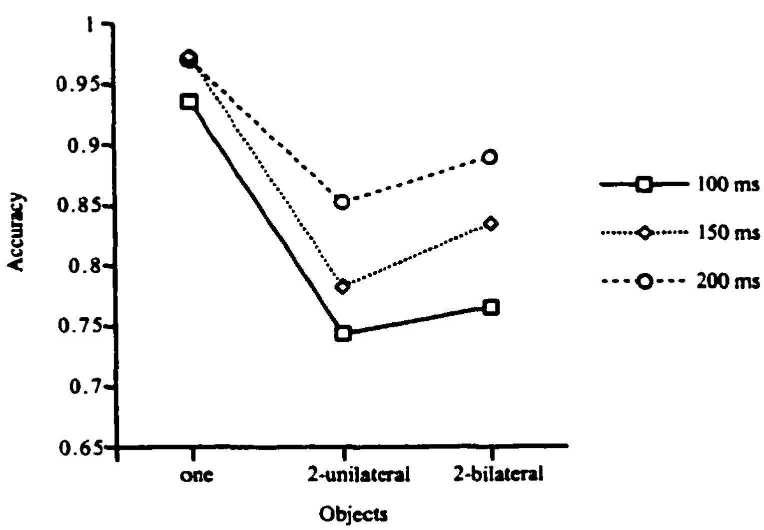

Figure 16: Experiment #3 - Interval by Object Interaction. The 2-bilateral advantage is greatest at 150 ms.

The difference in accuracy between the 2-unilateral and 2-bilateral conditions is not significant at a display duration of 100 ms (F(1,15)=1.928, p>0.1) but is significant at the 150 ms, F(1,15)=11.243, p<0.005, and 200 ms, F(1,15)=5.814, p<0.05, display durations. This may be due to the change in stimulus quality that comes with longer display durations. The field x interval x object interaction was not significant for this experiment, F (4,60)=1.648, p>0.05 (Figure 17).

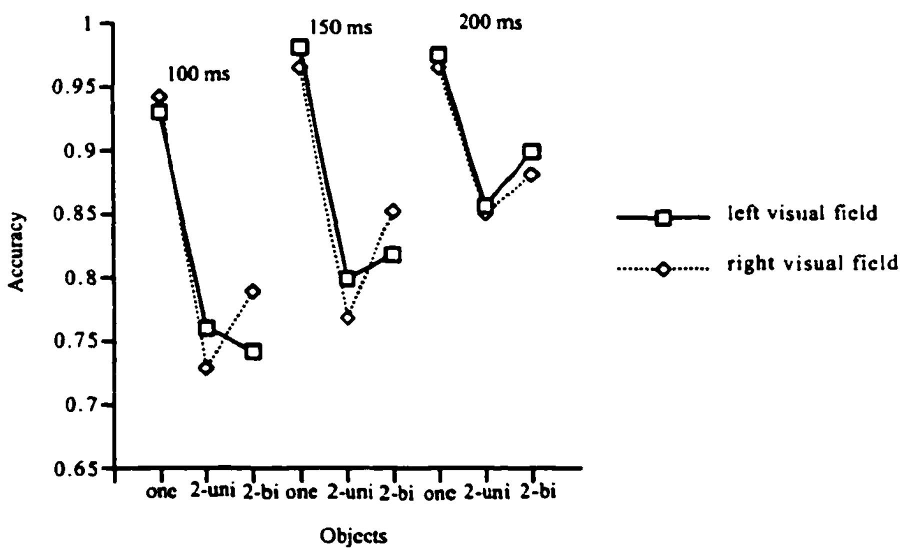

Figure 17: Experiment #3 - Field by Interval by Object Interaction. This three way interaction was not significant.

This experiment was conducted to investigate whether the 2-object cost and 2-bilateral advantage would emerge with exogenous or reflexive orienting as it had with endogenous orienting. Again, though not all the same effects emerged in this experiment as did in Experiment 1, the main effects remained consistent and this illustrates that the 2-object cost and 2-bilateral advantage also emerge during exogenous orienting of attention.

Therefore selective attention to objects is not solely limited to endogenous orienting. Kingstone et al. (1997) postulated that with exogenous orienting there is independence between hemispheres and this concurs with the 2-bilateral advantage. In this condition each hemisphere appears to be selectively attending to objects with a significant degree of independence.

As in Experiment 2, no significant field x object interaction was found. As this third experiment utilized the same response demands as the original study, the lack of a field effect in Experiment 2 cannot be attributed to an artifact of this type of response demand as had been postulated in the discussion of Experiment 2.

Experiment #4

At this point we have established that the 2-object cost and 2-bilateral advantage continue to emerge despite changes to response demands or removal of distractors. This is certainly an indication that that our data is the result of object-based selective attentional processing. However, there is still one more alternative explanation for our data. In the first three experiments, the bilateral condition contained only diagonal combinations (objects in the top right, left bottom or top left, right bottom locations). The paradigm was originally designed in this way to equalize the top/bottom discriminations made from the 2-unilateral condition to the 2-bilateral condition. In both conditions the subject only had to keep track of top and bottom discriminations; left/right discriminations did not help with the task. For example, if there is a vertical oval in the top right location and a horizontal oval in the bottom right location, the subject only has to keep track of which orientation was on top and which orientation was on the bottom; that it is presented in the right field has no relevancy except in the response. The same holds true for the diagonal combinations of the 2-bilateral condition. This manipulation introduces a possible confound however, as the distances between objects were shorter for the 2-unilateral configuration as compared to the 2-bilateral configuration. Perhaps the longer distances in the 2-bilateral condition made it easier to separate those objects and that is why, in the previous experiments, higher accuracies were seen in the 2-bilateral condition. The purpose of this fourth experiment was to examine this alternative explanation of the data. Therefore we added horizontal combinations of stimuli in the 2-bilateral condition (i.e. right top-left top, right bottom-left bottom) to determine if the distances between stimuli in this condition contributed to the 2-bilateral advantage in the previous experiments (Figure 18).

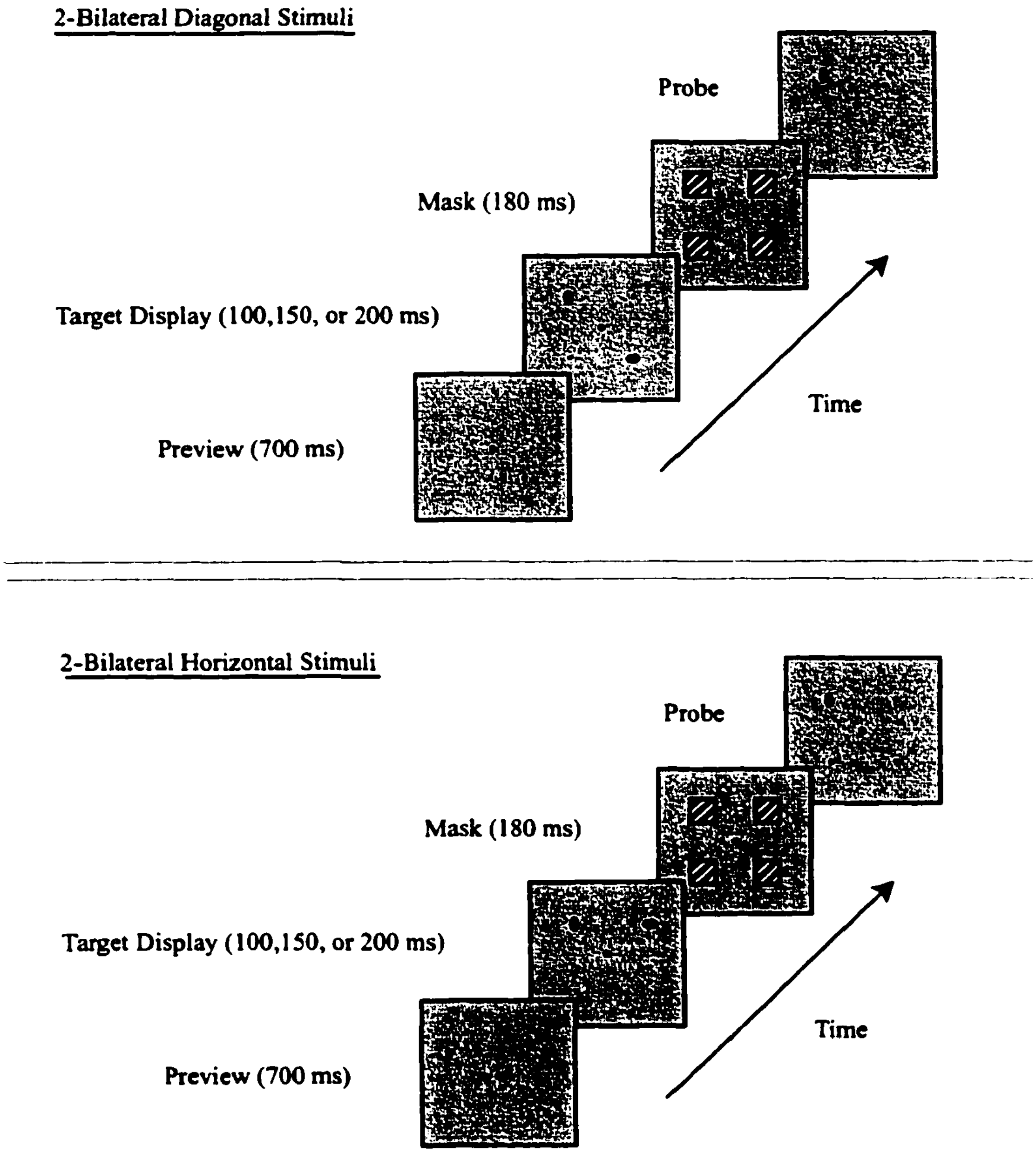

Figure 18: Experiment #4 Paradigm. In the 2-bilateral condition, both diagonal bilateral stimuli (top panel) as well as horizontal bilateral stimuli (bottom panel) were presented. In the previous experiments only diagonal combinations had been utilized.

Method

Methodological details were the same as in Experiment 3 except where indicated.

Sixteen new subjects were brought in for this experiment with the same profiles as the previous experiments. As it was found in Experiment 3 that the distractor white ovals did not affect the object effects, they were not included in this experiment. Also, 32 extra types of trials were added to include all horizontal combinations in the 2-bilateral condition. The probability of getting a specific trial continued to be completely random and the overall number of trials remained the same.

Results and Discussion

A three-way analysis of variance was conducted (Table 4). The main effect for field was not significant, $F(1,15) = 0.866$, $p>0.05$. Interval again had a significant effect, $F(2,30) = 38.599$, $p<0.001$, with higher accuracy for longer display durations. As in the previous experiments, there was a highly significant effect of object, $F(2,30) = 51.570$, $p<0.001$ with both the 2-object cost and 2-bilateral advantage emerging (Figure 19). Planned mean comparisons found that there was also a significant difference between the 2-unilateral and 2-bilateral object conditions, $F(1,15) = 5.652$, $p<0.05$. Therefore the main object effects were preserved in spite of the added stimuli locations. This suggests that the 2-bilateral advantage was not simply due to the objects' locations in the two fields. Individual analyses validated this conclusion, with the same data pattern emerging when the diagonal and horizontal conditions were considered in isolation.

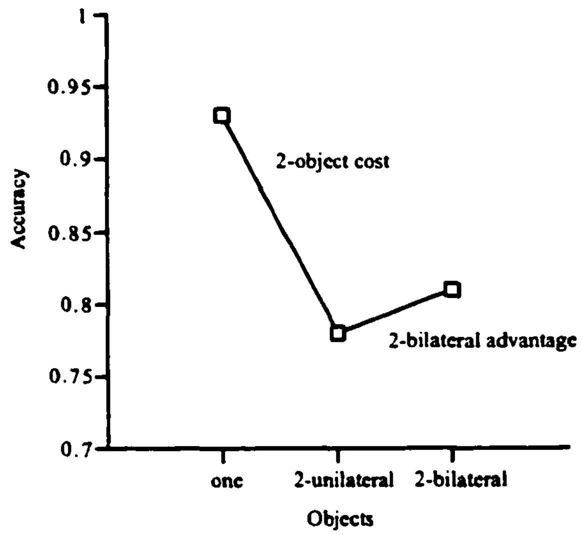

Figure 19: Experiment #4 - Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge.

The field x interval interaction was not significant, $F(2,30)=0.152$, $p>0.5$, nor was the field x object interaction, $F(2,30)=0.319$, $p>0.5$ (Figure 20). However the interaction between interval and object was significant, $F(4,60) = 3.121$, $p<0.05$ (Figure 21). Similar to the pattern of results found in Experiment 3, the 2-bilateral advantage was greater at longer display durations. Finally, there was not a significant field x interval x object interaction, $F(4,60)=0.669$, $p>0.5$ (Figure 22).

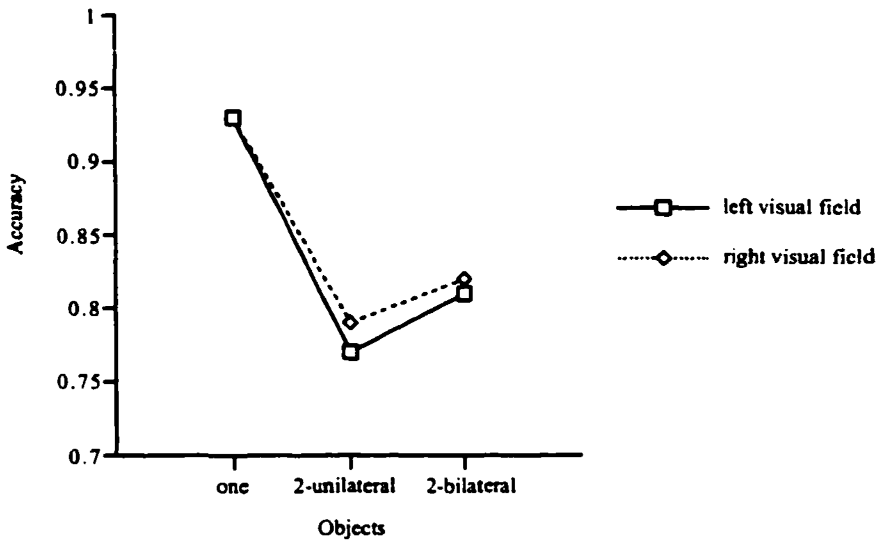

Figure 20: Experiment #4 - Field by Object Interaction. This interaction was not significant.

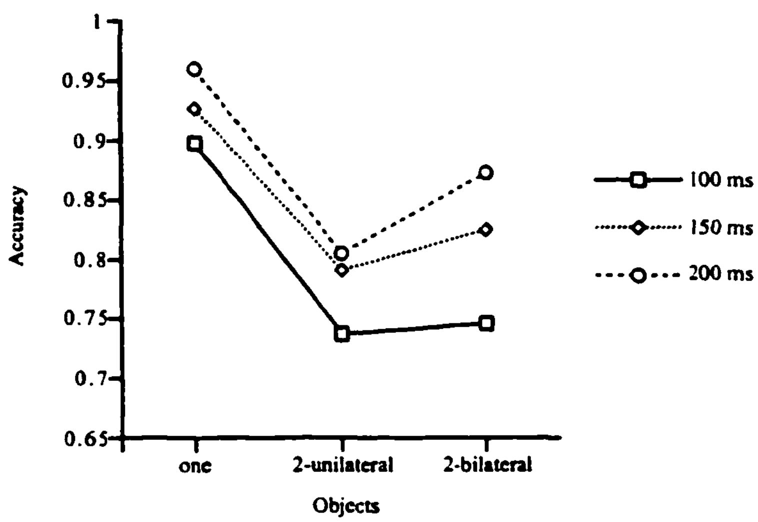

Figure 21: Experiment #4 - Interval by Object Interaction. The 2-bilateral advantage is greatest at 200 ms.

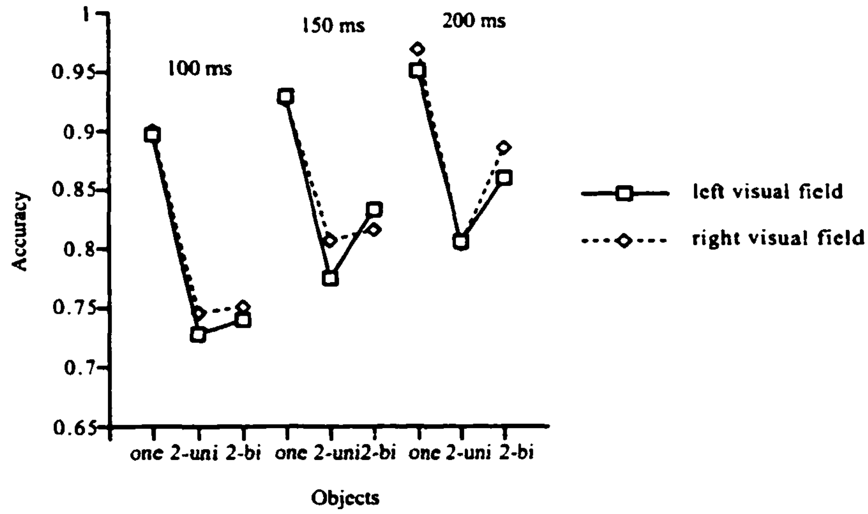

Figure 22: Experiment #4 - Field by Interval by Object Interaction. This three way interaction was not significant.

