2005

The effect of object boundaries on the flow of attention.

Simon J. Büchner
University of Massachusetts Amherst

THE EFFECT OF OBJECT BOUNDARIES ON THE FLOW OF ATTENTION

A Thesis Presented

by

SIMON J. BÜCHNER

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

September 2005

Psychology

THE EFFECT OF OBJECT BOUNDARIES ON THE FLOW OF ATTENTION

A Thesis Presented

by

SIMON J. BÜCHNER

Approved as to style and content by:

Kyle R. Cave, Chair

Alexander Pollatsek, Member

Ethan Gahtan, Member

Melinda Novak, Department Chair
Psychology

Meinen Eltern
Manfred and Margarete Büchner,
die mich von Anfang an so sehr unterstützt haben.

To my parents
Manfred and Margarete Büchner,
who supported me so well from the beginning.

ACKNOWLEDGMENTS

I want to thank the members of my Master's committee for their assistance and comprehensive advice, especially my advisor Kyle R. Cave who supported me sustainably in all matters and taught me many things about research in Psychology.

I also want to thank all members of the Visual Attention and Cognition Lab for their helpful comments especially Shannon Bailey for his programming work. Thanks to Elaina Ellis, who read the manuscript and provided helpful comments on orthography.

The idea for this thesis emerged while I was a visiting student at the University of Massachusetts, Amherst and was supported by the Landesstiftung Baden-Württemberg as well as the Fulbright Association. I not only want to thank these institutions for their financial support, but also want to endorse the realization of more student exchanges of this kind.

Finally I want to thank Barbara Hemforth, who quickened my interest in Cognitive Psychology and inspired me early on.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

When we first look at a scene, much happens between the point when the light from the scene hits the retina and the point when we understand what we see. Information is transmitted from retinal cells over ganglion cells in the lateral geniculate nucleus (LGN) to the primary visual cortex. Here the bits of information are integrated, in order to provide a stable and consistent picture of the environment. A further process brings out more details about the scene. This process is *visual attention*, which can be understood as the enhancement of relevant or inhibition of irrelevant information within the visual field. In order to understand the criteria that determine the selection of particular information, one has to distinguish between selections that are driven by top-down information and those that are driven by bottom-up information. Top-down information includes all kinds of background knowledge, expectations and goals that the observer holds. Waiting at a red traffic light may cause a person to attend to the lower part of the light, where the green light is about to appear, so that he or she can resume driving. Bottom-up information is information that derives from the scene itself and guides attention to a certain location. Flashing blue lights suddenly appearing from one side while waiting at the traffic light would guide the person's attention to an arriving ambulance. This research is about the way that lines that potentially serve as borders of objects and object parts can guide the flow of attention within and between objects.

1.1 Overt versus covert attention

In research on attention one has to distinguish between overt and covert visual attention (Posner, 1980). Overt attention is attention that is observable from the outside, i.e. perceptual engagement that is related to eye-movements. In a visual search task, for example, one would look sequentially at different locations by moving the gaze from one location to the next.

Covert attention involves perceptual engagement in locations within one gaze, i.e. without the movement of the eyes. For example, while in a conversation one can look at a person's face (in order to pretend to listen) but in fact attend to an event that is going on behind the person. The research presented in this paper will only deal with *covert* visual attention.

1.1.1 Eye-movements

Saccades (eye-movements) are an indicator of the allocation of overt attention. However, overt and covert attention interact insofar as covert attention is believed to guide shifts of overt attention. Thus investigating covert attention alone requires a separation of these two processes.

One way to assure that participants only use covert attention (and don't move their eyes) in an experiment is to monitor eye-movements with an eye-tracker, so that trials in which the participants move their eyes (even though they are instructed not to) are excluded from data analysis.

Another way to assure that participants only use covert attention is to time the stimulus display in a way that the participants are not able to use overt attention. It is known that it takes about 200ms to prepare and execute an eye-movement from one location in the visual field to another. Thus shifts of attention occurring within the first 200ms after the onset of the stimulus must be due to shifts in covert visual attention, because within this time range the participant isn't even able to execute a saccade and thus not able to use overt attention. Since eye-tracking experiments are rather laborious, experiments on covert visual attention may be designed such that the presentation time of stimuli doesn't exceed 200ms. Preventing eye-movements rules out possible confounds of overt and covert attention. This research will use the timing method in order to prevent participants from using overt attention.

1.2 Perception and attention

Covert attention can be considered as an enhancement of particular signals (or a suppression of irrelevant signals or a combination of both) that stem from a sensory organ. Thus (selective) visual attention can be considered as a change of the strength of signals that are conducted between the different visual areas of the brain. This change of signal strength may be reflected by a change in the firing rate of a neuron. Bundesen, Habekost & Kyllingsbaek (2005) provide a review of the literature on single-cell recording in research on visual attention. They report modulations of the firing rate of a neuron when attention is directed to one of multiple objects in the receptive field (RF) of a neuron, when attention is directed to a single object in the RF, and even when the appearance of an object in the RF is expected.

These changes of signal strength may provide the basis for the so called *saliency map* of attention (Koch and Ullman, 1985; Itti and Koch, 2000). This proposed map is organized retinotopically, i.e. information that stems from neighboring neurons in the retina is represented by adjacent neurons in the primary visual areas. It encodes the saliency (or conspicuity) of objects in the visual field. Different objects "compete" to be the most salient object. In a winner-takes-all manner the most salient object is attended next, while losing objects are inhibited.

Treisman & Gelade (1980) argued that features of a perceptual scene (like color, texture and the orientation of lines) are first processed independently and later integrated in order to constitute objects of perception. They show that features are processed in parallel and that the process is largely automatic. However, Pollatsek & Digman (1977) found evidence that features might not be processed independently and that there is an "integrative crosstalk" between spatial channels.

Treisman & Gelade (1980) also claim that although features may be processed in parallel, attention can only deal with a limited number of objects at a time. This limited amount of processing capacity is often referred to as the "Cognitive Bottleneck". This capacity limitation has been shown repeatedly in research using for example visual search tasks in which participants have to search for a target item among distractor items. It has been shown that the display size (number of distractors), and the similarity between target and distractor, affect search times (e.g. Huang and Pashler, 2005).

1.3 Space-based and object-based attention

A fundamental question in attentional research is whether attention operates on (preattentively completed) objects or within visual space, or if spatial and object-specific information contribute equally to attention. Space certainly plays a role, since it takes longer to respond to a stimulus when it is farther from a cued location (Downing & Pinker, 1985). Eriksen & Hoffman (1972b) showed that distracting probes cause more interference on the identification of a target the closer they are located to it. However, objecthood also plays a fundamental role in the flow of attention. For example, Duncan (1984) showed that two attributes of a single object were more easily (faster) reported than two attributes of two different objects, even if the two objects are superimposed on each other and thus located within the same section of the visual field.

Egly, Driver & Rafal (1994) strikingly showed the role of objecthood in visual attention. They used a display of two parallel arranged rectangles and cued one end of one rectangle by a inducing a luminance change of the boundary at the end of the rectangle. They found that probes that were presented on the other end of the cued rectangle were detected faster than equidistant probes on the other (non-cued) rectangle. In other words, objecthood as defined by connectedness and closure facilitates processing of visual information of two different locations.

This facilitation still remains even if another object occludes the two rectangles. Moore, Yantis & Vaughan (1998) used a three-dimensional display of one rectangle superimposed over the two rectangles used by Egly et al. and found that the same-object advantage remained. They concluded that the same-object advantage operates at a stage of processing at which occluded objects (in this case the rectangles in the back) are already amodally completed, that is, non-visible parts of an occluded object are already incorporated in the representation of the object.