This experiment was conducted mainly to ensure that the 2-bilateral advantage observed in the previous experiments was not due to the fact that in the 2-bilateral condition only diagonal combinations were used. As there were no significant differences by adding the horizontal combinations, it appears that minor differences in the distance between stimuli in the two fields are not a factor in the 2-bilateral advantage. Experiment 5 examined whether this will also be the case for large changes in spatial distance between stimuli.

Experiment #5

This series of experiments has attempted to distinguish the role of each of the hemispheres in object-based selection of attention. From the 2-bilateral condition it has been found that both hemispheres are able to selectively attend to objects. And contrary to Egly et al.'s 1994 results, some data (Experiment 1) suggest that the left hemisphere does not have an overall advantage and may actually be poorer than the right hemisphere in processing objects when it is required to process more than one object. This contradiction of Egly et al. (1994) may not be wholly unexpected as work by Vecera (1994) suggests that these previous studies may have failed to produce a pure measure of object-based attention. By adding a simple spatial manipulation, Vecera (1994) altered the original 'object-based' results. It has been the assumption that the experimental paradigm utilized in the previous experiments is tapping into object-based selection of attention, an assumption that is supported by the finding in Experiment 4 that manipulating the spatial distance between the stimuli did not impact the object-based effects. It is reasonable however, to question whether the spatial manipulations in Experiment 4 were too small and subtle to impact the object-based attention effects. Thus in order to test whether the paradigm being used in the present series of experiments is indeed providing a strong measure of object-based selective attention, the test advocated by Vecera (1994) was applied. If the object-based attention effects in Experiment 5 interact with larger variations in stimulus spacing, then the paradigm being used in the present series of experiments will be exposed as an inadequate test of object-based selective attention.

Method

Methodological details were the same as in Experiment 3 except where indicated. Thirty-two undergraduate psychology students were brought in for this experiment with the same profiles as the previous experiments. Half of these students (16) were placed in the near condition and the other half (16) were placed in the far conditions. No student was tested in both conditions.

The four displays continued to consist of four diamond shaped location markers and a central fixation point. However in the Near condition the location markers were located at the corners of an imaginary square 4° from central fixation while the markers were located at the corners of an imaginary square 8° from fixation in the Far condition (Figure 23). In both the Near and Far conditions the location markers were again positioned on the four corners of an imaginary square centered on fixation. Only black ovals were placed within the location markers and the task was again the same as in the previous experiments, with the subject indicating whether the probe and target stimuli matched by a keyboard press. There were 9 blocks of 64 trials.

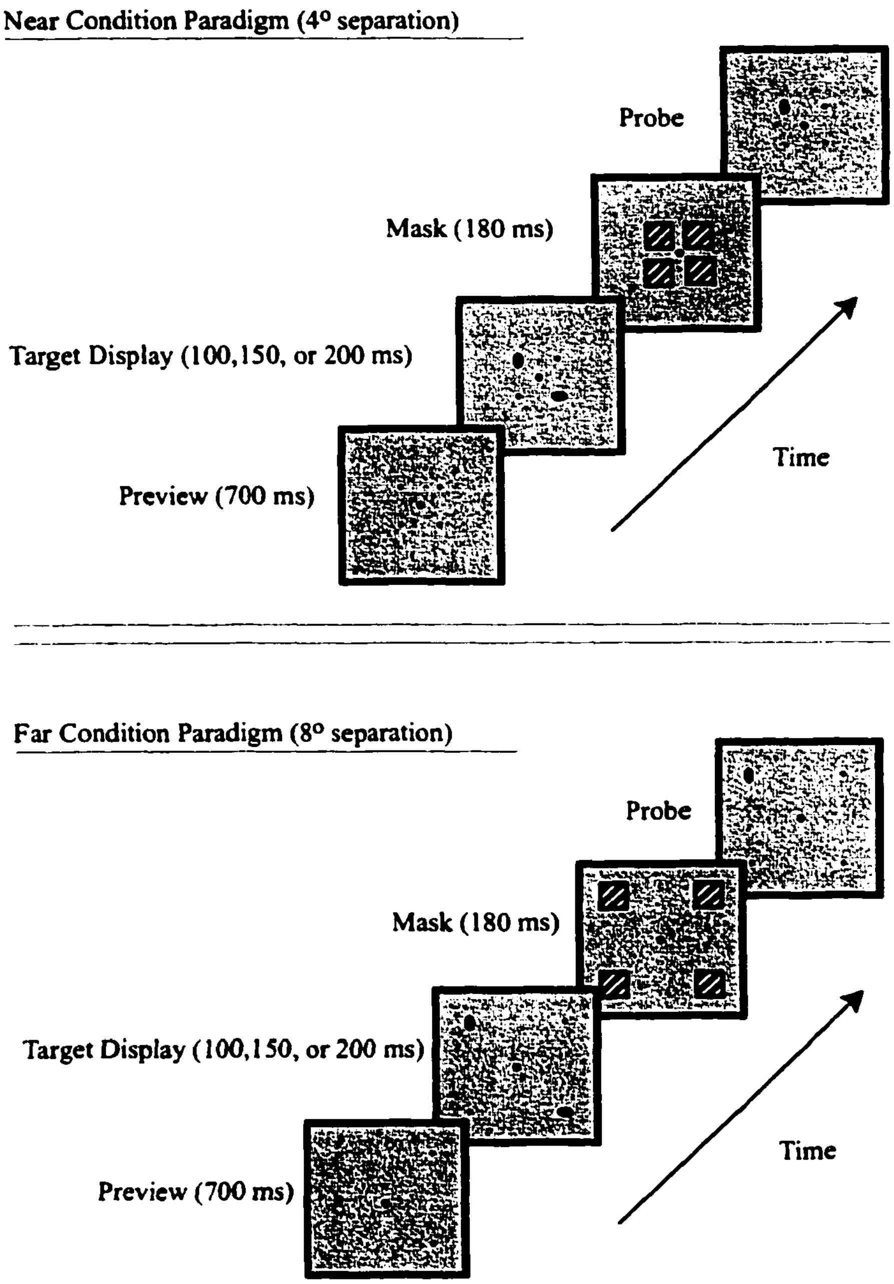

Figure 23: Experiment #5 Paradigm. The top panel depicts the Near condition in which the location markers and ovals are brought closer to central fixation (4° separation). The bottom panel shows the Far condition in which the location markers and ovals are placed farther from central fixation (8° separation). Each subject was presented with only one of these conditions.

Results and Discussion

Response accuracy was subjected to an ANOVA with object display, display duration, and target visual field as within-subject factors, and display distance (near or far) as a between-subject factor (Tables 5, 6).

Analysis revealed main effects for object display, $F(2,60) = 64.10$, $p < 0.0005$ (Figure 24), display duration, $F(2,60) = 45.24$, $p < 0.0005$, and visual field, $F(1,30) = 25.63$, $p < 0.0005$, reflecting the fact that response accuracy improved when there was only one object, when the display time was lengthened, and when the target was in the left visual field. There was no main effect of display distance, $F(1,30) = 0.09$, $p > 0.05$.

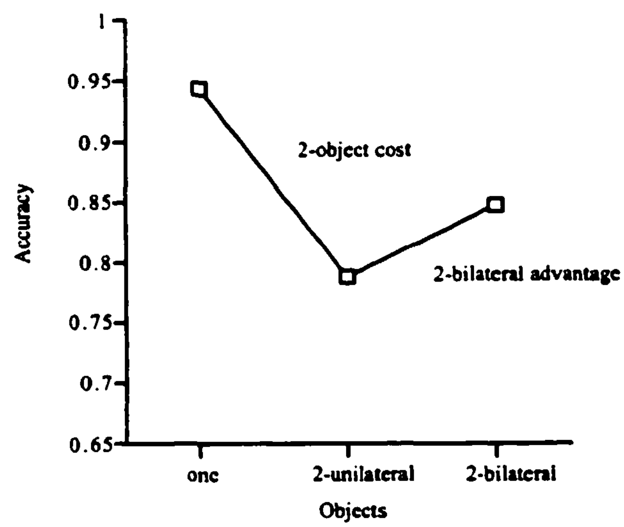

Figure 24: Experiment #5 - Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge despite the spatial manipulations.

There was, however, a field x distance interaction, $F(1,30) = 5.41$, $p < 0.05$ (Figure 25), indicating that the overall right hemisphere advantage increased when elements were placed further afield. Display distance had no other effect on performance. In particular, there was no interaction between object display and display distance (all p's >0.05) demonstrating that the object effects found in this and the previous experiments reflected object-based attention and were not merely an artifact of space-based attention (Vecera, 1994).

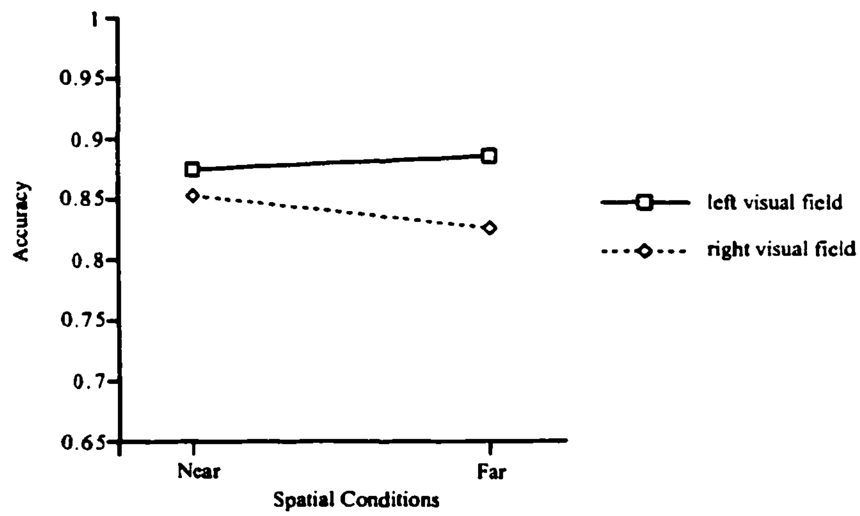

Figure 25: Experiment #5 - Field by Distance Interaction. There is a decrease in accuracy from the Near condition to the Far condition for the left hemisphere but not for the right hemisphere.

The interaction between interval and object was also significant, F (4,120)=8.82, p<. 0005 (Figure 26). This was due to the fact that the performance improvement that was produced when display time was lengthened was much greater for 2-object displays than 1-object displays, presumably because performance was near ceiling for the 1-object display even at the shortest display duration.

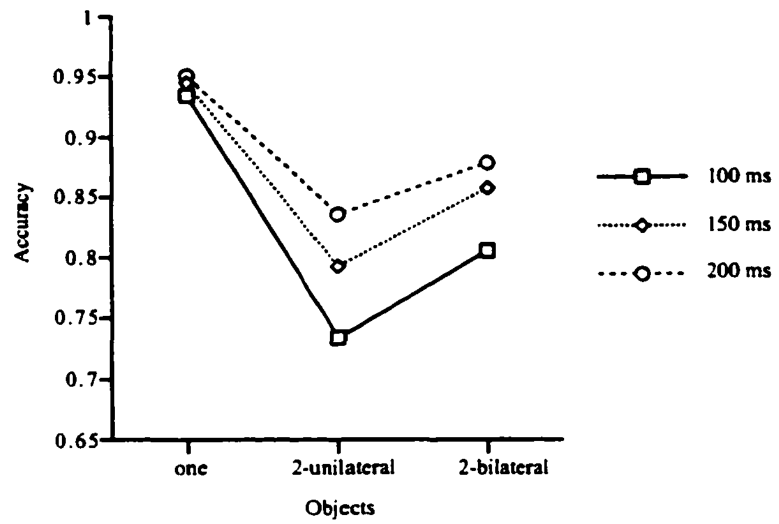

Figure 26: Experiment #5 - Interval by Object Interaction. Performance improves with longer intervals in the 2-unilateral and 2-bilateral conditions, but in the one object condition there is no difference between the three intervals.

The only other significant effect was an object x field interaction, F (2,60)=23.63, p<. 0005. As illustrated in Figure 27, this interaction reflects the fact that there was no difference between visual fields for 1-object displays, F (1,30)=0.30, p<1, but there was an advantage for the right hemisphere in 2-object displays. Planned contrasts showed that this right hemisphere advantage was highly significant for the 2-object unilateral display, F (1,30)=94.60, p<0.0005, and marginally significant for the 2-object bilateral display, F (1,30)=5.57, p<0.05. Planned contrasts also revealed that performance for 2-object bilateral displays was higher than for 2-object unilateral displays. This effect was marginally significant for the right hemisphere, F (1,30)=6.01, p<0.05, and highly significant for the left hemisphere, F (1,30)=96.37, p<0.0005, demonstrating that in the 2-

unilateral condition, the accuracy of the left hemisphere was much lower than the accuracy of the right hemisphere. Finally the field x interval x object was not significant, F(4,120)=0.836, p>0.5 (Figure 28).

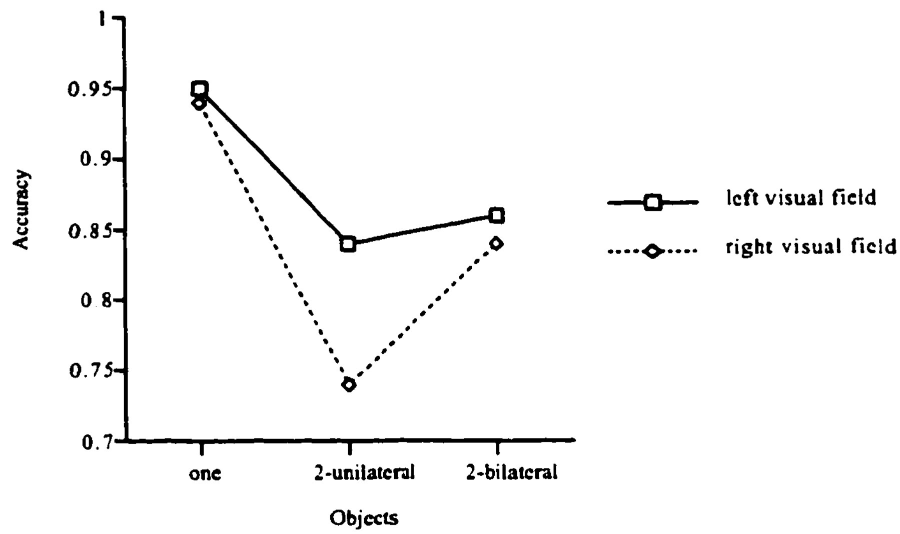

Figure 27: Experiment #5 - Field by Object Interaction. The left hemisphere performs very poorly in the 2-unilateral condition compared to the right hemisphere.

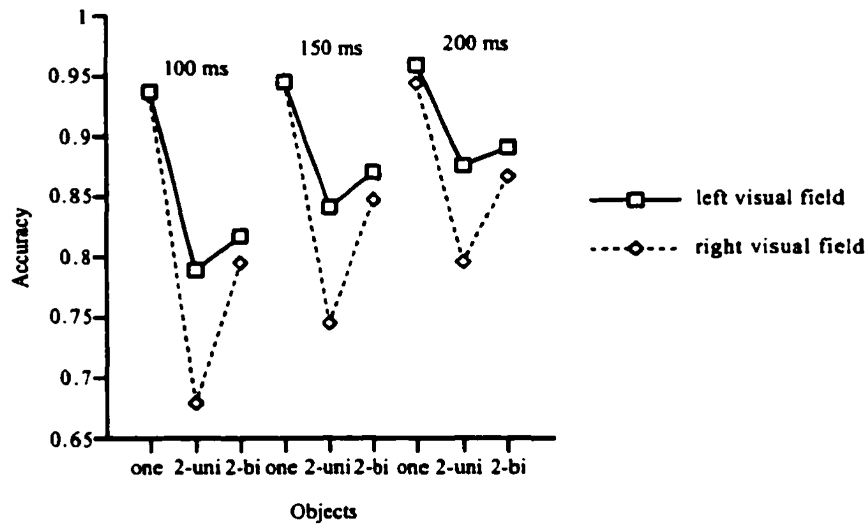

Figure 28: Experiment #5 - Field by Interval by Object Interaction. This three way interaction was not significant.

Therefore despite the spatial manipulations, both the 2-object cost and 2-bilateral advantage continued to emerge. Consequently this experiment was important in establishing that the results reflect object-based selective attention. Crucially a strong field effect was also seen, with higher accuracies for objects presented in the left visual field. Also, for the first time since the distractors were removed from the experimental paradigm, a significant field by object interaction emerged. The left hemisphere performed poorly as compared to the right hemisphere when more than one object was presented, a difference especially prominent in the 2-unilateral condition. This again suggests that the left hemisphere may not have an advantage in processing objects, as concluded by Egly et al. (1994a, 1994b). It is important to note that this field difference occurs in both endogenous orienting (Experiment 1) as well as exogenous orienting (Experiment 5).

The re-emergence of the field effect found in Experiment 1 suggests that not only may each hemisphere be able to selectively attend to objects, but the left hemisphere may not have an advantage in this type of processing as had been previously concluded (Egly et al., 1994a, 1994b). However as this field effect was not consistent across all experiments, the natural question emerges as to the robustness of this field effect. The difference in the field x object interaction was significant in two of the experiments, and though not significant in the remaining experiments, there was a similar pattern in these other studies. Perhaps by examining the results of all of the studies together, a more definitive answer will emerge.

Meta-Analysis of Experiments 1-5

As so many experiments were conducted with very similar paradigms, to evaluate the consistency of the results (especially the field effects), a meta-analysis was performed on Experiments 1-5 (Table 7). As stated above the motivation for this meta-analysis was to determine whether there was a reliable field effect in selective attention to objects, and if so, to determine its nature. Some statistically significant effects were found through this meta-analysis that were not necessarily significant for each of the individual experiments. There was a significant field effect, $F\ (1,95) = 6.40$, $p<0.05$, favouring those objects presented in the left visual field (right hemisphere). There was a significant interval effect, F (21,90) = 182.7, p<0.001, with accuracy increasing with longer display durations. The object effect was also significant, F (2,190) = 308.20, p<0.001, with both the 2-object cost and the 2-bilateral advantage emerging (Figure 29).

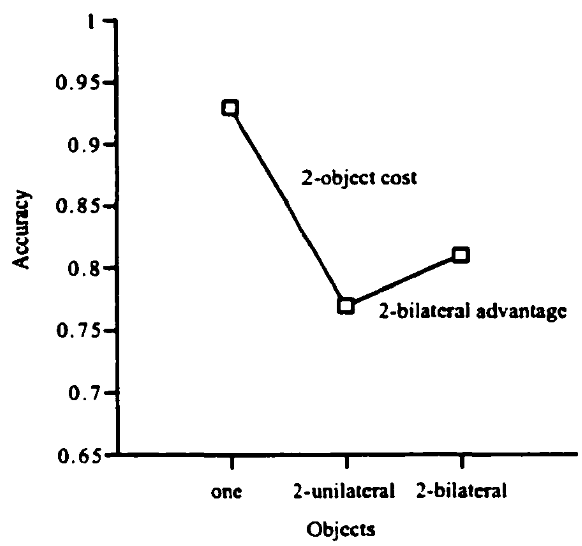

Figure 29: Meta-Analysis of Experiments 1-5 - Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge.

The field x interval was not significant, F (2,190) = 0.96, p>0.05. However the field x object effect was highly significant, F (2,190) = 14.90, p<0.001 (Figure 30). Planned means comparisons found that with the 2-bilateral advantage emerging more strongly for objects presented in the right visual field than those presented in the left visual field. Planned means comparisons found that there was a significant difference between the 2-unilateral and 2-bilateral conditions for both the right hemisphere, F(1,95)=15.83, p<0.001, and the left hemisphere, F(1,95)=115.76, p<0.001. In the 2-unilateral condition performance was significantly better for the right hemisphere as compared to the left hemisphere, F(195)=42.53, p<0.001, but there was no difference between the hemispheres in the 2-bilateral condition, $F(1, 95)=0.067$, $p>0.5$. This relates to the main field effect because for the 2-unilateral condition, accuracy is much higher for objects presented in the left visual field than those presented in the right visual field but the accuracies are equal for the two fields in the 2-bilateral condition. Therefore the overall significantly lower accuracy for objects in the right visual field arises largely from the left hemisphere's poor performance in the 2-unilateral condition. This again indicates that the left hemisphere may actually have a disadvantage in processing objects, rather than the previously reported advantage (Egly et al., 1994a; 1994b).

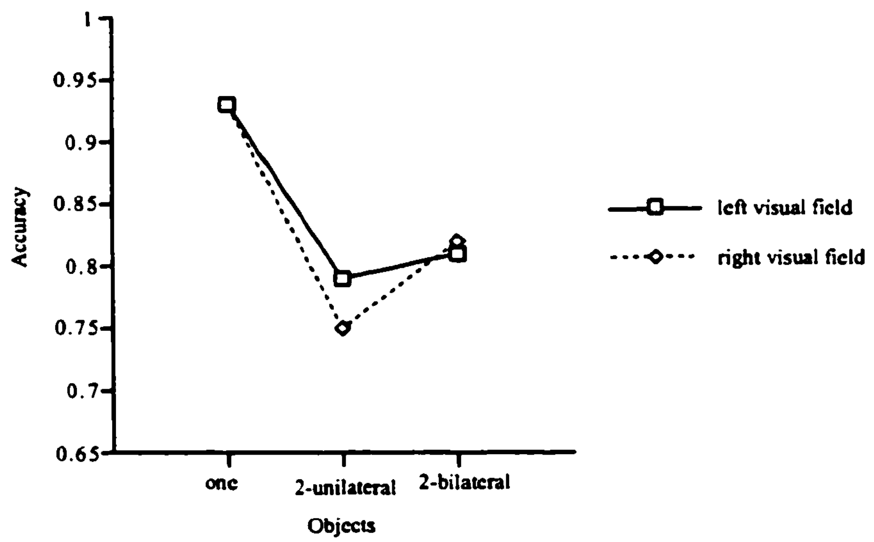

Figure 30: Meta-Analysis of Experiments 1-5 - Field by Object Interaction.
The 2 hemispheres perform similarly in the one object and 2-bilateral conditions. However, in the 2-unilateral condition, the left hemisphere performs very poorly.

The interval x object effect was also significant, $F(4,380) = 8.45$, $p<0.001$ (Figure 31), with the 2-bilateral advantage strongest for longer display durations. Finally, the field x interval x object interaction was not significant, $F(4,380) = 1.68$, $p>0.05$ (Figure 32).

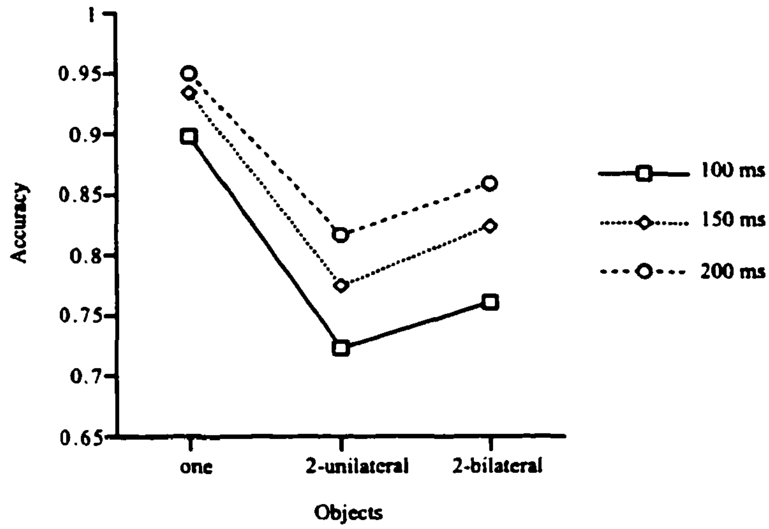

Figure 31: Meta-Analysis of Experiments 1-5 - Interval by Object Interaction. The 2-bilateral advantage is strongest at the 150 ms and 200 ms intervals.

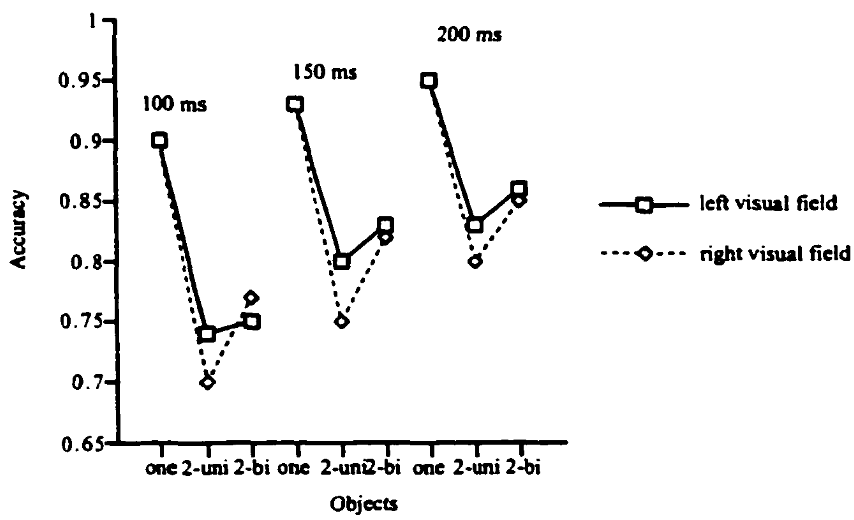

Figure 32: Meta-Analysis of Experiments 1-5 - Field by Interval by Object Interaction. This three way analysis was not significant.

The meta-analysis certainly supported the pattern of results found in the previous experiments and solidified trends pertaining to the visual field that had not been significant in all of the data. Firstly, there was a strong field effect, with higher accuracies for objects presented in the left visual field. This main effect had only previously been significant in Experiment 5.

The field by object interaction was also significant. In the meta-analysis the difference between the left and right hemispheres in the 2-bilateral condition is not evident anymore, but the advantage for the right hemisphere in the 2-unilateral condition is very strong. This difference in accuracy in the 2-unilateral condition appears to be driving the overall right hemisphere advantage. Therefore it may be concluded that contrary to Egly et al. (1994a, 1994b), the left hemisphere does not have an advantage in processing objects, but actually has more problems than the right hemisphere when required to process more than one object.

General Discussion

This series of experiments was designed to investigate hemispheric processing in object-based selection of attention by applying a modified version of the Enns and Kingstone (1997) object-based attention paradigm. The first experiment was conducted to determine how normal subjects would perform on a simple object identification when presented with one object, two objects presented unilaterally or two objects presented bilaterally. The results revealed that response accuracy was higher for 1-object displays than for 2-object displays (the 2-object cost in Duncan, 1984), and for both visual fields the 2-object cost was less pronounced when two target objects were presented between visual fields (2-object bilateral display) than within the same field (2-object unilateral display). This 2-bilateral advantage suggested that each of the hemispheres was able to selectively attend to the objects presented. The field by object interaction revealed that for both the 2-unilateral and 2-bilateral conditions, there was a significant difference between visual fields. At the 2-unilateral condition, the right hemisphere performed better but at the 2-bilateral condition the left hemisphere performed better. This suggested that there may be some differences between the hemispheres in ability to process objects but the nature of this lateralization was unclear.

Experiment 2 controlled for response task as the source of our object effects, by changing the keys required for responding. Both the 2-object cost and 2-bilateral advantage continued to emerge, indicating that these effects were not merely artifacts of the response task. However the field by object interaction was not significant in this study, bringing into question the consistency of the previously found hemispheric differences and whether it had been tied to the original response task.

By removing the distractor objects, Experiment 3 examined whether endogenous or exogenous orienting was the factor underlying the object effects. Again the 2-object cost and 2-bilateral advantage were evident, proving that distractor presence was not necessary to produce these effects. As in Experiment 2, the field by object effect was not observed. However, because the response task was the same as in Experiment 1, the original task was ruled out as being the source of the field effect.

Experiment 4 examined whether stimulus location in the 2-bilateral condition was producing the 2-object cost and 2-bilateral advantage. It continued to produce these effects, but again the field by object interaction was absent.

Experiment 5 was very important as by applying a spatial manipulation the previous object effects were confirmed as being products of object-based selective attention. As well, the field by object interaction reappeared, with a significant difference between the hemispheres at the 2-unilateral condition. The poor performance of the left hemisphere in the 2-unilateral condition was also the driving force of an overall right hemisphere advantage. The results proved that distractors were not required to produce the hemispheric differences.

Finally the meta-analysis examined whether the field effect was robust when the data were collapsed across experiments. As in Experiment 5, there was an overall right hemisphere advantage driven largely by the poor performance of the left hemisphere in the 2-unilateral condition.

The data from these experiments, especially the meta-analysis, indicates that the left hemisphere is particularly poor at committing attention selectively to multiple elements in its field. Thus, in agreement with Egly et al. (1994a, 1994b) our data suggest that object-based attention is a specialized form of orienting that is subserved by lateralized cortical brain mechanisms. However, contrary to the conclusions of Egly et al. (1994a, 1994b) our data indicate that the right hemisphere -- and not the left hemisphere -

- is preferentially biased for committing object-based attention to elements in the visual environment. This finding reinforces the concern first raised by Vecera (1994) that the conclusions regarding object-based attention based on the paradigm of Egly et al. (1994a, 1994b) may be compromised. To our knowledge the present investigation represents the first examination of purely object based attention effects across the cerebral hemispheres. How these object-based results will generalize across different types of objects and tasks will be the focus of the following chapter.

Chapter 3: Generalizabilty of Object-Based Attention Effects

The literature review presented in Chapter 1 laid a foundation for examining object-based attention. Attention is an essential cognitive function and appears to be subdivided into different modules, each of which devoted to a particular aspect of attention. One of these modules deals with selective attention of objects (Duncan, 1984). The functional modularity of object-based attention had been well established but there remain some questions as to the anatomical modularity, especially with respect to any hemispheric differences that may exist in this type of processing. This question was initially explored in the series of experiments presented in Chapter 2. One of the main conclusions from these studies was that accuracy was always reduced when 2 objects were presented as compared to when only one object was presented (2-object cost also found in Duncan's (1984) paradigm). And with respect to hemispheric processing, both hemispheres were able to orient their attention towards objects (2-bilateral advantage) but the left hemisphere performed worse than the right hemisphere when presented with more than one object.

This implies that the right hemisphere actually has an advantage rather than a disadvantage in processing objects, which directly contradicts Egly's (1994a, 1994b) conclusions. Thus, it would appear that Vecera's (1994) concerns that Egly's paradigm was not an accurate measure of object-based attention may have been valid as the conclusions about each of the hemisphere's roles in object-based attention have not been confirmed. As the paradigm used in Experiments 1-5 of this dissertation was also subjected to a spatial manipulation, similar to Vecera's treatment of Egly's paradigm, and our object effects, namely the 2-object cost and 2-bilateral advantage, continued to emerge, we are confident that our paradigm is an accurate measure of object-based attention.

A number of experiments were also undertaken to ensure that the results were not due to response demands, location of stimuli or distractors. Therefore it does appear that the paradigm produces hemispheric differences in selectively attending to objects, at least with the present task and stimuli.

The next important question to ask is whether this pattern of hemispheric processing emerges with different types of stimuli and/or tasks. If the effects do not generalize, they may not be true indicators of the underlying hemispheric processing, but rather just a by-product of the particular stimuli or task that we used. In the Duncan (1984) paradigm, he presented stimuli that consisted of a box with a line superimposed across it. There were four dimensions of the stimuli that could vary in this experiment: box (size), box (gap), line (tilt) and line (texture), and for each display, subjects had to judge one or two of these four properties. For example, box size and line texture might remain constant and the subject would be required to indicate where the box gap was and whether the line going through it was tilted to the left or the right. While neither the box size nor line texture has visuospatial components, both the location of where the gap is and the tilt of the line can be considered visuospatial object judgments in nature, very similar to the task required in our paradigm. Duncan (1984) found the 2-object cost with all of these stimuli and judgments, but did not look for any hemispheric differences. In the Enns and Kingstone (1997) paradigm elongated rectangles were used and the important object feature was visuospatial, the response depended on the orientation of the object. While object-based attention was indicated, no significant hemispheric differences were found. Therefore while we know from these previous studies that object-based attention can be examined using different types of stimuli and judgments, how hemispheric differences fluctuate accordingly is unknown. As in all of the previous experiments, only one type of stimulus was used and subjects were required to make only one type of judgment, it was important to ascertain whether any of the object or lateralization effects emerged simply due to the type of stimuli presented or the object judgment required. Perhaps by changing the stimuli, the task or both of these dimensions, the object effects might not emerge and any hemispheric differences might be reversed or disappear completely. Therefore the results may not be informing about general hemispheric processing in object-based selective attention, but rather just a specific response to object identification of the orientation of ovals.