Avrahami (1999) argues that neither closure nor proximity are prerequisites for this kind of facilitated processing, but that the grain of lines is sufficient to lead the attentional flow in a certain direction. She used a probe detection paradigm and presented participants with a display of seven parallel lines. A cue similar to the one used by Egly et al. was presented. The probe appeared either at the same location (valid trials), within the same stripe but not at the same location (invalid same), or on a different stripe and not at the same location (invalid different). Her results are similar to those of Egly et al. (1994): validly cued targets were detected fastest, invalidly cued targets in the same stripe were detected slower and invalidly cued targets in a different stripe were detected the slowest. Thus, when attention had to "go against the grain" it was slowed down.

Haimson & Behrmann (2001) replicated the object-based advantage for displays similar to those of Egly et al. (1994) and Moore et al. (1998). They showed that probes at the uncued end of a cued object are detected faster than equidistant probes on an uncued object, even if the cued object is occluded by another one. They were also able to show that attention also spreads to the occluding object, at least to the location where the occluded and the occluding object overlap. In addition, they showed that the results obtained by Moore et al. (1998) generalize from a stereoscopic (three-dimensional) presentation of the stimuli to two-dimensional stimuli that only supply pictorial depth cues.

For those cases when attention operates on objects rather than in space, some studies provide evidence that attention automatically moves or spreads along the constituents of these objects. Houtkamp, Spekreijse & Roelfsema (2003), for example, used ribbon like stimuli. They presented color probes along the ribbon at different times and were able to show that attention "wanders" along the stimulus. They used stimuli similar to those used by Jolicoeur, Ulman & Mackay (1986), who showed that people trace curved lines very fast but that their reaction time in a discrimination task increases with increasing length of the curve. He & Nakayama (1995) required their participants to search for a target within a set of items that formed a 3-D surface (just as paving stones form the surface of a sidewalk). They found that it was easier for the participants to find the target if it was within a perceived surface than when it was outside. They conclude that attention automatically spreads to all locations within a surface, and that this process is difficult to suppress.

1.4 The cueing paradigm

Cues have been used in many experiments (e.g. Eriksen and Hoffman, 1972a; Posner et al., 1980; Downing and Pinker, 1985; Castiello and Umiltà, 1990; He and

Nakayama, 1995) on visual attention in order to tell the participant where to direct his or her attention. For example, Eriksen & Hoffman (1974) used a detection task in which participants had to press a button when a target letter was present. A small black line (the cue) informed participants of the location where the target was to appear, approximately 50-100ms later. This cue of the target's location, led to faster target detection than an un-cued control condition in which the line appeared simultaneously with the display. Posner (1980) used an arrow (pointing to the left or to the right), or a non-informative cue (a plus sign) in order to tell participants at which location the target stimulus was most likely to appear. Eighty percent of the trials in which the informative cue appeared were valid (the target appeared where the arrow was pointing), while 20% were invalid (the target appeared the opposite direction of the arrow). Reaction times to the target were slowest in the invalid condition, faster in the neutral condtion, and fastest in the valid condition. These two experiments show that a cue facilitates the processing of information from the cued location. In both experiments the cues informed the participant (at least in the majority of the trials) about the location where a target was about to appear.

Posner & Snyder (1975) and Jonides (1981) pointed out the distinction between two kinds of cues, exogenous and endogenous, which influence the use of object-based attention differently. *Exogenous* cues like flashes or abrupt changes of luminance are usually presented in the periphery of the visual field, they automatically capture attention and are difficult to ignore. *Endogenous* cues require the participant to follow them voluntarily and with effort. They are usually arrows or indicators that are presented in the center of the visual field and the participant has to obey them (Yantis and Jonides, 1984; Klein et al., 1992).The within-object advantage as it was described by Egly, Driver & Rafal (1994) was only observed under *exogenous* cueing (Macquistan, 1997), though it can be re-instantiated with endogenous cues under certain conditions (Goldsmith and Yeari, 2003).

The goal of this study was to find out how attention spreads from a starting location to adjacent areas and what influence boundaries have on that spread. Thus it was necessary to first direct a participant's attention to the starting location. For this purpose a non-informative exogenous cue was used that didn't tell the participant anything about the location of the targets. The exogenous nature of the cue should have captured the participants' attention automatically. However, participants were also instructed to deploy their attention to the location where the cue appeared.

CHAPTER 2

EXPERIMENT I

2.1 Introduction

Experiment I was carried out in order to investigate the effect of object-constituting boundaries on the flow of attention. Boundaries seem to guide attention such that attention spreads within the area that is enclosed by boundaries. That is, attention can be considered spreading automatically over an area until it reaches a boundary. The boundary doesn't stop attention from crossing it, but it seems to interfere with the spread. Previous work has demonstrated that attention moves faster over the same distance within objects than between objects (Egly et al., 1994, Moore et al., 1998). Avrahami (1999) showed that attention follows lines rather than crossing them and Houtkamp, Spekreijse & Roelfsema (2003) demonstrated that attention *spreads* over curved objects. Moore, Yantis & Vaughan (1998) as well as Haimson & Behrmann (2001) showed that an occluding object does not have an effect on the spread of attention from one part of the occluded (but amodally completed) object to another.

One goal of Experiment I was to replicate the results that attention follows lines rather than crossing them and that the spread of attention within objects is not influenced by an occluding object. A second goal of Experiment I was to investigate the effect of different kinds of boundaries on the flow of attention. In particular one can distinguish the following 3 kinds of boundaries:

- boundaries that separate an object from its background

- boundaries that separate two objects

- boundaries that separate two different parts of a single object

If attention operates on a fairly late representation that includes object representation rather than just a collection of lines, then these boundaries should have different effects on attention. If attention operates on a fairly early representation (before objects are represented as objects) the boundaries should be treated equally and thus have equal effects on attention.

A third goal was to replicate the results of Kim & Cave (1995) on the time course of attention. They found that the variation of the stimulus onset asynchrony (SOA), i.e. the delay between the onset of the cue and the onset of the probe, only had an effect in a probe *detection* task (fastest response times were measured with an SOA of about 100ms) but no effect in a probe *reporting* task. Thus it was expected that the manipulation had no effect on report frequencies. If a difference would be found anyway, it would allow to observe the spread of attention over time.

Recapitulatorily speaking, Experiment I was designed to find out where attention spreads from different onset locations when it reaches different kinds of boundaries, how attention is affected by occluding objects, and how attention spreads over time.

2.2 Method

The probe technique allows the measurement of processing priority at different locations. The amount of attention to a location affects the speed and accuracy with which a probe at that location is identified. If the participant is asked to report a number of probes that are simultaneously presented at different locations, he or she will report the probes that were most salient. Thus the probes that are reported are the ones that received the most attention.

Probes can be used in different ways:

1. **Probe *detection* task:** in this version of the probe technique the participant simply has to respond as quickly as possible if the probe (often a dot) was presented or not by pressing a single button (e.g. Posner et al., 1980; Kim and Cave, 1995).

2. **Probe *discrimination* task:** participants have to report the identity of a probe (e.g. the identity of a letter or the direction in which an arrow points) by pressing one of a set of buttons that has been previously assigned to that particular probe (e.g. Tsal and Lavie, 1993; Hoffman and Nelson, 1981; Davis and Driver, 1997).