Accordingly, this chapter will focus on utilizing the same basic paradigm used in the experiments presented in chapter 2, but will include manipulations to the type of stimuli and/or the judgments required to respond correctly to the objects. These manipulations will ensure that the 2-bilateral advantage as well as the hemispheric differences found in the previous experiments are generalizable and not simply constrained to ovals and judgments of their orientation. Even though it has been demonstrated that there are some differences in hemispheric processing within object-based attention, given that only one type of stimulus and only one type of judgment were tested, little at this point can be stated in general about hemispheric differences in object-based selection of attention. Therefore, the goal of the following experiments will be to establish that the 2-object cost, the 2-bilateral advantage and the poor performance of the left hemisphere in processing multiple objects are consistent across various stimuli and judgments.

Experiment #6

From the results of the studies presented in Chapter 2, there appears to be a strong field effect favouring the right hemisphere over the left hemisphere for the present object-based selection task. Subjects did better overall when objects were presented to the left visual field than when objects were presented to the right visual field. It was obvious by examining the field x object interaction that this advantage was driven by the poor accuracy of the left hemisphere when presented with two objects. This disparity between the processing of the hemispheres may have been because the important object feature in the task was visuospatial in nature (decision on orientation), which has been shown to be preferentially lateralized to the right hemisphere. In order to test whether these hemispheric effects emerged solely because "right hemisphere" stimuli were presented, it was decided that the experiment should be run with stimuli that are thought to be processed better by the left hemisphere.

One of the first cognitive functions to be examined with respect to hemispheric differences was language. Since the time of Broca and Wernicke it was noticed that there was a higher incidence of language disorders after unilateral brain damage to the left hemisphere. In a number of important aspects of language, including reading, writing, understanding and speaking, deficits are always more prominent with left hemisphere damage. More recent investigations have determined that 95% of right-handers have their language abilities lateralized to the left hemisphere so it is not surprising that damage to this area of the brain results in so many language deficits (for review see Hellige, 1993).

As it was important to determine whether the object effects (including the hemispheric differences) from the previous set of results were simply due to the type of stimuli presented, and given the strong lateralization for language to the left hemisphere, the ovals presented in Experiments 1-5 were replaced with letters. If the conclusion about the right hemisphere advantage for objects is correct, the fact that the stimuli are highly skewed towards a left hemisphere advantage should not change the pattern of results. Basically, the right hemisphere should continue to outperform the left hemisphere, especially when two objects are presented in the same visual field, despite the manipulation in stimuli.

Method

Methodological details were the same as in Experiment 1 except where indicated. Twenty new subjects were brought in for this experiment. All were undergraduate psychology students at the University of Alberta during summer session, had normal or corrected-to-normal vision and all received course credit for their participation in the study. We again presented four RSVP displays, the background display, probe display, mask and target display. The main difference in this study from the previous experiments was that instead of ovals, letters were used as stimuli (Figure 33). Either black or white

'Z's or 'N's (1.3 ° x 1.3 °) were presented in the four location markers and the task was the same as in the first experiment. Subjects were required to attend to only the one or two black letters and decide whether the probe letter and target letter matched. If the probe letter did not match the target letter no response was made. However if the probe and target letters were the same, either a right or left key was pressed, depending on the field of the probe letter. Another difference was that the intervals used were 60, 100, and 150 ms, as pilot work revealed that response performance was near ceiling with the previous and longer range of display durations.

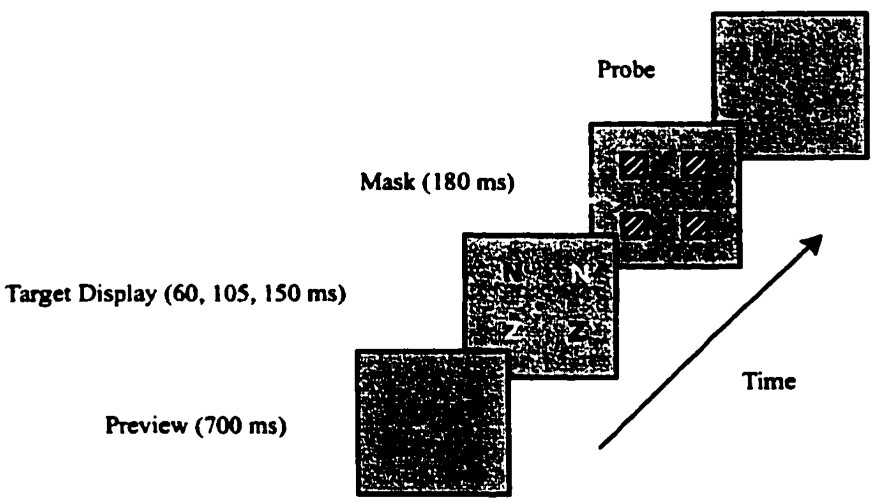

Figure 33: Experiment #6 Paradigm. A trial consisted of four displays. A central fixation dot and 4 location markers were presented in the preview. In the target display black target or white distractor letters (N or Z) were presented at the location markers. After a brief mask a probe letter was presented inone of the black target letter locations. The subject's task was to indicate whether the probe and target letters matched.

Results and Discussion

Response accuracy (percent correct) was subjected to an analysis of variance

(ANOVA) with target visual field (left or right), object display (1-object, 2-object unilateral, 2-object bilateral), and interval (60, 100, 150 ms) as within-subject factors Table 8).

There was a significant field effect, $F(1,19) = 4.890$, $p<0.05$. In this experiment and similar to the previous set of results, accuracy was greater when the objects were presented to the right hemisphere. Despite the fact that letter stimuli (which are usually processed better by the left hemisphere) were presented, the right hemisphere continued to perform better in this task. Therefore one important conclusion from this experiment appears to be that the right hemisphere has an advantage in processing objects regardless of the nature of these objects.

The interval effect was highly significant, $F(2,38) = 41.567$, $p<0.001$, with higher accuracies for longer display durations. The ANOVA also showed a highly significant effect of object, $F(2,38) = 30.60$, $p<0.001$ with the 2-object cost and 2-bilateral advantage patterns emerging (Figure 34). Planned means comparisons were again conducted to determine whether there was a significant difference between the 2-unilateral and 2-bilateral conditions and the result was significant, $F(1,19) = 5.199$, $p<0.05$. Therefore, both the 2-object cost and the 2-bilateral condition advantage found in the previous experiments were preserved despite the manipulation of stimuli.

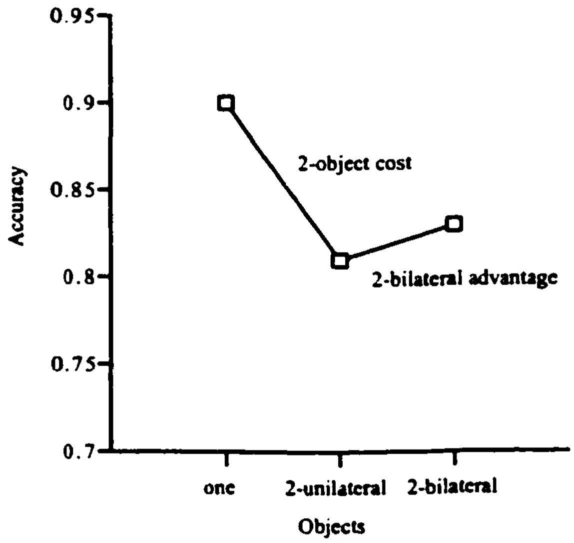

Figure 34: Experiment #6 - Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge.

There were no significant two-way interactions for this experiment: field x interval, $F(2,38) = .699$, $p>0.05$; field x object, $F(2,38) = 2.795$, $p>0.05$ (Figure 35); interval x object, $F(4,76) = 2.077$, $p>0.05$. However, in the field by object interaction, planned means comparisons showed a significant difference between the right and left visual fields in the 2-unilateral condition, $F(1,18)=11.159$, $p<0.005$ with the right hemisphere being more accurate than the left hemisphere. No such difference was found for the 2-bilateral condition, $F(1,18)=0.024$, $p>0.5$. Therefore even though the field x object interaction was not significant, one can see from the graph that the overall right hemisphere advantage is driven by the poor performance of the left hemisphere in the 2-unilateral condition, even though letters were presented. Planned means comparisons also showed that there was a significant 2-bilateral advantage in the right visual field, $F(1,18)=15.740$, $p<0.001$, but not in the left visual field, $F(1,18)=0.610$, $p>0.5$. Finally, there was also not a significant field by interval by object interaction, $F(4,76) = 1.599$, $p>0.05$ (Figure 36).

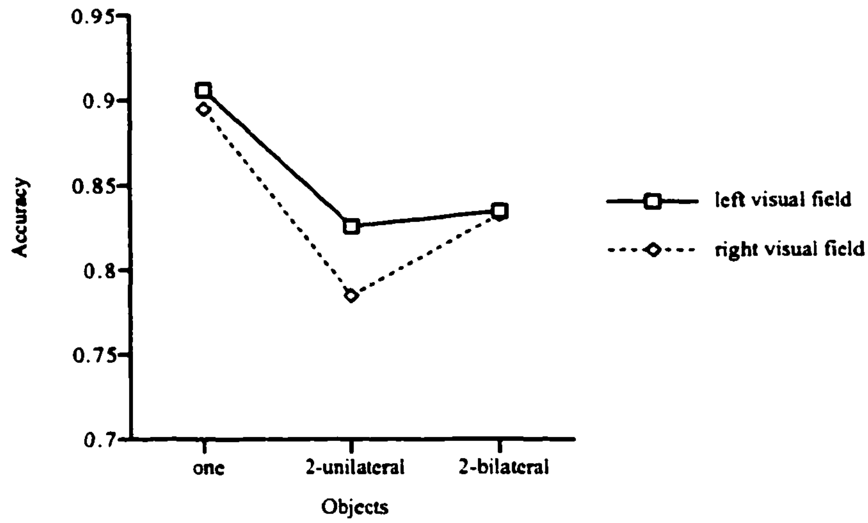

Figure 35: Experiment #6 - Field by Object Interaction. This interaction was not significant. However planned means comparisons found that the accuracy of the left hemisphere was significantly lower than the right hemisphere in the 2-unilateral condition.

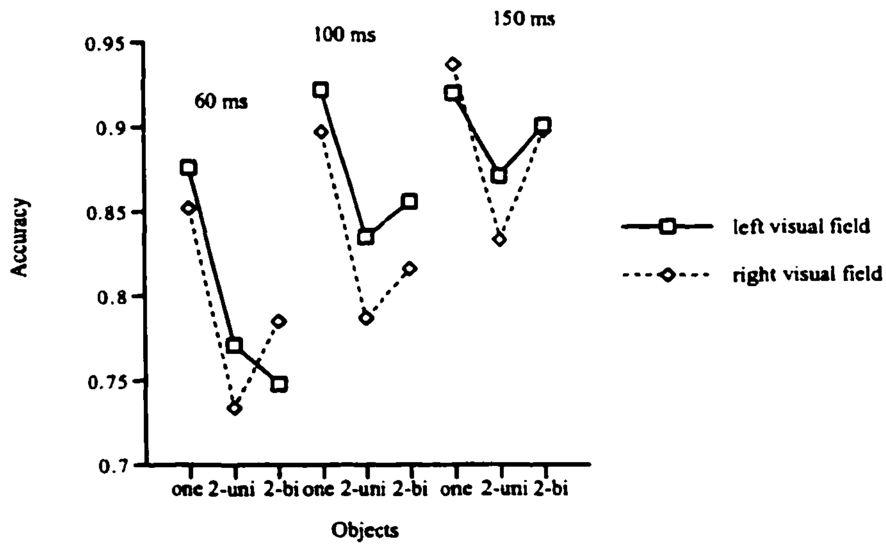

Figure 36: Experiment #6 - Field by Interval by Object Interaction.This three way analysis was not significant.

This experiment was conducted to determine whether the object effects and hemispheric differences established in Experiments 1-5, would be altered when a different type of stimulus was presented. Especially important is the fact that letters were chosen as stimuli as they tend to be processed better by the left hemisphere, rather than the right hemisphere, which showed an advantage in the meta-analysis.

The first important result was that the 2-object cost emerged in this experiment despite the change in stimuli. Also, the 2-bilateral advantage was also preserved, with accuracy being higher when 2 letters were presented bilaterally as compared to when they were presented unilaterally. These results mirror the pattern found in the previous experiments. With respect to hemispheric differences, there was a significant field effect, with an overall greater performance by the right hemisphere on the task, which was again driven largely by the left hemisphere's poor performance in the 2-unilateral condition. Therefore even though the stimuli presented might favor processing by the left hemisphere, the right hemisphere continued to outperform it. Though Egly et al. (1994a, 1994b) claimed a left hemisphere advantage for object-based attention, there continues to be no evidence for this conclusion. In fact the results, even with different types of stimuli, suggest that the opposite is true: the left hemisphere is particularly poor at allocating attention to multiple objects. This conclusion holds true even when the paradigm is biased towards an advantage for the left hemisphere, by using letters as the stimuli. Therefore Experiment 6 demonstrates that the right hemisphere specialization for object-based selection of attention, is not stimuli specific but generalizable to different types of stimuli.

Experiment #7

Along similar lines, the next issue of interest was whether the type of object judgment required would have an effect on how both hemispheres processed the information and whether one hemisphere would continue to show an advantage. Though not consistent across all the previous studies, when there was a field effect it always favoured the right hemisphere, contrary to the conclusions drawn by Egly et al. (1994a, 1994b). From the meta-analysis conducted in Chapter 2 that looked at the results of the first five experiments, there was a strong hemispheric difference in favour of the right hemisphere for the object-based selection required for the paradigm and Experiment 6 also showed this right hemisphere advantage. There have been some theories that propose that attention is primarily a right hemisphere process with the left hemisphere playing only a minor role in that process (Posner, 1995). However, the 2-bilateral advantage that has emerged consistently during the first set of experiments demonstrated that when stimuli are presented to the left hemisphere it is able to process them, just not as well as the right hemisphere.

Different types of judgments have been used to study object-based attention. Duncan (1984) included visuospatial judgments as well as texture judgments in his task. For example sometimes the tilt of the line (towards the right or left) was important for the subject's task while at other times the composition of the line (dashed or dotted) was important. Duncan found that either of these judgments produced the 2-object cost. In the first set of experiments, subjects have always only made a visuospatial judgment of the object, and for this type of judgment the right hemisphere has had the advantage. In Experiment 6 it was discovered that this pattern of results remained consistent despite changing the stimuli from ovals to letters. Therefore it does appear that the results do generalize to different types of stimuli. However one might argue that subjects in Experiment 6 were not representing the letter stimuli as letters, per se. In order to minimize the differences between Experiment 6 and the previous studies, the letter stimuli were chosen so that their identity changed merely by rotating 90 degrees (e.g., an N becomes a Z when rotated 90 degrees). In this way the display presentations were comparable to the previous experiments in which subjects judged whether the items were oriented vertically or horizontally (a translation difference of 90 degrees). Thus it is possible that subjects in Experiment 6 were performing the task simply based simply on whether the target and probe were of the same orientation or displaced by 90 degrees. In this way one might argue that whether different types of object judgments affect hemispheric processing has yet to be determined. So in this next experiment, either a judgment about the actual shape of the object is required or a judgment based on whether the object is tilted to the right or left is required. The results of this experiment should support the previous data, namely with the 2-object cost, 2-bilateral advantage and right hemisphere advantage continuing to emerge. This would again lead to the conclusion that it is the right and not the left hemisphere that plays a special role in object-based selection of attention.

This experiment is again very similar to all the previous experiments in that subjects were required to judge whether objects in a probe display were the same or different than objects presented in a previous target display. However, one important difference was that this experiment was divided into two tasks, even though the stimuli remained the same for both tasks. In the shape task, subjects were required to indicate whether the shape of the object was the same in both the target and probe displays, regardless of the orientation of the object. In the orientation task, subjects were required to indicate whether the orientation of the object was the same in both the target and probe displays, regardless of the shape of the object. Because there was no difference in the presentation of the stimuli, any lateralization effects that emerged could be attributed to differences in the processing abilities of objects rather than any differences in the experimental paradigm. As this paradigm so closely matched the first set of experiments, one would expect to see a 2-object cost or reduced accuracy when subjects attended to 2 objects as well as an overall 2-bilateral advantage. Higher accuracies for objects presented in the left visual field regardless of whether a shape or orientation judgment is required were also expected.

Method

Nineteen undergraduate psychology students (15 female, 4 male) at the University of Alberta were tested with the same profiles as the previous experiments. They were tested during two sessions that were exactly one week apart.