3. **Probe *reporting* task:** participants have to report as many probes as possible from a set of probes by selecting the ones that they saw from a set that contains all possible probes (e.g. Tsal and Lavie, 1993; Kim and Cave, 1995)

All instances of the probe technique have in common the idea that probe processing depends on the degree to which its location is attended. That is, the more accurate and the faster probes are reported, the more they must have been attended.

2.2.1 Participants

The participants were 43 undergraduate students of the University of Massachusetts, Amherst. All of them had normal or corrected to normal vision according to their own statement. They received course credit as compensation for their participation.

2.2.2 Stimuli

Figure 2.1 shows the stimuli that were used to "guide" attention: an object, shaped like the numeral 8 (about 24°x12° of visual angle), a loop (about 18°x12° of visual angle) and two superimposed rectangular shapes forming a cross (about 12°x12° of

Figure 2.1. The six stimuli: eight, loop and cross in both *flips* (upper and lower row).

visual angle). The latter two are subsets of the "figure-8". All objects were composed of black lines. In half of the trials, the segment from the upper right to the lower left was in front of the one from the upper left to the lower right. In the other half of the trials it was vice versa. There was no difference expected between these two mirror images (flips); they were only included for the reason of counterbalancing the directions of the two segments.

A small blue square (about 1°x1° of visual angle) served as the cue. It appeared in one of seven possible positions on the screen and told the participant where to move his or her attention. The probes were black capital letters randomly picked from the Latin alphabet. They were adjusted in size in order to compensate for the drop-off in acuity that emerges with increasing eccentricity from the focus of the gaze. Figure 2.2 shows an example of what the participant saw when the probes were flashed over the figure.

2.2.3 Apparatus

The experiment was controlled with the Vision Shell presentation program (version 1.5) which ran on a Power Mac G4 computer with two 1.25 GHz processors. Stimuli were presented on an NEC 17" ClearFlat monitor (model MultiSync FE990) which was set to 75MHz and a resolution of 1152x870 pixels. Participants viewed the screen

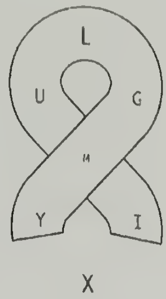

Figure 2.2. The loop shape with the seven sealed probes.

from a distance of 57cm. During the experiment they had to keep their head in a chin rest in order to prevent head movements. Response times were measured with a Cedrus Response Pad button box (model RB-530) with four buttons.

2.2.4 Procedure

Participants were instructed to report four of seven letter probes that were presented on one of the figures. They were forced to report a fixed number of probes in order to control differences regarding their disposition of taking risks in uncertain situations. If a participant was not certain if he or she saw a particular probe, a more conservative participant might decide not to report the probe, while a participant who is more willing to take a risk might decide to report the probe, even if he or she is not absolutely positive about having seen it. Forcing all participants to report a particular number of probes controlled for these possible differences. The decision to ask participants to report 4 probes (rather than any other number) was based on experience from earlier experiments in the same lab. Reporting 4 of 7 probes was a challenging task but not impossible to accomplish.

First, a small cross was presented in the center of the screen for approximately 900ms which the participant had to fixate (see Figure 2.3). Then one of the three

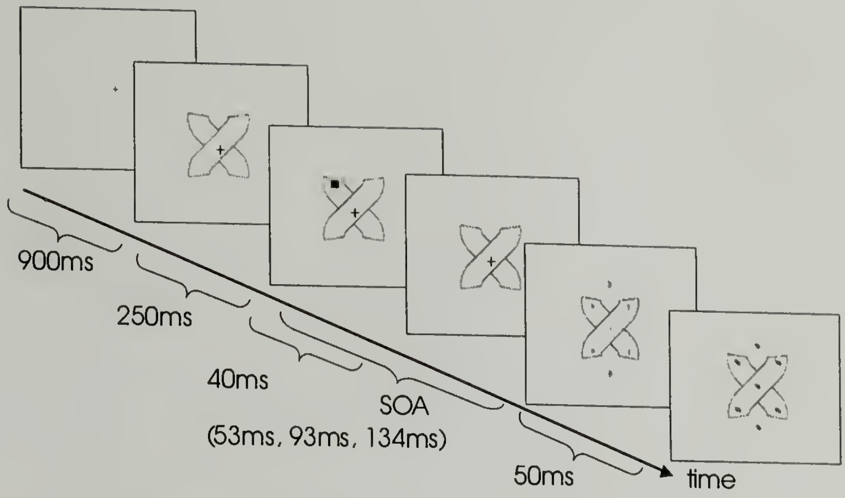

Figure 2.3. The procedure of Experiment I.

figures appeared followed 250ms later by a cue that told participants where to move their attention, and which remained on the screen for 40ms. The exogenous nature of the cue presumably automatically attracted attention to that location. However, the participants were also instructed to *move* their attention to this location. Across trials, the cue was equally likely to appear at each of the seven possible cue positions. The cue then disappeared, and with one of the three different SOAs (53ms, 93ms or 134ms) seven letter probes were presented at fixed locations evenly spaced all over and outside the shape (see Figure 2.2). They remained on the screen for 50ms, before they were each masked with a "%"-sign. The display was removed from the screen and the particpiant was asked to report four of the seven letters that were presented. Each figure was combined with all possible cue positions and all three SOA's, leading to 3x7x3 trials in each block. There were eight blocks resulting in a total of 504 trials for each participant. It took 50-55 minutes to run through all trials. Throughout each trial the participant's head was fixed with a chin rest in order to prevent head movements.

2.3 Results

The dependent measure of the following analyses is always the frequency with which a probe letter from a certain location was reported.

As expected, the flip of the objects (which segment was in the front) didn't make a difference. A repeated measures ANOVA with factors "flip" (flipped, unflipped) and "figure" (eight, loop, cross) neither showed a main effect of "flip" [F(1,43) = .12, p = N/S], nor a main effect of "figure" [F(2,86) = .354, p = N/S] nor an interaction [F(2,86) = .076, p = N/S]. Thus the data for the two flips were collapsed for further analysis.

In order to facilitate the report of the results, I numbered the seven cue positions and probe locations from 1 to 7. From now on I will refer to the center location as location 1, the top location as location 2, the bottom location as location 3, the location that is in the upper part of the front segment (regardless of the flip) as location 4, the location that is in the lower part of the front segment (regardless of the flip) as location 5, the location that is in the upper part of the back segment (regardless of the flip) as location 6 and the location that is in the lower part of the back segment (regardless of the flip) as location 7. Figure 2.4 shows how each location was numbered.

A preliminary analysis of the data revealed that object did not affect the frequencies with which a probe was reported and that SOA only had a small effect. Therefore for the initial analysis the mean frequencies of each combination of probe location and cue position were averaged for each subject over object and SOA, so that 49 scores for each participant remained (one for each combination of the 7 cue positions and the 7 locations). A repeated measures ANOVA with factors cue position and probe location yielded main effects for probe location [F(6,258) = 47.2, p < .001] and cue position [F(6,258) = 5.349, p < .001] as well as an interaction of both [F(36,1548) = 18.379, p < .001]. This means, that there was at least one probe location that was

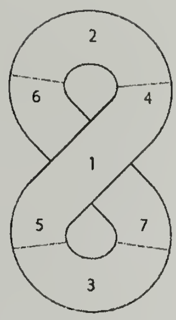

Figure 2.4. The figure shows the labels of the location as they are referred to in this section. The numbers did not appear in the actual experiment; neither did the horizontal lines next to locations 4, 5, 6, and 7. They lines show the location where the loop and the cross were "cut out" from the eight shape

reported more or less frequently than others, that there was at least one position of the cue under which probe locations were more or less frequently reported compared to other positions of the cue. The interaction means that the report frequencies of probes from the differnet locations differ for different positions of the cue.