The procedure and stimuli were similar to Experiment 4 with the following exceptions. The initial display signaled the start of a trial and for 700 ms consisted of a black central fixation point with four black location markers (in the shape of diamonds) on a gray background located 8° from fixation. These location markers were again positioned on the four corners of an imaginary square centered on fixation. The following target display was composed of either one or two black ovals or rectangles being presented within the location markers. Both the ovals and rectangles subtended 1° x 0.6° visual angle, and were oriented either 45° to the left or right. This display was always presented for 150 ms. Exactly as in the previous experiments, a mask display with four squares with a pattern of thick white and black oblique lines was then presented for 180 ms. The final probe display was similar to the second display except that only one object was presented. This probe always appeared in the same location as an object in the target display.

This experiment was divided into a shape judgment task and an orientation judgment task, and subjects performed one type of judgment task in the first testing session and then one week later, performed the second judgment task. The sequence of judgments was randomized across the subjects. For the shape judgment task, the subject had to decide whether the probe object matched the target object in shape only. Therefore all that was important was whether the two objects were ovals or rectangles, their orientation was not a factor. For the orientation judgment task, the subject had to decide if the objects matched on orientation only (either oriented to the left or right), regardless of the shape of the object (Figure 37). For both of these types of judgment tasks the response demands were the same. If the probe matched the target, and the probe was in the left visual field, then the subject pressed the "z" keyboard key with the left hand. If the probe matched the target, and the probe was in the right visual field, then the subject pressed the "/" keyboard key with the right hand. However, if the probe and targets did not match, no response was required and after 1350 ms, the next trial would begin.

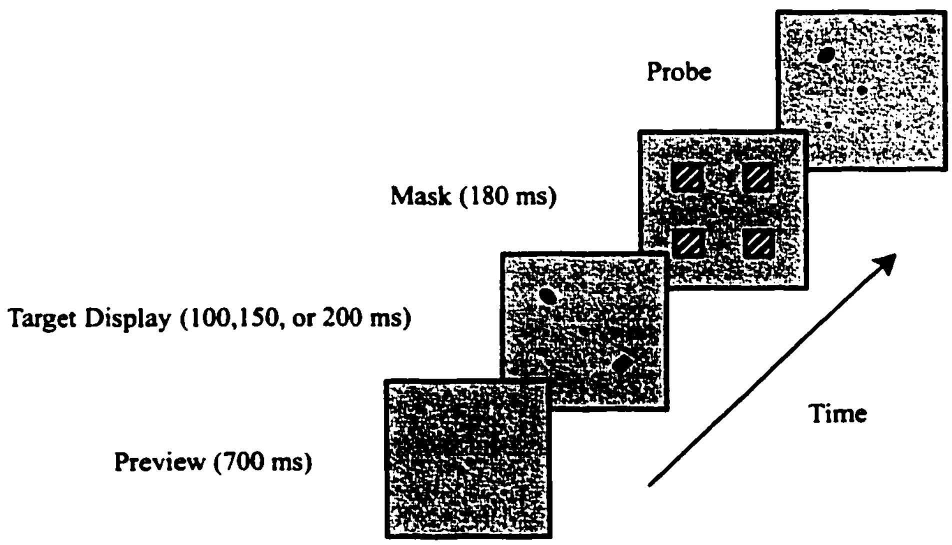

Figure 37: Experiment #7 Paradigm - The sequence of displays is similar to the previous experiments, however the task is different and the stimuli consist of both ovals and rectangles oriented 45° from vertical. If the judgement required is orientation, the probe and target objects must match on this dimension, regardless of the shape of the object. However if a shape judgement is required, the shape of both the probe and target objects must match regardless of orientation. In the present example, the probe and target would match for a shape judgement, but not for an orientation judgement.

Results and Discussion

Response accuracy (percent correct) was subjected to an analysis of variance

(ANOVA) with judgment (shape, orientation), object display (1-object, 2-object unilateral, 2-object bilateral), and target visual field (left or right) as within-subject factors (Table 9). Analysis revealed main effects for judgment, $F(1,18)=11.28$, $p<0.005$, and object display, $F(2,36)= 34.88$, $p<.0005$ (Figure 38), reflecting the fact that response accuracy was higher for the shape judgment as compared to the orientation judgment and also that there was a 2-object cost when 2 objects were presented. Planned means comparisons again found that there was a significant increase in accuracy for 2-bilateral trials as compared to 2-unilateral trials, $F(1,18)=11.32$, $p<0.005$. So, in accordance with all previous experiments, there was a 2-bilateral advantage indicating that both of the cerebral hemispheres were able to orient attention regardless of the judgment required.

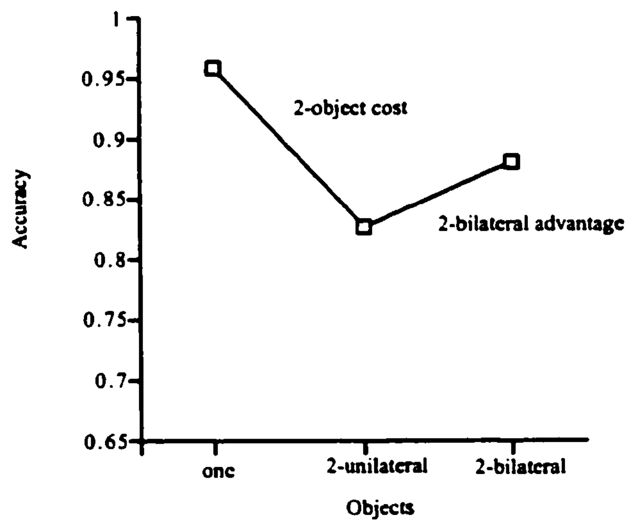

Figure 38: Experiment #7 - Object Effect. Both the 2-object cost and the 2-bilateral advantage continue to emerge.

The target visual field, $F(1,18)=2.63$, $p>0.1$ was not a significant factor. Nor were any of the interactions between factors significant: judgment x object, $F(2,36)=3.25$

(Figure 39), p>0.051, judgment x field, F(1,18)= 0.553, p>0.05, object x field, F(2,36)= 2.52, p>0.05 (Figure 40) and judgment x object x field F(2,36)=0.497, p>0.5 (Figure 41).

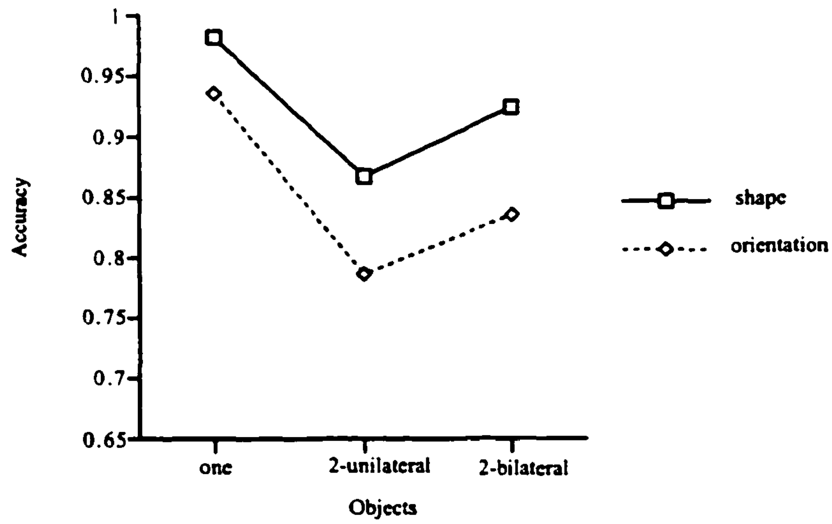

Figure 39: Experiment #7 - Judgement by Object Interaction. This interaction was not significant.

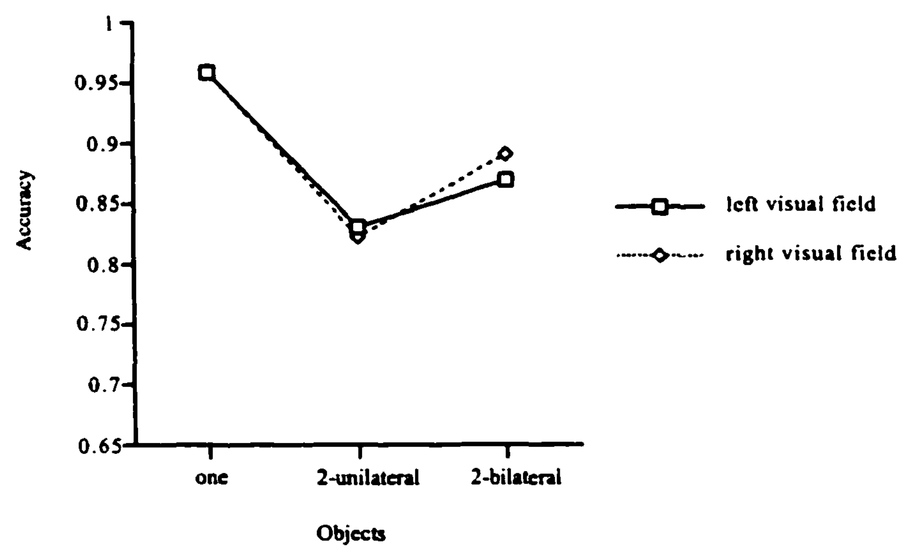

Figure 40: Experiment #7 - Field by Object Interaction. This interaction was not significant.

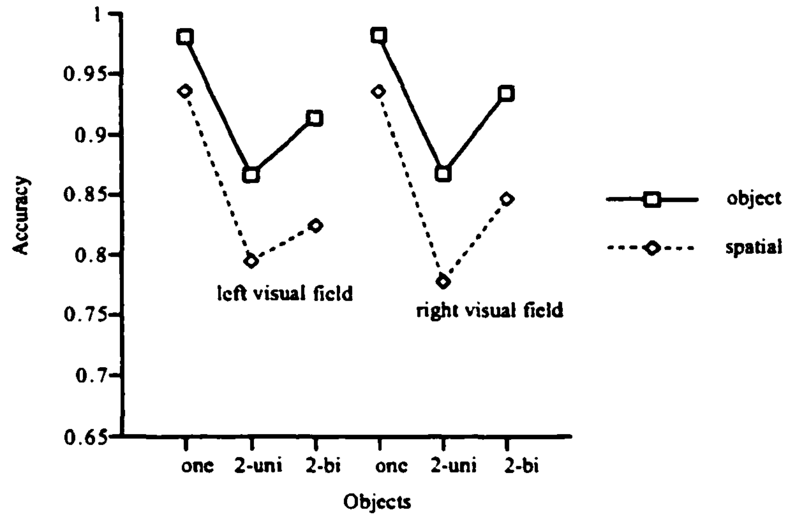

Figure 41: Experiment #7 - Judgement by Field by Object Interaction. This three way analysis was not significant.

The purpose of conducting this experiment was to ascertain whether changing both the stimuli presented as well as the type of judgment required in the task, would change the now established pattern of results. Both the 2-object cost and 2-bilateral advantage continued to emerge. Thus, object-based attention is definitely being accessed and the two hemispheres, regardless of which judgment is required, can process this selection independently. One of the added dimensions of this experiment was that two different judgments were required and here we do find a significant difference. Subjects were more accurate when shape discriminations were required as compared to orientation discriminations were required in all object conditions: 1, 2-unilateral and 2-bilateral. In fact, for the one object-shape judgment trials they were 98% accurate. This is extremely problematic, as when subjects are at ceiling it is difficult to discriminate any significant differences within the data that might emerge if the task was more challenging for the subjects to complete. Therefore, in the future, one might want to equalize the difficulty of the two tasks to better compare their results.

With respect to hemispheric processing, no significant differences were found in this experiment. Overall the two hemispheres performed similarly and there were no differences either between the object conditions or the judgment required. However, one must remember that the fact that the subjects are at ceiling unquestionably compromised any opportunity to observe hemispheric differences. It is also worth noting that even in the first set of experiments presented in Chapter 2, not all the experiments produced significant hemispheric differences, but the meta-analysis did show a strong effect.

Therefore the issue of whether the type of judgment required plays an important role in hemispheric processing must be examined further, perhaps by equalizing the difficulty of the different types of judgments as well as increasing the number of subjects participating in the experiment.

Meta-Analysis of Experiments 6 & 7

As with the experiments in Chapter 2, after conducting Experiments 6 and 7 there was some ambiguity with respect to hemispheric differences when different stimuli or judgements were included in the paradigm. Therefore, once again, a meta-analysis was conducted to evaluate the consistency of the results, particularly those concerning visual field presentation. As in Experiment 7, only a display duration of 150 ms was used, only the data from that interval in Experiment 6 was included for analysis (Table 10). Through this meta-analysis the role of the hemispheres in selective attention to objects, when different stimuli or judgements are required, should be elucidated.

There was not a significant field effect, $F(1,57) = 0.016$, $p>0.5$, but there was a significant object effect, $F(2,114)=60.243$, $p<0.0005$ with both the 2-object cost and the 2-bilateral advantage emerging. The field x object effect was also significant, $F(2,114) = 4.258$, $p<0.05$ (Figure 42). Planned means comparisons found that there was a significant difference between the 2-unilateral and 2-bilateral conditions for both the right hemisphere, $F(1,57)=20.197$, $p<0.001$, and the left hemisphere, $F(1,57)=70.885$, $p<0.001$. In the 2-unilateral condition performance was significantly better for the right hemisphere as compared to the left hemisphere, $F(1,57)=5.001$, $p<0.05$, but there was no difference between the hemispheres in the 2-bilateral condition, $F(1, 57)=2.853$, $p>0.05$. Therefore even though there appeared to be a contradiction between the field effects in Experiments 6 and 7, the meta-analysis revealed that overall, the left hemisphere continues to perform poorly in the 2-unilateral condition. This again indicates that the left hemisphere may actually have a disadvantage in processing objects, rather than the previously reported advantage (Egly et al., 1994a; 1994b).

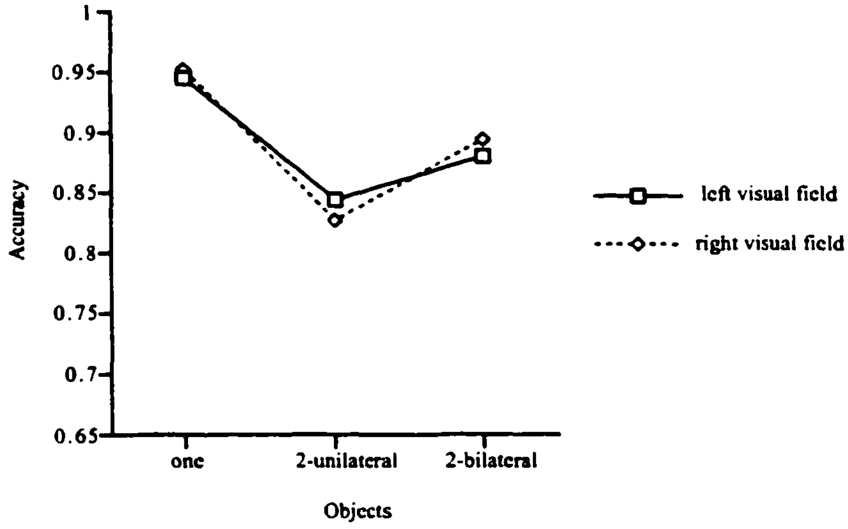

Figure 42: Meta-Analysis of Experiments 6 & 7- Field by Object Interaction. The right hemisphere performs significantly better than the left hemisphere in the 2-unilateral condition, but there is no significant difference in the 2-bilateral condition.

General Discussion

The goal of the experiments in this chapter was to ensure that the results found in the set of experiments presented in Chapter 2 were not constrained to a particular type of stimulus or judgment.

The 2-object cost was preserved in both of the experiments. It was always more difficult to make a judgment about an object when more than one object was presented. Another significant point is that the 2-bilateral advantage continued to emerge despite changes in stimuli or judgment required. Accuracy was always higher in the 2-bilateral condition in which each hemisphere was responsible for processing only one object as compared to the 2-unilateral condition in which one hemisphere was responsible for processing two objects. Therefore even with the manipulations, both hemispheres were able to orient attention towards objects independently.

While the first two findings were quite robust, the issue of hemispheric differences in processing in Experiments 6 and 7 was somewhat ambiguous. In Experiment 6, which used letters as stimuli, there was a strong advantage in processing for the right hemisphere, and even though the field x object interaction was not significant, the overall right hemisphere advantage was driven by the poor performance of the left hemisphere in the 2-unilateral condition. In Experiment 7 no significant field effects emerged but this could be due to the disproportionate difficulty of the judgments (object task was much easier) as well as the fact that only a display duration of 150 ms was utilized. The meta-analysis illustrates that when the data are collapsed, a pattern of results emerges which is consistent with the previous findings. That is, the left hemisphere performs poorly in the 2-unilateral condition. This stands as further evidence that the left hemisphere is not specialized for selectively attending to objects but actually has problems when more than one object is presented.