2.3.1 Cue effect

Separate ANOVAs were conducted for each probe location, each comparing the seven different cue positions. They showed that the probe location that was cued was always reported most frequently, with exception of the center location (probe location 1). Table 2.1 shows the mean frequencies for each combination of cue position and probe location. Within each column the cued location is significantly more frequently reported than any other location. Surprisingly, the report frequency of the probe at the center location (location 1) was unaffected by the position of the cue. Even though the numbers in the column for probe location 1 suggest that this location was less frequently reported when the cue was at position 1 than when it was at any other position, there is no significant difference between the 7 cue positions [F(6,258)

		probe location						
		1	2	3	4	5	6	7
cue position	1	0.595	0.251	0.156	0.330	0.248	0.290	0.214
	2	0.623	**0.345**	0.152	0.307	0.207	0.305	0.196
	3	0.619	0.248	**0.238**	0.299	0.230	0.283	0.231
	4	0.628	0.271	0.138	**0.446**	0.240	0.291	0.193
	5	0.626	0.236	0.152	0.313	**0.356**	0.288	0.205
	6	0.617	0.261	0.143	0.297	0.213	**0.420**	0.209
	7	0.629	0.244	0.145	0.304	0.234	0.291	**0.336**

Table 2.1. The mean frequencies and the results of the ANOVAs for each probe location. The highest frequency is highlighted indicating the cue position at which a probe location received the most attention.

= 1.318, p = N/S]. Thus generally the cue was effective, but not for probes at the center location.

Seven separate ANOVAs (one for each cue position) with factors continuity (continuous and non-continuous segement), field (upper, lower), SOA (53ms, 93ms, 134ms) and object (eight, loop, cross) yielded expected as well as unexpected results:

2.3.2 Continuity effect

In order to find out about the movement of attention along the continuous segment and the non-continuous segment, the report frequencies from probe location 7 when position 6 was cued (and vice versa) as well as the data from probe location 5 when position 4 was cued (and vice versa) were analyzed. Between locations 6 and 7 there was the occluding segment, while between locations 4 and 5 there was not. Since the distance between the locations was the same for these two pairs, this comparison allowed the measurement of the effect of the occluding segment on attention. An ANOVA with factors continuity (continuous segment, non-continuous segment) and field (upper field, lower field) showed main effects for continuity [$F(1,43) = 11.6$, $p < .001$] and field [$F(1,43) = 6.5$, $p < .015$], but no interaction. For now I will only address the effect of continuity. Attention spread more readily across the continuous segment (mean frequency = .277) than the non-continuous segment (mean = .250). Thus attention moved more easily from location 4 to 5 (and vice versa) than from 6 to 7 (and vice versa). The occluding segment **had** an effect on the movement of attention from one location to the other in so far as the occluding object limited the flow of attention from one location to the other, though it didn't prevent it from moving there.

These results stand in contradiction to Moore, Yantis & Vaughan (1998) who didn't find a significant effect of an occluding segment on the flow of attention, even though there was a trend that an occluding segment hampers attention. In contrast to Moore, Yantis & Vaughan (1998) this study used stimuli in which the two segments were connected with each other (in the case of the loop only at the top, in the case of the eight at the top and the bottom). Attention may have spread primarily to these connecting parts rather than to the other part of the segment. To clarify, the same analysis was done only for the cross, which is very similar to the object used by Moore, Yantis & Vaughan (1998). The results show that the difference between the continuous segment (mean = .284) and the non-continuous segment (mean = .251) became even larger [$F(1,43) = 6.2$, $p < .016$]. Thus it seems that when attention moves along a segment, an occluding object hampers the spread of attention to the part of the segment on the other side of the occluding object.

2.3.3 Field effect

Preliminary inspection of the data suggested that probes from the upper visual field were more frequently reported than those from the lower field. In order to explore this effect more fully, a more general repeated measures ANOVA was conducted. The factors were "cued location", "cued field", "probe location" and "probe field". For the factors "cued location" as well as "probe location" the six locations besides the center location were paired up by their relative position to the occlusion. They had the three levels "front" (pos 4 and 5), "back" (pos 6 and 7) and "extreme locations" (pos 2 and 3). "Cued field" and "probe field" had two levels, "upper" (pos 2, 4 and 6) and "lower" (pos 3, 5 and 7). Position 1 was not included in the analysis, since it is the center position and in this case can be considered neutral.

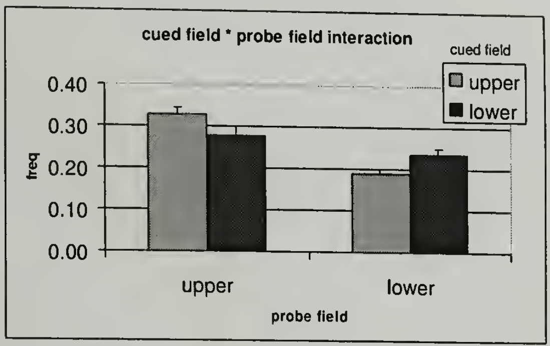

Figure 2.5. The figure shows the interaction between the cued field and the field where the reported probe was in. When the upper visual field is cued it receives more attention than when the lower visual field is cued. However, when the lower visual field is cued the upper field still receives more attention.

There was a main effect for the probe field [F(1,43) = 12.452, p < .001], that showed that probes in the upper field received more attention (mean = 0.303) than those in the lower field (mean = 0.212). There was no main effect for the cued field, i.e. probes were equally frequently reported regardless of the field in which the cue was presented. However, Figure 2.5 shows that there was an interaction between both [F(1,43) = 40.201, p < .001]. This interaction means that the difference in attention between the upper and lower field is larger when the upper field is cued than when the lower field is cued. The upper field receives the most attention when it is cued (cue effect) but it still receives more attention than the lower field even when the lower field is cued.

2.3.4 Object effect

Inner probe locations, that is locations that were close to or at the center of the display (locations 1, 4, 5, 6 and 7) were always located on the object (regardless of whether it was the cross, the loop or the eight). *Outer* locations (locations 2 and 3) were sometimes on the object (e.g. both were located on the eight) and sometimes outside (e.g. both were located outside the object when the cross was presented). Refer to figure 2.6 for a visual presentation. Thus, separate ANOVAs were done on data from inner and outer probe locations.

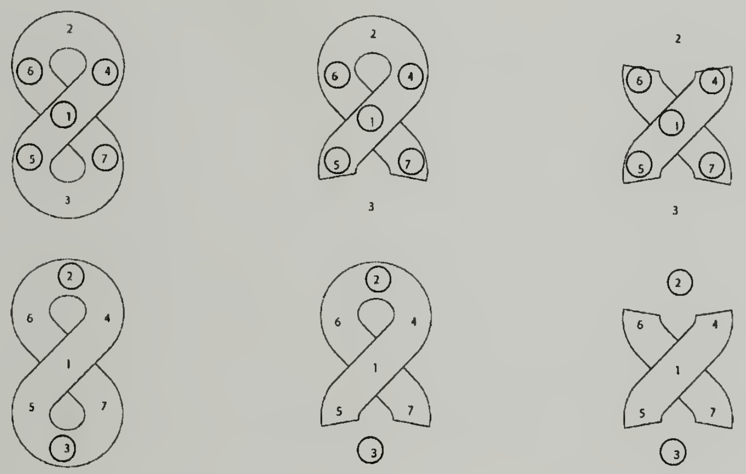

Figure 2.6. The upper row shows inner locations, the lower row outer locations.

As expected, for inner probe locations there was neither a main effect of object [F(2,86) = .095] nor was there any significant interaction. This was expected because the inner part of the display was the same for all three shapes. In order to avoid a possible confounding with the cue-effect, the ANOVA for the outer probe locations only included data from trials where the location itself was not cued. Probe locations

2 and 3 were analyzed separately since location 2 was on the object in $\frac{2}{3}$ of the trials (on the eight, on the loop, but off the cross) while location 3 was only on the object in $\frac{1}{3}$ of the trials (on the eight, but off the loop and off the cross).

Location 2: There was a main effect for object [$F(2,86) = 9.014$, $p < .004$]. The location received the most attention in the eight ($M = .281$, $SE = .023$), less in the loop ($M = .258$, $SE = .025$) and the least in the cross ($M = .234$, $SE = .020$). Since the eight and the loop are identical at location 2 it was expected that the location would receive the same amount of attention in these two objects but less attention in the cross. Surprisingly post-hoc comparisons revealed that there was a difference between the eight and the loop ($p < .004$) and that the difference between the loop and the cross was marginally significant ($p < .078$).

Location 3: Surprisingly, there was no main effect of object [$F(2,86) = .152$]. All three objects received the an equal amount of attention: eight ($M = .150$, $SE = .009$), loop ($M = .152$, $SE = .011$), cross ($M = .149$, $SE = .009$). For the inner locations the results confirmed the expectation that objecthad no effect on attention.

The effects of object at the outer locations were different than expected. Location 2 received less attention in the loop than in the eight even though there was no difference in the contour in this region. However, in the cross, location 2 received less attention than in the loop and the eight. This confirms the expectation that locations outside the object receive less attention. At location 3, object had no effect on attention. This location was reported equally often in all three objects. Due to the field effect, there was not much of attention in the lower visual field. Thus the differences between the effect of object on location 2 and 3 might be related to the field effect.

2.3.5 Boundary effect

In order to test the effect of internal boundaries (boundaries that separate one part of an object from another) planned comparisons of single probe locations were conducted. When the cue was presented at the center position, location 4 was compared to location 6. In this case there was a boundary between the center location and location 6 (Figure 2.7), but no boundary between the center and location 4. Thus attention should flow more easily from the center to location 4 rather than to location 6. This was in fact the case. Location 4 received more attention (M = .33, SE = .023) than location 6 (M = .29, SE = .022). This difference was significant [F(1,43) = 7.59, p < .009].

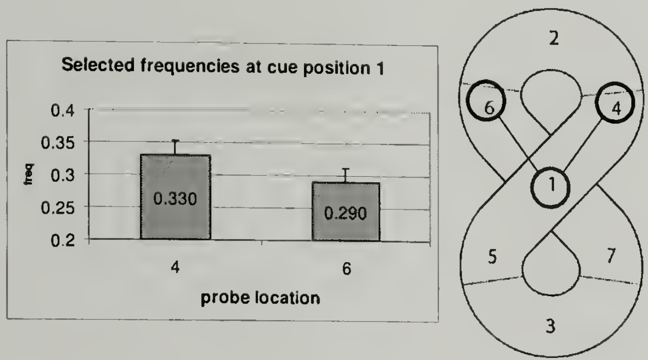

Figure 2.7. When there is a boundary between the cue (center) and location 6 it was reported less frequently than equidistant location 4.

As a control condition, the comparison between location 4 and 6 was made when position 2 was cued (Figure 2.8). In this case there was no boundary between the cued position and any of the two probe locations, thus both locations should receive the same amount of attention. This was indeed the case. When position 2 was cued, location 4 received the same amount of attention (M = .307, SE = .023) as location 6 (M = .307, SE = .020). This difference was not significant [F(1,43) = .018].

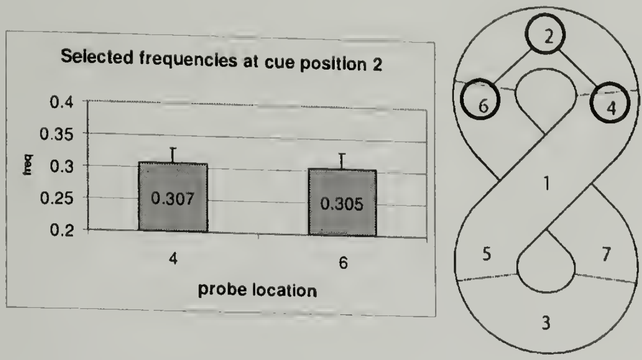

Figure 2.8. When no boundary separated the cue (center location) from the two probe locations 4 and 6 were reported with equal frequency.

The same comparisons were made for locations 5 and 7, when the center position was cued. As Figure 2.9 shows location 5 received more attention (M = .248, SE = .020) than location 7 (M = .214, SE = .019). The difference was significant [F(1,43) = 8.643, p < .005].

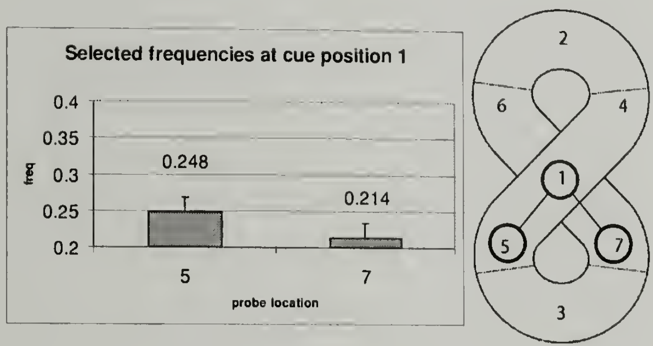

Figure 2.9. When there was a boundary between the cue (center) and location 7 it was less frequently reported than location 5.

No difference was observed for the control condition, when position 3 was cued. Here location 5 received an equal amount of attention (M = .230, SE = .018) as location 7 (M = .231, SE = .018). Again, the difference was not significant [F(1,43) = .008].

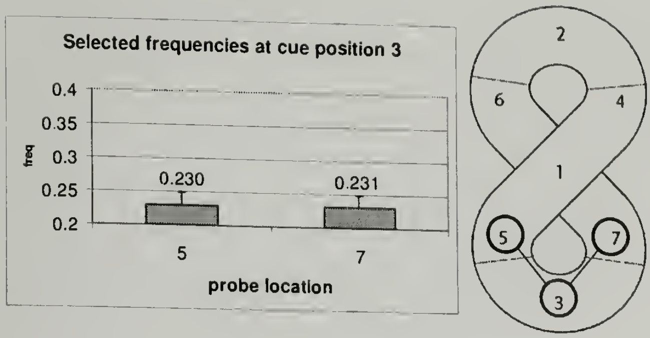

Figure 2.10. When no boundary separated the cue from locations 5 and 7 both were reported equally often.

The results clearly show that inner boundaries had an effect on the flow of attention. Since locations 4, 5, 6, and 7 had the same distance from the center, a space-based explanation for this effect can be ruled out.

2.3.6 SOA effect

Probe stimuli were presented with three different delays (SOAs) after the onset of the cue, namely 53ms, 93ms and 134 ms. Separate ANOVAs for each cue position showed no main effect of SOA. However, SOA interacted with probe location in all ANOVAS except the one for cue position 2. These interactions suggest that at each location attention changes differently over time. Post hoc pairwise comparisons would have required comparisons of all locations with each other for each cue position. In order to make a more general statement, only the extreme cue positions in the upper and lower visual field as well as the center position were examined further. The graphs shown in figure 2.11 suggest that attention moves from the upper visual field to the lower visual field over time, at least when the cue is not in the upper visual field. Especially within the first 100ms, there is a drop off in the upper visual field with a simultaneous increase of attention in the lower visual field.