As all of the experiments have been run on normal subjects, it was felt that to get a definitive conclusion on how the two hemispheres selectively attend to objects, the results with normal subjects would have to be combined with an appropriate patient population. As has been mentioned throughout this dissertation, split-brain subjects allow experimenters to examine each of the hemispheres in order to isolate the extent of processing by each hemisphere in a given task. Therefore the focus of the next chapter will be to investigate how a spilt-brain patient performs on the now well-established object-based attentional paradigm used in the previous experiments.

Chapter 4: Object-Based Selective Attention in a Split-Brain

The primary purpose of this dissertation has been to clarify the issue of lateralization in object-based selective attention. Previous research by Egly et al. (1994a, 1994b) suggested that the left hemisphere had an advantage in processing objects, but Vecera (1994) have taken issue with the experimental paradigm that led to that conclusion. The present series of experiments has determined that with a simple object-based attentional paradigm, normal subjects exhibit a 2-object cost, a 2-bilateral advantage and a left hemisphere disadvantage in the 2-unilateral condition that is robust across a broad range of stimulus and response manipulations.

Because it is important to understand the neural mechanisms underlying object-based attention, any behavioral asymmetries are important to explore as they may indicate differences in the processing abilities of the two hemispheres. As was reviewed in Chapter 1, lateralization issues can sometimes be clarified by examining how a split-brain patient performs on the task of interest. In this way, the degree of processing that occurs in each of the two hemispheres can be examined. Therefore, the focus of this chapter will be to test a split-brain patient in order to establish how the hemispheres perform in isolation during selective attention to objects.

Experiment 8

From the results of the experiments in Chapters 2 and 3, a more accurate picture of the neural processing involved in object-based selective attention is emerging. When two objects are presented accuracy is lower than when only one object is presented. Also subjects perform better when the two objects are divided between the two visual fields as compared to when both objects are presented to the same visual field. This indicates that there may be independent processing of objects by the two hemispheres, with each hemisphere possessing the ability to selectively attend to objects. While both hemispheres are able to process this type of information, it also appears that the left hemisphere is not as efficient at processing more than one object as the right hemisphere. In order to determine the extent to which these lateralization effects reflect properties intrinsic to each of the hemispheres and/or cortical competition between the two hemispheres, a split-brain patient was tested on the object-based attention paradigm.

Method

Subject

This experiment was conducted with J.W., a 43 year old right-handed split-brain patient whose corpus collosum was severed in 1979 as treatment for intractable epilepsy. A subsequent MRI confirmed that the colossal transection was complete. This patient has participated in a number of behavioral experiments and a detailed history of this patient can be found in Sidtis, Volpe, Wilson, Rayport and Gazzaniga (1981). This experiment was conducted at Dartmouth College over 4 sessions in two successive days. J.W. was monetarily compensated for his participation in this study.

Apparatus

This experiment was conducted on a Macintosh 66 computer. The stimuli were presented on a 14-inch Apple color monitor (set to black and white) at a viewing distance of approximately 57 cm. Responses were collected from keyboard button presses.

Stimuli and Procedure

Figure 43 illustrates the sequence of stimulus events presented in a given trial. The initial display signaled the start of a trial and consisted of a black central fixation point with four black location markers (in the shape of diamonds) on a gray background. These markers were positioned on the four corners of an imaginary square 4° from central fixation. J.W. was instructed to keep his eyes on the fixation point at the start of each trial, and to withhold any eye movements until the end of the trial. The duration of this initial display was 700 ms. The next display (target display) was composed of either one or two horizontal or vertical black rectangles being presented within the location markers and the remaining location markers were filled with horizontal or vertical white rectangles. The rectangles subtended 0.9° x 0.3° visual angle, and were presented for 60, 100 or 150 ms (each duration was equiprobable and randomly selected). Rectangles were presented instead of the ovals used in the previous experiments, as patient J.W. was familiar with making same/different judgements of rectangle stimuli, thereby reducing the difficulty in explaining the task to J.W. Immediately following this display was a 180 ms display consisting of four white squares which subtended 2° x 2.2° visual angle and were centered on each of the four location markers. The final display (probe display) was similar to the second display except that only one black rectangle was presented. This probe always appeared in the same location as a black rectangle in the target display. Half the time the probe matched, and half the time the probe did not match the orientation of the target black rectangle that had preceded it.

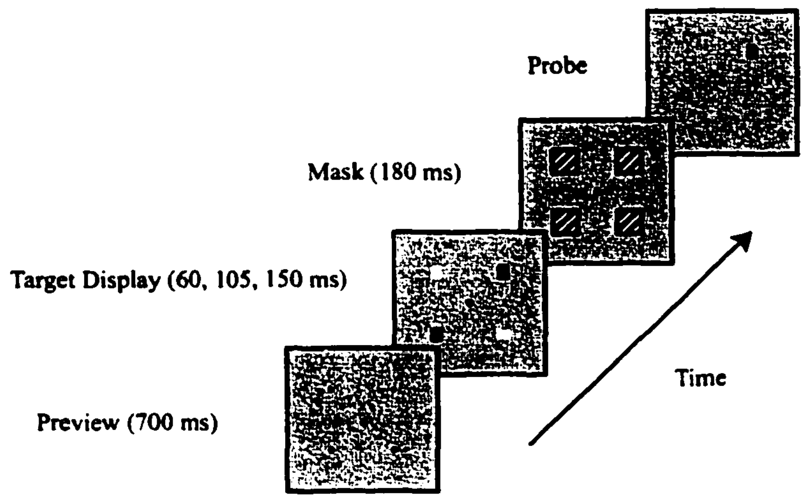

Figure 43: Experiment #8 Paradigm. A trial consisted of four displays. A central fixation dot and 4 location markers were presented in the preview. In the target display black target or white distractor rectangles (oriented vertically or horizontally) were presented at the location markers. After a brief mask a probe rectangle was presented in one black target locations. J.W.'s task was to indicate whether the probe and target rectangles matched on orientation.

J.W.'s task was to decide whether the probe matched or mismatched the target. If the probe matched the target, and the probe was in the left visual field, then he pressed the "z" keyboard key with the left hand. If the probe matched the target, and the probe was in the right visual field, then J.W. pressed the "/" keyboard key with the right hand. When a response was executed the probe was extinguished and following an intertrial interval of 1350 ms the next trial began. If the probe did not match the target, no response was to be made. On these trials the probe was extinguished after 1995 ms, and following an intertrial interval of 1350 ms, the next trial began. This paradigm is similar to the previous experiments presented in this dissertation.

A single object, two objects in the same visual field (2-object unilateral display), and two objects in different visual fields (2-object bilateral display) were equally likely and were selected randomly from trial to trial. As well, all possible combinations of visual field presentation, interval and object conditions were randomly selected.
The subject received 20 practice trials followed by 4 sessions of 5 blocks of 64 trials. Approximately 4 hours were required for the subject to complete the 1261 trials.

Results and Discussion

Response accuracy (percent correct) was subjected to an analysis of variance (ANOVA) with object display (1-object, 2-object unilateral, 2-object bilateral), display duration (60, 100, 150 ms), and target visual field (left or right) as factors (Table 11).

There was a significant field effect, $F(1,1261) = 57.269$, $p<0.001$. In this experiment and similar to the meta-analysis conducted in Chapter 2, accuracy was much greater when the objects were presented to the right hemisphere. This again indicates that contrary to Egly et al's (1994) conclusions, it is the right hemisphere that has an advantage in selectively attending to objects. The interval effect was not significant, $F(2,1261) = 0.096$, $p>0.5$. The ANOVA showed a significant effect of object, $F(2,1261) = 5.486$, $p<0.005$ with the 2-object cost emerging (Figure 44). Planned means comparisons were conducted to determine whether there was a significant difference between the 2-unilateral and 2-bilateral conditions and the result was not significant, $F(1,850) = 0.15$, $p>0.05$. Therefore, unlike the previous experiments the 2-bilateral advantage was not evident with J.W. This was somewhat surprising as it was expected that the accuracy in the 2-bilateral condition should be much higher than the 2-unilateral condition as each isolated hemisphere only had one object to process. If the hemispheres are truly isolated then accuracy in the 2-bilateral condition should be close to or equivalent to the accuracy in the one object condition. As the accuracies for the 2-unilateral condition and the 2-bilateral condition are not significantly different, this suggests that the processing in one hemisphere is affecting processing by the other hemisphere. Similarly, Holztmann et al.'s (1984) study found that in a cueing paradigm presented to split-brain patients, conflicting arrows to the hemispheres did affect reaction times and they concluded from this result that the hemispheres must share an attentional pool or network.

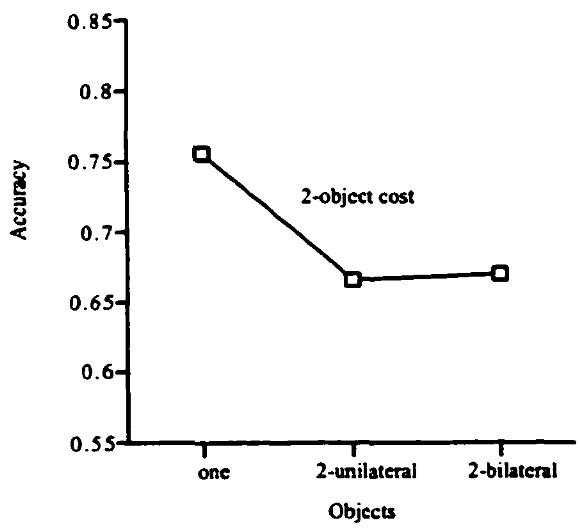

Figure 44: Experiment #8 - Object Effect. There is a decrease in accuracy from the one object condition to the 2-unilateral condition (2-object cost) but no 2-bilateral advantage.

With respect to the two-way interactions for this experiment the field x interval interaction, $F(2,1261) = 0.826$, $p>0.1$, as well as the interval x object, $F(4,1261) = 0.881$, $p>0.1$, were not significant. However the field x object interaction, $F(2,1261) = 4.331$, $p<0.05$ (Figure 45) was significant. As one can see from the graph there appears to be some gating or competition between the two hemispheres in the 2-bilateral condition. While the accuracy of the left hemisphere plummets from the 2-unilateral condition, the accuracy of the right hemisphere increases substantially. This seems to indicate that while there was no overall 2-bilateral advantage, the right hemisphere decidedly outperforms the left hemisphere in the 2-bilateral condition. Interestingly, Enns and Kingstone (1997) also found that in a visual search paradigm with intact subjects there was an interaction between bilateral vs. unilateral displays and field of presentation, with the right hemisphere having an advantage. They concluded that the hemispheres may actually be competing with each other when presented bilateral displays and for their task, the right hemisphere was dominant. A similar pattern of processing may be emerging with this experiment, namely that there is competition between the two hemispheres with the right hemisphere winning that competition.

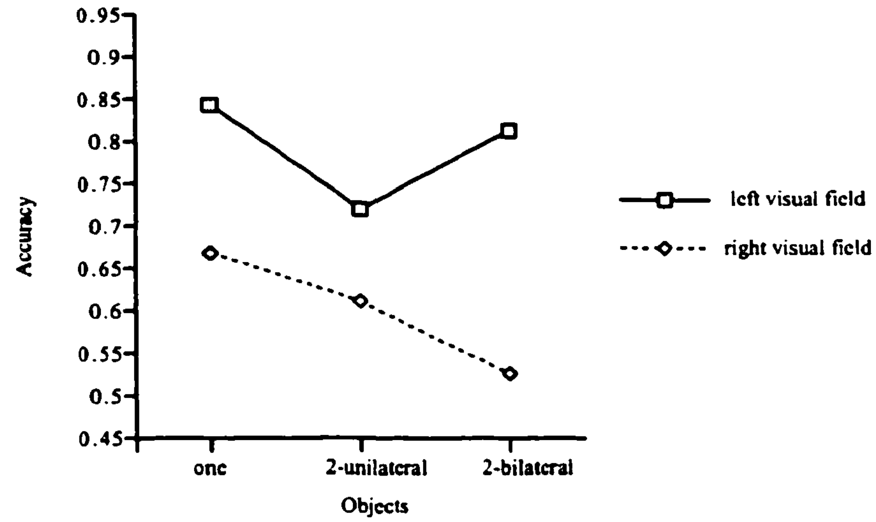

Figure 45: Experiment #8 - Field by Object Interaction. At the 2-bilateral condition there appears to be competition between the hemispheres with the right hemisphere performing better than in the 2-unilateral condition and the left hemisphere performing worse.

One possibility for this result is that there could be sharing of attentional resources and therefore competition between the hemispheres for these resources with the right hemisphere winning. That is why there is an increase in accuracy for the right hemisphere and a decrease in accuracy for the left hemisphere. In this split-brain experiment, the two cortices are working in isolation, so their access to a shared attentional resource may be mediated through subcortical pathways. It has been determined that perceptual information, including spatial orientation, can be transferred subcortically between the disconnected hemispheres (Cronin-Golomb, 1986; Sergent, 1990; Corballis & Trudel, 1993) and that may be the case in this selective attention task.

There was not a significant field by interval by object interaction, $F(4,1261) = 0.666$, $p>0.5$ (Figure 46).

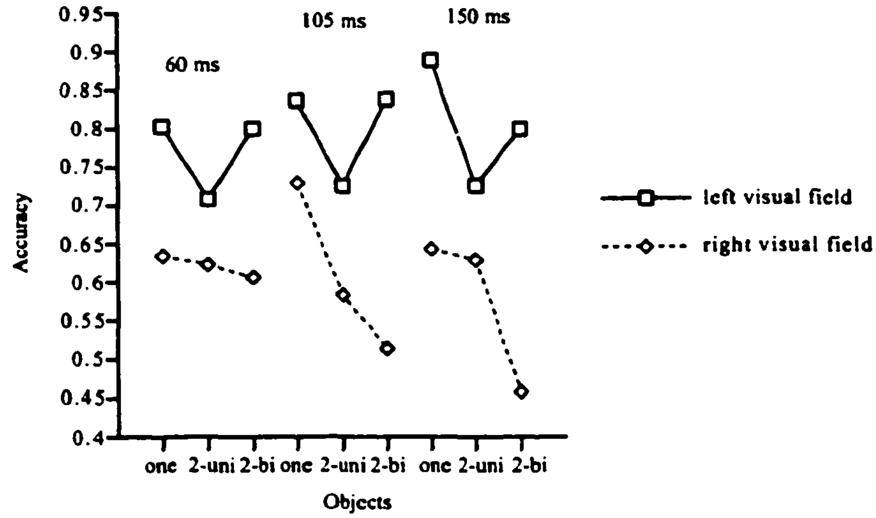

Figure 46: Experiment #8 - Field by Interval by Object Interaction. This three way analysis was not significant.

Therefore, when the hemispheres are isolated in a split-brain patient, the right hemisphere continues to have an advantage in selectively attending to objects. Also when both hemispheres must process one object each, there appears to be competition between the two hemispheres with the right hemisphere winning. This right hemisphere dominance on bilateral displays could be the result of the fact that in a split-brain the major interhemispheric connection is lost, a connecetion which could be crucial for mediating interhemispheric competition for attentional resources (Enns & Kingstone, 1997). This would explain why for both healthy and split-brain subjects, the object-based attentional advantage is lateralized to the right hemisphere, but only in the split-brain patient does this advantage result in a bilateral-display deficit for the "weaker" left hemisphere. In other words, the right hemisphere is better at selectively attending to objects, and this advantage is observed in both the healthy and split-brain subjects. However, when there is competition for object-based attention in the bilateral display, a cortical connection between the hemispheres permits healthy subjects to equalize the efficiency of object-selection both in the right and the left hemisphere. Without this cortical connection, the right hemisphere simply dominates the left hemisphere, seizing access to attentional resources that would other wise be available to the left hemisphere. This is evidenced by the bilateral display deficit in the left hemisphere that is matched in magnitude by a bilateral display performance improvement in the right hemisphere.

Experiment 9

As with the experiments conducted with intact subjects, it was important to see how a split-brain patient performed on this object task when different stimuli were substituted for the rectangles. As rectangles are visuospatial in nature an advantage for the right hemisphere may have been created based on the nature of the stimuli rather than any differences in hemispheric attentional processing. With the right hemisphere advantage again emerging in the previous experiment, it was crucial to ascertain whether any hemispheric differences were simply due to the type of stimuli that the subject was selectively attending towards. Therefore, the rectangles from the previous experiment were replaced with letters, which are preferentially processed by the left hemisphere. A key issue was if a right hemisphere advantage emerged in this experiment for unilateral display presentations, would the right hemisphere again exhibit dominance of the left hemisphere for bilateral displays?