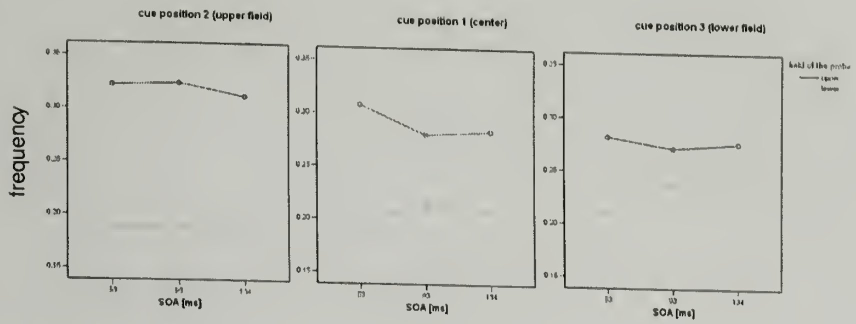

Figure 2.11. The left panel shows no interaction between SOA and field when the cue is in the upper visual field. However, there is an interaction if the cue is in the center. The center panel shows an interaction between SOA and field insofar as between 53ms and 93ms there is an increase in the amount of attention allocated to the lower visual field while at the same time there is a decrease in the upper visual field. The right panel (when the cue is in the lower visual field) also shows an interaction between SOA and field such that attention in the upper visual field remains at the same level over time, but it increases in the lower visual field.

2.4 Conclusion

Experiment I showed that the cue effectively drew attention to the location where it appeared. Probes from the cued location were more frequently reported than those from uncued locations. This result was not surprising, as cueing is a common technique in visual attention experiments and has been successfully used in countless experiments. A cue directs attention to the location where it appears and thus facilitates information processing from that location. Notably, the center location was reported equally often regardless of the position of the cue. This was probably because it is the location with the lowest eccentricity from the focus of the gaze. Thus probes from this location were perceived more easily than those further away form the focus. Even though the size of the probes had been adjusted according to their eccentricity from the focus (probes closer to the focus were smaller in contrast to those further apart), this ceiling effect was observed at the center location.

It was clearly shown that an occluding object interferes with the spread of attention from one part of an occluded object to another. The result is inconsistent with the results of Moore, Yantis & Vaughan (1998) and Haimson & Behrmann (2001) who found no effect of an occluding object on attention. In the context of the debate about "early" and "late" selection (whether attention operates early on in the perceptual process or if it operates on preattentively completed scenes) the current results are consistent with an early involvement of attention in perceptual processes. At the time when the probes were presented, the lines that constituted the occluding segment hampered attention from crossing them. The two parts on either side of it were not yet represented as belonging to the same object. If they were represented as belonging to the same segment, the probe on the other side of the occluding segment should have received a within-object advantage. The difference between the current experiment and Moore et al. (1998) and Haimson & Behrmann (2001) was the location of the occlusion relative to the fovea. In the current experiment the occlusion occurred in a region that was fixated. In both of the earlier experiments the occlusion occurred in parafoveal regions. Thus in these experiments the effect could have been blurred by the increased eccentricity from fixation.

The comparisons of locations 4 and 6 when the cue was at the center location, in contrast to when it was at location 2 (and likewise for the lower visual field), showed that the presence of boundaries let attention flow within the region they bordered rather than crossing them. However, it is important to point out that boundaries don't *prevent* attention from crossing them, but *hamper* the allocation of attention to areas beyond the boundaries. The direct comparison of different kinds of boundaries (those that separate parts of a single object, those that separate two objects and those that separate an object from the background) was impossible due to the very high frequencies at the center probe location. Thus any comparison that involved the center location was inconclusive, since this location was always more frequently reported than any other location, probably for its eccentricity. Boundaries that separate an object from its background were only effective in the upper visual field but not in the lower. This may be due to the general field effect. Since the lower field received much less attention than the upper field, the amount of attention may not have been sufficient to reveal differences due to boundaries. In addition, in the upper field the boundaries had different effects in the three different objects. It was expected that probe location 2 would be reported equally often in the eight and the loop and that it would be less frequently reported in the cross, because in the eight and the loop the probe was located on the object and thus should receive a within-object advantage, while in the cross it was located outside the object. In the cross, attention had to cross a boundary in order to facilitate the probe location, which should have led to fewer probe reports. However, the results showed a difference between the eight and the loop (even though the objects were equal in this part) and only a marginally significant difference between the loop and the cross. The only explanation that seems reasonable is the asymmetry of the loop, which may have let attention flow differently than in the two symmetrical objects, the eight and cross.

An unexpected difference in the amount of attention that was allocated to the upper and the lower visual field was observed. There might be two reasons for the preference for the upper visual field:

1. The probes that were used were letters, which might have induced the participant to "read" the letters and thus start in the upper left corner of the screen, then screening the visual field from the left to the right, line by line, from the top to the bottom. Probes in the upper visual field would be reported more frequently, since they would be attended first and have more time to build up

a stable memory. In this case the advantage should disappear when neutral probes were used, that would not suggest a reading pattern.

2. Two-thirds of the objects contained structures (lines) in the upper visual field, while only $\frac{1}{3}$ contained structures (lines) in the lower visual field (i.e. the "eight" and the "loop" contained lines in the upper visual field, but only the "eight" contained lines in the lower visual field). This might have caused attention to be captured by the lines, causing a bias for the upper visual field. This bias could be removed by removing the "loop" from the set of objects. The remaining objects, the "eight" and the "cross", are symmetrical in the upper and lower visual field. Thus no such bias should occur.

Experiment II was designed in order to replicate the results of Experiment I and to eliminate the preference of the upper visual field as well as the ceiling effect at the center probe location.

CHAPTER 3

EXPERIMENT II

3.1 Introduction

One goal of Experiment II was to eliminate the undesired preference of the upper visual field. A potential explanation for this preference was that letter probes may have encouraged participants to "read" the probes and thus start scanning the display from the upper left corner to the lower right. In order to exclude any effects related to reading, no alphanumerical probes were used in Experiment II. In order to exclude the possibility that the field effect was caused by the asymmetry of the "loop" this object was removed in Experiment II. Only the "eight" and the "cross" were used. Using only symmetrical objects resulted in an equal amount of structure in the upper and lower field and shouldn't have caused any bias.

In addition participants had to perform a probe *discrimination* task rather than a probe *reporting* task. The finding in Experiment I that an occluding segment hampers the spread of attention from one part of the occluded object to another is inconsistent with previous findings. Thus a second goal of Experiment II was to replicate the described effect with a different method, in order to increase its external validity. Many other studies used *probe detection* or *probe discrimination* tasks. The probe discrimination task has two potential advantages:

1. A probe discrimination task requires the exertion of attention, where this is not necessarily the case for a probe detection task. A probe detection task could be accomplished on a purely perceptual level of processing without the involvement

of attention, although many studies have found attention to be involved in the detection of probes (e.g. Eriksen and Hoffman, 1974, Posner et al., 1980, Kim and Cave, 1995, Cepeda et al., 1998)

2. The second advantage of a probe discrimination task is related to the design of the experiment. In order to avoid responses from the participant before he or she had actually seen the probe, a probe detection task requires the insertion of catch trials in which no probe is shown and the participant does not respond. These additional trials would have increased the number of trials to a level that exceeded the total number that a participant can handle within one experimental session.

In a probe discrimination task, the participant is told to respond to the identity of a probe by, for example, pressing one or another button. In Experiment II participants had to respond to the direction of an arrow (pointing either to the left or to the right) by pressing either the left or the right button on a button box. This task yields two dependent measures: response time and accuracy. The more attention a participant directs to a location, the faster and/or the more accurately the response should be.

In Experiment I the probe from the center location was reported equally often regardless of the cue. One potential reason is that the center location was in the participant's fovea and thus more salient to him or her than probes of higher eccentricity from the center. In Experiment I the size of the probes was adjusted proportionately to their eccentricity. However, the size of the center probe may have been still too large to account for its very high saliency. Thus in Experiment II the size of the center probe was further decreased. The size of the other probes remained unchanged.

One goal of Experiment I was to investigate differences between different kinds of boundaries (those that separate an object from the background in contrast to those that separate different parts of a single object as well as those that separate two different objects). It was not possible to make the planned comparisons due to the ceiling effect at the center location. Thus this goal remained in Experiment II. The surprising result of Experiment I that probes at locations inside and outside the three different objects received the same amount of attention led to the speculation that the participants did not attend to the objects. Since the task in Experiment I required them only to report probes, they potentially could have ignored the objects altogether. In order to direct participants' attention to the different objects in Experiment II, a second task was added, which required the participants to name the object that was presented. Since the manipulation of the delay between the onset of the cue and the onset of the stimulus (SOA) had no effect on the results of Experiment I, SOA was not manipulated in Experiment II.

3.2 Method

3.2.1 Participants

The participants were 41 undergraduate students of the University of Massachusetts, Amherst. All of them had normal or corrected to normal vision according to their own statement. They received course credit as compensation for their participation.

3.2.2 Stimuli

The stimuli were the eight-shaped object and the cross from Experiment I (the left and the right figure in Figure 2.1). Again, half of the trials showed each object "flipped", the other half not "flipped". The size of the stimuli was the same as in Experiment I. The cue was again a small blue square of the same size as in Experiment

I and appeared in one of the same seven possible positions. The target probe was the outline drawing of an arrow either pointing to the left or to the right. It covered an area of 0.5 square degrees of visual angle at the center, 1 square degree at locations 4, 5, 6 and 7 and 1.5 square degrees at location 2 and 3.

3.2.3 Apparatus

The same equipment as in Experiment I was used: the experiment was controlled with the Vision Shell presentation program (version 1.5) which ran on a Power Mac G4 computer with two 1.25 GHz processors. Stimuli were presented on an NEC 17" ClearFlat monitor (model MultiSync FE990) which was set to 75MHz and a resolution of 1152x870 pixels. Participants viewed the screen from a distance of 57cm. During the whole experiment they had to keep their head in a chin rest in order to avoid head movements. Response times were measured with a Cedrus Response Pad button box (model RB-530) with four buttons.

3.2.4 Procedure

Figure 3.1 shows the procedure of Experiment II: first, a fixation cross was presented in the center of the screen for 900ms and the participant had to fixate it. Then one of the objects appeared and stayed on the screen. Eighty milliseconds later a cue was flashed for 50ms in one of the seven cue positions. 30ms after the cue had disappeared an arrow pointing either to the left or to the right was presented for 70ms. After the arrow had disappeared the participant had 670ms to respond with the left or the right button on the button box according to the direction in which the arrow was pointing. If the participant responded incorrectly, an error sound was played, otherwise no sound was played. Then a screen came up, which showed the four possible objects (the eight, flipped and not flipped as well as the cross, flipped and not flipped). The participant had to select the object that he/she saw by pressing the corresponding button on the button box. The participant had 5 seconds to make the selection. If the participant had not made a selection after 5 seconds or the response was incorrect, an error sound was played; if the response was correct no sound was played. After an inter trial interval (ITI) of 1 second the next trial was presented. Every 40 trials the participant was allowed to take a break.

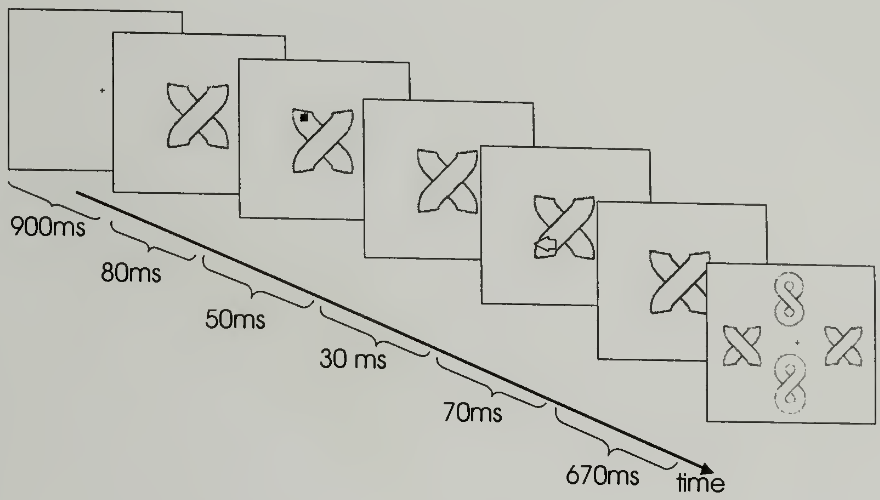

Figure 3.1. The procedure of Experiment 2.

Although the response to the arrow preceded the object naming task, the latter task was introduced to the participant as the *primary* task, and the arrow response task was introduced as the *secondary* task, indicating that the object naming task was more important.

3.3 Results

The data of 1 participant was excluded from the analysis because she quit early and thus her data was incomplete. The mean response time to the arrow was 668ms. Three participants whose mean response times were more than 2 standard deviations above the mean were excluded from further analysis declaring them as outliers.

The following analyses have been done including all participants except for those with extraordinary long response times. The lack of positive results led to further analyses excluding the data from participants whose error rates were extraordinarily high. However, the results with and without participants with high error rates were similar.

In 97% of the trials participants responded with the correct direction of the arrow. The data of 2 participants whose performance was more than 2 standard deviations below the mean were excluded from further analysis. In 90% of the trials participants named the figure correctly. The data of 2 participants whose performance was more than 2 standard deviations below the mean was excluded from further analysis.

3.3.1 Preliminary analysis

3.3.1.1 Response times

A repeated measures ANOVA with factors "arrow direction" (left, right), "flip" (flipped, not flipped), "block" (1-4) and "object" (eight, cross) showed no main effects of "arrow direction" [$F(1,32) = 1.063$, p = N/S] and "flip" [$F(1,32) = .019$, p = N/S]. Thus in the further analysis the data was collapsed over these two factors. "Block" showed a significant main effect [$F(3,96) = 95.799$, $p < .001$]. Reaction times decreased from block 1 to block 4 reflecting a learning effect. Table 3.1 shows the mean response times and accuracy rates for each block. Post-hoc pairwise comparisons showed that response times in block 1 were slower than in any other block, in block 2 they were faster than in block 1 but slower than in block 3 and 4 and that in block 3 and 4 response times were faster than in the first two blocks but did not differ from each other. "Object" showed a main effect [$F(1,32) = 53.703$, $p < .001$] showing that participants responded faster to probes presented on the "cross" (mean = 572ms) than on the "eight" (mean = 688ms). The interaction of "block" and "object" was also significant [F(3,96) = 6.942, p < .013] expressing different learning effects for each object. The difference in response time between the two objects increased from 66ms in block 1 to 121ms in block 2 to 139ms in blocks 3 and 4 (see Figure 3.2).