Method

Methodological details were the same as in Experiment 8 except where indicated. J.W was again tested during 4 sessions over 2 days. Four RSVP displays were presented: the background display, probe display, mask and target display. The main difference in this study from the previous experiment was that instead of rectangles, letters were used as stimuli (Figure 47). Either black or white 'Z's or 'N's (1.3 ° x 1.3 °) were presented in the four location markers and the task was the same as in the first experiment. J.W. was required to attend to only the one or two black letters and decide whether the probe and target displays matched. If the probe did not match the target no response was made. However if the probe and target objects were the same, either a right or left key was pressed, depending on the field.

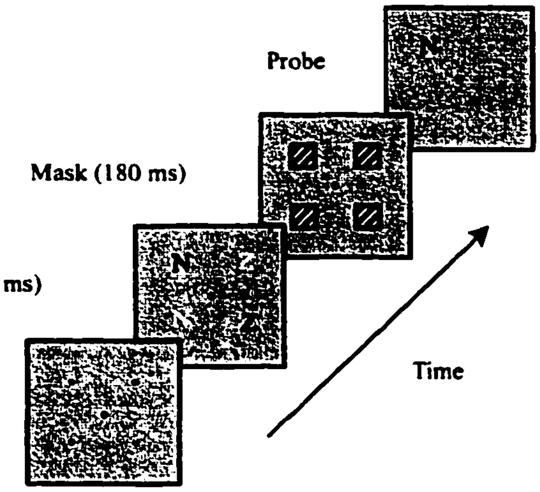

Figure 47: Experiment #9 Paradigm. A trial consisted of four displays. A central fixation dot and 4 location markers (4° separation) were presented in the preview. In the target display black target or white distractor letters (N or Z) were presented at the location markers. After a brief mask a probe letter was presented in one of the black target letter locations. J.W.'s task was to indicate whether the probe and target letters matched.

Results and Discussion

Response accuracy (percent correct) was subjected to an analysis of variance (ANOVA) with object display (1-object, 2-object unilateral, 2-object bilateral), display duration (60, 100, 150 ms), and target visual field (left or right) as factors (Table 12).

There was a significant field effect, $F(1,1582) = 8.415$, $p<0.005$. In this experiment and similar to the previous set of results, accuracy was greater when the objects were presented to the right hemisphere. Therefore despite using stimuli that would be expected to produce a left hemisphere advantage, the right hemisphere continued to outperform the left hemisphere even when disconnected in the split-brain patient. The display duration effect was significant, $F(2,1582) = 6.587$, $p<0.005$, with higher accuracies at longer display durations. The ANOVA also showed a highly significant effect of object, $F(2,1582) = 12.024$, $p<0.001$ with again only the 2-object cost emerging (Figure 48). Planned means comparisons were again conducted to determine whether there was a significant difference between the 2-unilateral and 2-bilateral conditions and the result was not significant, $F(1,1066) = 0.586$, $p>0.05$. Therefore, similar to the previous experiment with J.W., there was no advantage when two objects were divided between the hemispheres. It would appear again that processing in one hemisphere is affecting processing in the other hemisphere.

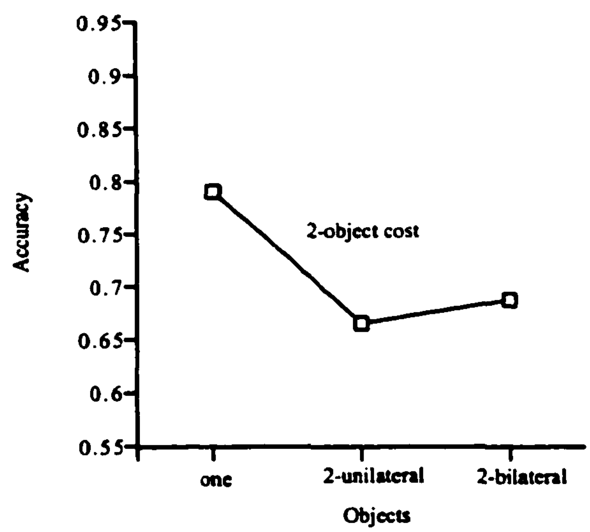

Figure 48: Experiment #9 - Object Effect. Only the 2-object cost emerged when J.W. was presented letters.

There were no significant two-way interactions for this experiment: field x interval, $F(2,1582) = 1.412$, $p>0.1$; field x object, $F(2,1261) = 0.009$, $p>0.5$ (Figure 49); interval x object, $F(4,1582) = 0.665$, $p>0.5$. There was also not a significant field by interval by object interaction, $F(4,1582) = 0.816$, $p>0.5$ (Figure 50).

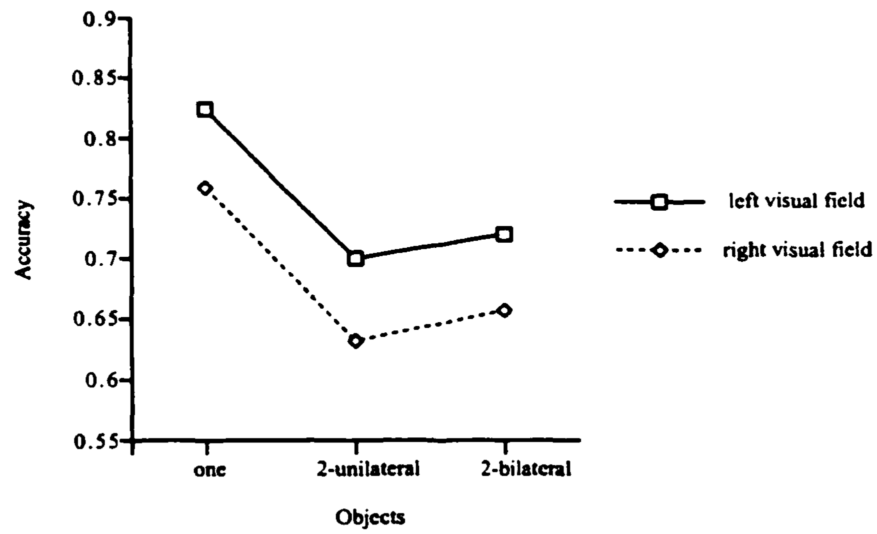

Figure 49: Experiment #9 - Field x Object Interaction. This analysis was not significant.

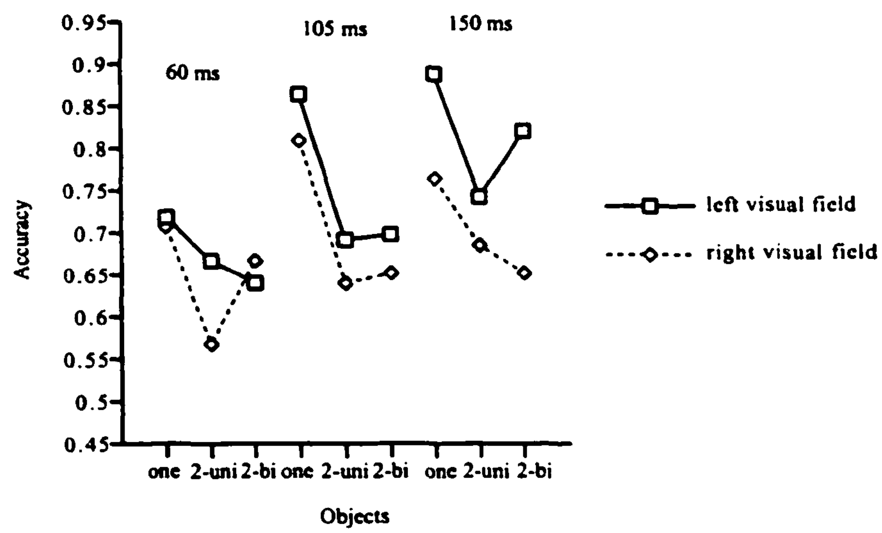

Figure 50: Experiment #9 - Field x Interval x Object Interaction. This three way analysis was not significant.

The fact that there was not a significant difference in the field x object interaction is extremely interesting. There are at least two possible explanations for this additivity between object-attention effects and display field. As mentioned in the discussion of Experiment 8, part of the information processing in this task may be mediated by subcortical mechanisms. The efficiency of these mechanisms has been under a great deal of debate with split-brain patients. Corballis and Trudel (1993) as well as others (Cronin-Golomb, 1986; Sergent, 1990) have found that there can be low-level subcortical integration of visual information including spatial orientation. However subcortical integration does not carry sufficient information to permit higher order percepts such as words to be integrated across the midline (Kingstone & Gazzaniga, 1995). Perhaps the letters are tapping into higher order information processing that cannot be processed as efficiently subcortically. The other possibility is that the nature of the stimuli may be affecting the efficiency of processing so that even if there is competition between the two hemispheres, neither hemisphere has the advantage. While the right hemisphere may generally have an advantage with selective attention to objects, the left hemisphere may be more efficient in this paradigm because letters are presented as stimuli as opposed to rectangles. Given that the hemispheres are isolated, any such processing differences would be magnified in this patient. When normal subjects were presented letters in Experiment 6, the field x object interaction was significant and was mainly driven by the poor performance of the left hemisphere in the 2-unilateral condition. However, with the present interaction there might be no significant difference because if one utilizes stimuli that are more conducive to left hemisphere processing (letters) then the right hemisphere advantage is neutralized and the hemispheres are well matched in their competition for a shared object-based attentional resource. In any case, it is clear that when the cortices are disconnected and there is a right hemisphere advantage overall, it is the case that competition between the hemispheres need not lead inevitably to dominance of the left hemisphere by the right hemisphere.

General Discussion

From studies with normal subjects, it appeared that, contrary to previous research, the right hemisphere outperformed the left hemisphere in a object-based selective attention task. This conclusion was confirmed with two studies testing a split-brain patient on our object-based attentional paradigm. In Experiment 8, where rectangles were used as stimuli, there was an overall right hemisphere advantage, no 2-bilateral advantage and a significant field x object interaction. The lack of a 2-bilateral advantage suggests that processing in one hemisphere is affecting processing in the other hemisphere even though the corpus collosum has been transected. The field x object interaction demonstrates that in the 2-bilateral condition there is competition between the two hemispheres with the right hemisphere again having the advantage. This interhemispheric interaction may be mediated by subcortical mechanisms, as it has been established that there can be subcortical low-level transfer of perceptual information.

In Experiment 9, where letters were used as stimuli, both the overall right hemisphere advantage and the lack of a 2-bilateral advantage emerged but unlike the previous experiment, the field x object interaction was not significant. This difference may have been due to the nature of stimuli that was conducive to the left hemisphere. This may have resulted in both of the hemispheres being equal in their competition for attentional resources.

Overall the conclusion based on the studies with intact subjects appears to be confirmed with the split-brain subject, namely that the right hemisphere and not the left hemisphere, has an advantage when selectively attending to objects. These experiments also demonstrated that in the split-brain there is competition between the two hemispheres when two objects are divided between the visual fields. Whether the two hemispheres orient attention independently appears to be affected by a gating mechanism imposed by the dominant hemisphere. In Experiment 8, the right hemisphere was dominant whereas in Experiment 9 the two hemispheres appears to be equal in their ability to access a shared attentional resource.

Chapter 5: Conclusion

The issue of modularity in the brain has been under investigation for many years and the idea that the brain is divided into functional and corresponding anatomical modules for some cognitive behaviours including attention has been well documented. Attention has been broken down into numerous modules including separate space-based and object-based attentional systems. While much research has been conducted to determine the existence of these separate selective attentional modules, efforts to determine their underlying neural mechanisms have resulted in equivocal data. The Egly et al (1994a,b) studies concluded that there was distinct lateralization between space-based and object-based selective attention, with the left hemisphere being especially adept with objects and the right hemisphere having an advantage in spatial tasks. These conclusions were questioned when Vecera (1994) provided evidence that the paradigm used in the Egly studies was not providing a measure of object-based selective attention. Thus, the question of lateralization and object-based selective attentional remained unresolved. The goal of this dissertation has been to elucidate the anatomical modularity underlying object-based selective attention. Particular emphasis was placed on whether each of the hemispheres selectively attends to objects, and if so, whether one hemisphere was more efficient at the task than the other hemisphere.

The first set of experiments (Experiments 1 - 5) examined how normal subjects would perform on a simple object identification task in which they were required to decide whether a target and probe object matched on a particular object dimension: the orientation of an oval. Of particular interest was whether each of the hemispheres was able to perform this task. Subjects were found to perform with higher accuracy when only one target object was presented as compared to when two target objects were presented (2-object cost). As well, subjects performed better when the two target objects were divided between the visual fields rather than both being presented in the same visual field (2-bilateral advantage). This suggested that both hemispheres were capable of selectively attending to objects. Finally there appeared to be a bias of the left hemisphere to perform quite poorly as compared to the right hemisphere especially in the 2-unilateral condition, in which two objects were presented in the same visual field. This last finding suggests that rather than having a special ability for selective attention to objects, the left hemisphere may actually be at a disadvantage for object-based selective attention. This pattern of results remained consistent despite significant changes to fundamental stimulus and response task demands.

One of the most important tests came in Experiment 5 when a spatial manipulation recommended by Vecera (1994) was applied. Even when the stimuli were brought in closer to or further away from central fixation, the 2-object cost, 2-bilateral advantage and the poor performance of the left hemisphere in the 2-bilateral condition continued to emerge without any interaction involving object and distance emerging. Therefore we could be confident that the paradigm was providing a true test of object-based selective attention. Moreover the fact that the lateralization effects differ from Egly's reinforces the concern first raised by Vecera (1994) that the conclusions regarding object-based attention based on the paradigm of Egly et al. (1994a, 1994b) may be compromised.

The meta-analysis of the first five experiments confirmed the results of the individual studies and also pulled out a strong main effect of field. Overall the right hemisphere outperformed the left hemisphere. This was driven primarily by the poor performance of the left hemisphere in the 2-unilateral condition, although the right hemisphere marginally outperformed the left hemisphere in the 2-bilateral condition. Therefore from this first set of experiments it was concluded that each hemisphere was able to selectively attend to objects, but the right hemisphere appeared to be better at this particular task, contrary to the results of Egly et al. (1994a; 1994b).

In the second set of experiments (Experiments 6 and 7) the objective was to ensure that the results would generalize to different types of stimuli and/or tasks. The aim was to ascertain whether the object effects were simply a by-product of processing the orientation of ovals or whether they were indicative of more general selective attentional processing of objects. Therefore in Experiment 6 the ovals used in the previous experiments were replaced with letters. Letters were chosen as stimuli because, as the left hemisphere processes them more efficiently, one could test whether the hemispheric effects found in the first set of experiments emerged solely because the display presentations were composed of "right hemisphere" stimuli. The first important result was that the 2-object cost emerged in this experiment despite the change in stimuli. Also, the 2-bilateral advantage was also preserved, with accuracy being higher when 2 letters were presented bilaterally as compared to when they were presented unilaterally. These results emulate the pattern found in the previous experiments. With respect to hemispheric differences, there was a significant main field effect, with an overall greater performance by the right hemisphere on the task, which was again driven largely by the left hemisphere's poor performance in the 2-unilateral condition. Therefore even though the stimuli utilized in this paradigm might favor processing by the left hemisphere, the right hemisphere continued to outperform the left hemisphere in this selective attention task.

The next important issue to determine was whether this pattern of results would be manipulated if both the stimuli and the task were changed. In Experiment 7, either a judgment about the actual shape of the object was required (circle or square) or a judgment based on whether the object was tilted to the right or left was required. This experiment was divided into two tasks: in the shape task, subjects were required to indicate whether the shape of the object was the same in both the target and probe displays, regardless of the orientation of the object. In the orientation task, subjects were required to indicate whether the orientation of the object was the same in both the target and probe displays, regardless of the shape of the object.

Despite the manipulations to both the stimuli and judgment required, both the 2-object cost and 2-bilateral advantage continued to emerge suggesting that regardless of these changes, selective attention to objects can be performed independently by each of the two hemispheres. With respect to hemispheric processing, no significant differences were found with this experiment. However to better evaluate the consistency of the results in Experiments 6 and 7, a meta-analysis was conducted. The significant field by object interaction confirmed our previous pattern of results, with performance in the 2-unilateral condition significantly better for the right hemisphere than the left hemisphere.

This second set of experiments indicated that even when different types of stimuli or tasks were utilized in the paradigm, both hemispheres continued to selectively attend to the objects. And in terms of a bias in processing, even when left hemisphere stimuli were presented, contrary to the Egly work, the right hemisphere continued to outperform the left hemisphere, especially when a single hemisphere was required to process more than one object.

As cited in the literature review of Chapter 1, lateralization issues can sometimes be clarified by examining how a split-brain patient performs on a particular task and therefore a third and final set of experiments (Experiments 8 and 9) were conducted to examine object-based selective attention effects when the left and right cortices are disconnected.

In Experiment 8 a split-brain subject was tested on the original paradigm with rectangles. There was an overall main effect of field with objects presented in the left visual field resulting in higher accuracies. While the 2-object cost was apparent with this subject, surprisingly the 2-bilateral advantage was not significant. This finding was clarified with the significant field x object interaction, where there appeared to be some gating or competition between the two hemispheres in the 2-bilateral condition. While the accuracy of the left hemisphere decreased from the 2-unilateral condition, the accuracy of the right hemisphere increased substantially. This indicated that while there was no overall significant 2-bilateral advantage, the right hemisphere decidedly outperformed the left hemisphere in the 2-bilateral condition. This dominance appears to reflect subcortical competition between the hemispheres for shared attentional resources that, in the absence of a cortical connection between the hemispheres, the right hemisphere wins to the detriment of the left hemisphere. In other words, because no similar gating was seen with any of the experiments with normal cortically intact subjects, it would appear that cortical connections can mediate subcortical competiton between the hemispheres for shared object-based attentional resources. Enns & Kingstone (1997) have pointed to the thalamus and the superior colliculus as being possible subcortical mechanisms involved in this competition. Both of these areas have been implicated in Posner's covert attentional network: the thalamus being important in engaging attention onto a new target and the superior colliculus playing a role in moving attention.

As with the experiments conducted with intact subjects, it was important to see how a split-brain patient performed on this object-based attention task when different types of stimuli were substituted for the rectangles. So as in Experiment 7, letters replaced the ovals as stimuli in the paradigm presented in Experiment 9. Again there was a significant field effect; accuracy was greater when the objects were presented to the right hemisphere. Therefore despite using stimuli that would be expected to produce a left hemisphere advantage, the right hemisphere continued to outperform the left hemisphere even when disconnected in the split-brain patient. The field by object interaction was not significant in this experiment, however this does not rule out competition between the hemispheres in the 2-bilateral condition for performance in the 2-bilateral condition was the same as in the 2-unilateral condition. It would appear then that with stimuli more conducive to left hemisphere processing (letters) any right hemisphere advantage in processing objects may be neutralized. Therefore subcortical dominance of the left hemsiphere by the right hemisphere is not inevitable. These last experiments provided converging evidence that while both hemispheres may be able to selectively attend to objects, the right hemisphere has a strong advantage in this type of processing

At the outset of this dissertation research, it was established that the goal was to examine how the hemispheres performed on a simple object identification task that required selective attention to objects. Over a number of experiments it was discovered that while both hemispheres are able to orient attention to objects, as evidenced by the 2-bilateral advantage, the right hemisphere is actually better than the left hemisphere on this type of task. Despite manipulations to the distractors, response demands and location of the stimuli these effects consistently emerged. When the generalizability of these effects was tested with different types of stimuli and judgments, again the same pattern of data resulted. Finally, and most convincingly, is the evidence from the split-brain patient. When the hemispheres are isolated there is actually competition between the hemispheres with, as has been the trend, the right hemisphere having the advantage. Together these data indicate that while both hemispheres are able to selectively attend to objects, it is the right hemisphere and not the left hemisphere that is specialized for this function.

This finding has important implications in the understanding of selective attention as well as other related brain functions. It has been suggested that the left hemisphere is able to orient attention only to the right visual field, while the right hemisphere is able to orient attention to both the left and right visual fields (Posner, 1995). This implies that the right hemisphere might play an important role in many different types of attention, including object-based selective attention. The present data could certainly be used to support this hypothesis.

Another area that could be affected by these findings is in the treatment and rehabilitation of stroke damage. While attentional deficits have been well documented, especially with stroke patients who have sustained right hemisphere damage, the focus has been on spatial deficits. Perhaps part of these patients' problems is a result of specific damage to an object-based attentional system. While they might be having difficulty attending to a particular location in space, the problem may be amplified by a further difficulty in attending to multiple objects within that location of space. Possibly in the future, rehabilitation efforts could concentrate not only on orienting towards general locations in space but also orienting towards multiple objects within that space.

These findings also have implications with respect to the relationship between space-based and object-based attentional systems. As both of these functions appear to be housed in the same hemisphere, one might expect some overlap between these two types of processing. Duncan and Desimone (1995) have suggested that while space-based and object-based modules may be separate, they work together to maximize our ability to orient attention to a specific object, location or event. While a spatial system may produce a spotlight within which attention is focused, if there are multiple objects within that focus, an object-based system might take over and attend to each of the objects differentially. These multiple objects must then compete for representation in multiple brain systems, "sensory and motor, cortical and subcortical" (Duncan, Humphreys & Ward, 1997). If in fact these two independent systems do work closely together one might expect their anatomical modules to be located in close proximity to each other, a proposal that is supported by the present body of work.

In conclusion, the set of experiments presented in this dissertation have succeeded in shedding light on the anatomical modularity underlying object-based selective attention. While each hemisphere is able to attend to objects, contrary to previous research, the right hemisphere actually has an advantage in this type of selection. This suggests that not only does the right hemisphere have an advantage in space-based attention, which has been previously established, but also it may actually be more efficient at processing many different types of nonspatial information.

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Appendix A: Tables

Table 1: Mean Accuracies, Standard Deviations and Standard Error for Experiment 1

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	100 ms	1 object	0.852	0.133	0.033
		2-unilateral	0.721	0.113	0.028
		2-bilateral	0.697	0.134	0.034
	150 ms	1 object	0.883	0.129	0.032
		2-unilateral	0.775	0.129	0.032
		2-bilateral	0.779	0.142	0.035
	200 ms	1 object	0.943	0.125	0.031
		2-unilateral	0.795	0.131	0.033
		2-bilateral	0.816	0.115	0.029
Right	100 ms	1 object	0.844	0.142	0.036
		2-unilateral	0.701	0.126	0.031
		2-bilateral	0.752	0.132	0.033
	150 ms	1 object	0.928	0.120	0.030
		2-unilateral	0.727	0.118	0.029
		2-bilateral	0.805	0.125	0.031
	200 ms	1 object	0.928	0.121	0.030
		2-unilateral	0.785	0.117	0.029
		2-bilateral	0.840	0.138	0.035

Table 2: Mean Accuracies, Standard Deviations and Standard Error for Experiment 2 with changes to response demands

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	100 ms	1 object	0.824	0.117	0.029
		2-unilateral	0.677	0.118	0.030
		2-bilateral	0.697	0.117	0.029
	150 ms	1 object	0.918	0.093	0.023
		2-unilateral	0.752	0.115	0.029
		2-bilateral	0.787	0.119	0.030
	200 ms	1 object	0.924	0.068	0.017
		2-unilateral	0.775	0.101	0.025
		2-bilateral	0.822	0.134	0.033
Right	100 ms	1 object	0.846	0.107	0.027
		2-unilateral	0.680	0.097	0.024
		2-bilateral	0.735	0.128	0.032
	150 ms	1 object	0.899	0.085	0.021
		2-unilateral	0.728	0.115	0.029
		2-bilateral	0.764	0.144	0.036
	200 ms	1 object	0.936	0.073	0.018
		2-unilateral	0.783	0.106	0.027
		2-bilateral	0.787	0.119	0.030

Table 3: Mean Accuracies, Standard Deviations and Standard Error for Experiment 3 with only black ovals presented

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	100 ms	1 object	0.930	0.080	0.020
		2-unilateral	0.760	0.096	0.024
		2-bilateral	0.742	0.118	0.030
	150 ms	1 object	0.981	0.032	0.008
		2-unilateral	0.799	0.112	0.028
		2-bilateral	0.818	0.095	0.024
	200 ms	1 object	0.975	0.035	0.009
		2-unilateral	0.856	0.103	0.026
		2-bilateral	0.899	0.062	0.016
Right	100 ms	1 object	0.942	0.045	0.011
		2-unilateral	0.729	0.104	0.026
		2-bilateral	0.789	0.115	0.029
	150 ms	1 object	0.965	0.045	0.011
		2-unilateral	0.768	0.111	0.028
		2-bilateral	0.852	0.095	0.024
	200 ms	1 object	0.965	0.038	0.009
		2-unilateral	0.850	0.055	0.014
		2-bilateral	0.881	0.080	0.020

Table 4: Mean Accuracies, Standard Deviations and Standard Error for Experiment 4 with only both horizontal and diagonal bilateral stimuli presented

Hemisphere	Interval	Object	Mean	Standard Deviation	Standard Error
Left	100 ms	1 object	0.897	0.090	0.023
		2-unilateral	0.728	0.140	0.035
		2-bilateral	0.740	0.119	0.030
	150 ms	1 object	0.929	0.069	0.017
		2-unilateral	0.775	0.124	0.031
		2-bilateral	0.833	0.106	0.027
	200 ms	1 object	0.951	0.055	0.014
		2-unilateral	0.806	0.120	0.030
		2-bilateral	0.860	0.110	0.028
Right	100 ms	1 object	0.900	0.075	0.019
		2-unilateral	0.746	0.128	0.032
		2-bilateral	0.751	0.134	0.034
	150 ms	1 object	0.926	0.072	0.018
		2-unilateral	0.807	0.081	0.020
		2-bilateral	0.816	0.115	0.029
	200 ms	1 object	0.969	0.034	0.008
		2-unilateral	0.804	0.109	0.027
		2-bilateral	0.886	0.078	0.019

Table 5: Mean Accuracies, Standard Deviations and Standard Error for Experiment 5 in the Near condition

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Right	100 ms	1 object	0.944	0.071	0 018
		2-unilateral	0.787	0.131	0.033
		2-bilateral	0.822	0.139	0.035
	150 ms	1 object	0.938	0.081	0.020
		2-unilateral	0.828	0.158	0.040
		2-bilateral	0.865	0.156	0.039
	200 ms	1 object	0.959	0.066	0.017
		2-unilateral	0.847	0.155	0.039
		2-bilateral	0.888	0.138	0.035
Left	100 ms	1 object	0.954	0.054	0.013
		2-unilateral	0.699	0.133	0.033
		2-bilateral	0.821	0.094	0.023
	150 ms	1 object	0.952	0.049	0.012
		2-unilateral	0.772	0.138	0.034
		2-bilateral	0.850	0.143	0.036
	200 ms	1 object	0.946	0.077	0.019
		2-unilateral	0.815	0.193	0.048
		2-bilateral	0.867	0.132	0.033

Table 6: Mean Accuracies, Standard Deviations and Standard Error for Experiment 5 in the Far condition

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Right	100 ms	1 object	0.930	0.068	0.017
		2-unilateral	0.791	0.092	0.023
		2-bilateral	0.813	0.093	0.023
	150 ms	1 object	0.951	0.062	0.015
		2-unilateral	0.854	0.086	0.022
		2-bilateral	0.875	0.076	0.019
	200 ms	1 object	0.959	0.076	0.019
		2-unilateral	0.906	0.066	0.016
		2-bilateral	0.895	0.077	0.019
Left	100 ms	1 object	0.914	0.077	0.019
		2-unilateral	0.658	0.144	0.036
		2-bilateral	0.769	0.080	0.020
	150 ms	1 object	0.941	0.081	0.020
		2-unilateral	0.719	0.135	0.034
		2-bilateral	0.843	0.071	0.018
	200 ms	1 object	0.942	0.080	0.020
		2-unilateral	0.777	0.113	0.028
		2-bilateral	0.868	0.069	0.017

Table 7: Mean Accuracies, Standard Deviations and Standard Error for the Meta-analysis of Expts 1-5

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	100 ms	1 object	0.896	0.104	0.011
		2-unilateral	0.744	0.120	0.012
		2-bilateral	0.752	0.128	0.013
	150 ms	1 object	0.933	0.086	0.009
		2-unilateral	0.797	0.124	0.013
		2-bilateral	0.826	0.121	0.012
	200 ms	1 object	0.952	0.075	0.008
		2-unilateral	0.831	0.121	0.012
		2-bilateral	0.863	0.112	0.011
Right	100 ms	1 object	0.900	0.097	0.010
		2-unilateral	0.702	0.123	0.013
		2-bilateral	0.769	0.116	0.012
	150 ms	1 object	0.935	0.080	0.008
		2-unilateral	0.753	0.119	0.012
		2-bilateral	0.822	0.120	0.012
	200 ms	1 object	0.948	0.076	0.008
		2-unilateral	0.802	0.122	0.012
		2-bilateral	0.855	0.109	0.011

Table 8: Mean Accuracies, Standard Deviations and Standard Error for Experiment 6 using letter stimuli

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	60 ms	1 object	0.876	0.108	0.024
		2-unilateral	0.771	0.116	0.026
		2-bilateral	0.748	0.167	0.037
	105 ms	1 object	0.922	0.096	0.021
		2-unilateral	0.835	0.090	0.020
		2-bilateral	0.856	0.112	0.025
	150 ms	1 object	0.920	0.115	0.026
		2-unilateral	0.871	0.113	0.025
		2-bilateral	0.901	0.083	0.019
Right	60 ms	1 object	0.852	0.128	0.029
		2-unilateral	0.734	0.089	0.020
		2-bilateral	0.785	0.097	0.022
	105 ms	1 object	0.897	0.095	0.021
		2-unilateral	0.787	0.102	0.023
		2-bilateral	0.816	0.120	0.027
	150 ms	1 object	0.937	0.097	0.022
		2-unilateral	0.833	0.114	0.026
		2-bilateral	0.898	0.099	0.022

Table 9: Mean Accuracies, Standard Deviations and Standard Error for Experiment 7 with either object or spatial judgements

Visual Field	Task	Object	Mean	Standard Deviation	Standard Error
Left	Object	1 object	0.981	0.021	0.005
		2-unilateral	0.867	0.114	0.026
		2-bilateral	0.914	0.085	0.020
	Spatial	1 object	0.936	0.078	0.018
		2-unilateral	0.795	0.110	0.025
		2-bilateral	0.825	0.120	0.028
Right	Object	1 object	0.983	0.022	0.005
		2-unilateral	0.868	0.106	0.024
		2-bilateral	0.935	0.072	0.017
	Spatial	1 object	0.936	0.078	0.018
		2-unilateral	0.778	0.121	0.028
		2-bilateral	0.847	0.139	0.032

Table 10: Mean Accuracies, Standard Deviations and Standard Error for Meta-analysis of Expt 6 & 7

Visual Field	Object	Mean	Standard Deviation	Standard Error
Left	1 object	0.945	0.085	0.005
	2-unilateral	0.844	0.116	0.026
	2-bilateral	0.880	0.103	0.020
Right	1 object	0.952	0.075	0.005
	2-unilateral	0.827	0.118	0.024
	2-bilateral	0.894	0.111	0.017

Table 11: Mean Accuracies, Standard Deviations and Standard Error for Experiment 8 with JW

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	60 ms	1 object	0.803	0.401	0.048
		2-unilateral	0.708	0.458	0.054
		2-bilateral	0.800	0.403	0.048
	105 ms	1 object	0.836	0.373	0.044
		2-unilateral	0.725	0.450	0.054
		2-bilateral	0.838	0.371	0.043
	150 ms	1 object	0.889	0.316	0.037
		2-unilateral	0.726	0.449	0.053
		2-bilateral	0.800	0.403	0.048
Right	100 ms	1 object	0.634	0.485	0.058
		2-unilateral	0.623	0.488	0.059
		2-bilateral	0.606	0.492	0.058
	150 ms	1 object	0.729	0.448	0.054
		2-unilateral	0.583	0.496	0.059
		2-bilateral	0.514	0.503	0.060
	200 ms	1 object	0.643	0.483	0.058
		2-unilateral	0.629	0.487	0.058
		2-bilateral	0.458	0.502	0.059

Table 12: Mean Accuracies, Standard Deviations and Standard Error for Experiment 9 with JW and letters

Visual Field	Interval	Object	Mean	Standard Deviation	Standard Error
Left	60 ms	1 object	0.718	0.453	0.049
		2-unilateral	0.667	0.474	0.050
		2-bilateral	0.640	0.483	0.052
	105 ms	1 object	0.864	0.345	0.037
		2-unilateral	0.692	0.464	0.049
		2-bilateral	0.698	0.462	0.050
	150 ms	1 object	0.888	0.318	0.034
		2-unilateral	0.742	0.440	0.047
		2-bilateral	0.820	0.386	0.041
Right	100 ms	1 object	0.707	0.458	0.048
		2-unilateral	0.568	0.498	0.053
		2-bilateral	0.667	0.474	0.050
	150 ms	1 object	0.809	0.395	0.042
		2-unilateral	0.640	0.483	0.051
		2-bilateral	0.652	0.479	0.050
	200 ms	1 object	0.764	0.427	0.045
		2-unilateral	0.685	0.467	0.050
		2-bilateral	0.652	0.479	0.051