3.3.1.2 Accuracy

A repeated measures ANOVA with the same factors was done on accuracy rates of the probe discrimination task. As for response times there was neither a main effect of "arrow direction" [F(1,32) = 1.038, p = N/S] nor of "flip" [F(1,32) = 2.795, p = N/S]. However, as Table 3.1 shows, response times improved from block 1 to block 4, but accuracy remained constant [F(3,96) = .766, p = N/S]. Regarding the two different objects, participants were better (more accurate) when the probe was presented on the "eight" (mean = 0.979) than on the "cross" (mean = 0.974). This difference was significant [F(1,32) = 5.119, p < 0.031]. Apparently participants were faster, but less accurate responding to probes presented on the "cross" and slower, but more accurate responding to probes presented on the "eight". There was no interaction of "object" and "block" [F(3,96) = 0.396, p = N/S]. The different learning effects for the two objects that were observed for response times, were not reflected in response accuracy.

Block	Mean RT in ms	Accuracy
1	841	0.975
2	628	0.979
3	540	0.975
4	511	0.978

Table 3.1. Mean response times and accuracy rates for the four blocks. Participants' response times improved from block 1 to 4, but not accuracy.

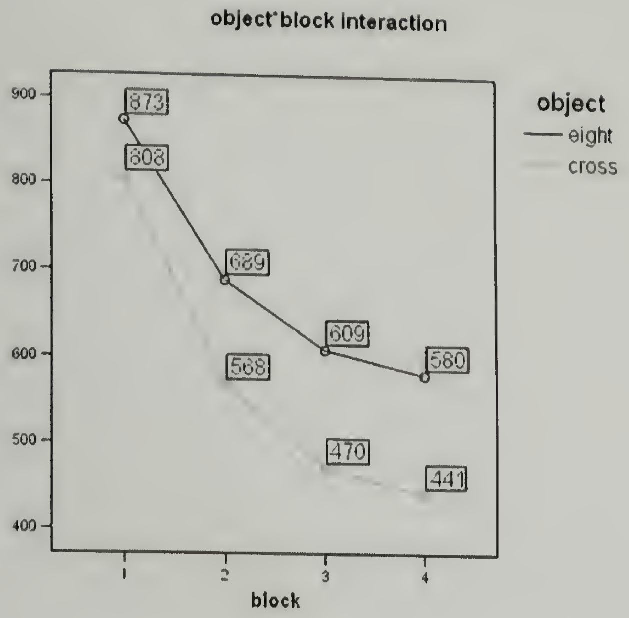

Figure 3.2. The interaction between "object" and "block" reflects a different learning effect for the eight and the cross. The difference between the two objects increases from block 1 (66ms) to block 3 and 4 (139ms each)

3.3.2 Center location

In Experiment I the center location was always the one that was most frequently reported, while the location of cue did not have an effect at that location. It was assumed that this was due to a ceiling effect which was presumably caused by the fact that the center location is in the focus of the gaze. Thus it was easier for participants to perceive probes from this location than from locations with higher eccentricity from the focus.

3.3.2.1 Response times

A repeated measures ANOVA with factors "block" (1-4), "cue position" (1-7), "probe location" (1-7) and "object" (eight, cross) showed no main effect of "probe location" [F(6,192) = .429, p = N/S]. No interaction in which "probe location" was involved was significant. Figure 3.3 shows that the response times to the probe were equal at all locations. In contrast to Experiment 1 the center location did not receive an advantage that was reflected in response times.

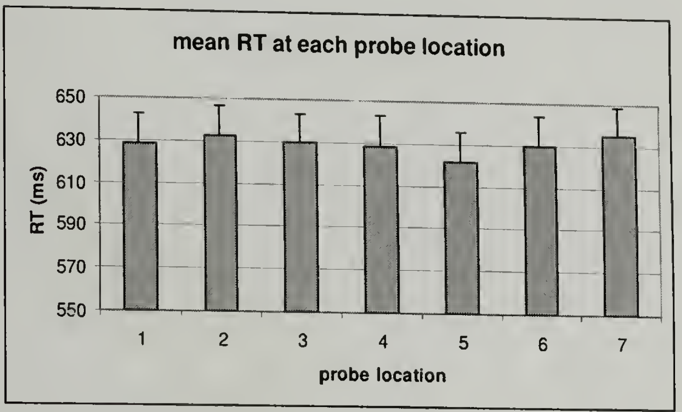

Figure 3.3. Equal response times to the target at each probe location

3.3.2.2 Accuracy

In contrast to the analysis of the response times, the analysis of accuracy rates showed an advantage for the center location: a repeated measures ANOVA with factors "block" (1-4), "cue position" (1-7), "probe location" (1-7) and "object" (eight, cross) showed a main effect of "probe location" [F(6,192) = 5.153, $p < .001$]. Post-hoc pairwise comparisons showed that participants were equally accurate (p = 0.140) responding to the probe at location 1 (mean = 0.988) and location 4 (mean = 0.983), but that they were more accurate responding to location 1 in contrast to all other probe locations besides location 4 (all p-values below 0.005). Table 3.2 shows the mean accuracy rates for probes from the seven different locations. Although the response times to all probe locations were not significantly different, accuracy in the probe task was better at the center location than at all other locations (except for location 4). The advantage for the center location may be explained by the fact that it was the location in the participants' focus (like in Experiment I). However, this doesn't explain why location 4 received a similar advantage and why location 3 was more accurately reported than locations 6 and 7. It also doesn't explain why these advantages occur only for accuracy rates, but not for response times.

Probe location	Mean accuracy
1	0.988
2	0.976
3	0.973
4	0.983
5	0.971
6	0.975
7	0.971

Table 3.2. Accuracy rates from the 7 different probe locations. Location 1 was more accurately reported than all other locations (except for location 4). Location 4 was more accurately reported than all other locations (except for locatoins 1 and 2). Location 3 was more accurately reported than locations 6 and 7.

3.3.3 Cue effect

3.3.3.1 Response times

Separate ANOVAs were conducted for each probe location, each comparing the seven different cue positions. They included the factors "block" (1-4), "cue position" (1-7) and "object" (eight, cross). There was no main effect of "cue position" at any of the probe locations. This means that response times to the cued location were not different from locations that were not cued. Table 3.3 shows the F-values for the main effect of "cue position" for each of the seven probe locations. Table 3.4 shows the mean response times for each combination of cue position and probe location.

Probe location	ANOVA results for the main effect "cue position"
1	F(6,192) = 0.682, p = N/S
2	F(6,192) = 1.831, p = N/S
3	F(6,192) = 0.744, p = N/S
4	F(6,192) = 1.267, p = N/S
5	F(6,192) = 1.693, p = N/S
6	F(6,192) = 1.746, p = N/S
7	F(6,192) = 0.855, p = N/S

Table 3.3. ANOVA results for the separate analyses of each probe location showed that the factor "cue position" was not significant at the .05 level at any probe location.

3.3.3.2 Accuracy

As for response times, separate ANOVAs on accuracy rates were conducted for each probe location. They included the factors "block" (1-4), "cue position" (1-7) and "object" (eight, cross). There was no main effect of "cue position" in the ANOVAs for probe locations 1, 2, 4, 6 and 7. However, there was a main effect of "cue position" at locations 3 [$F(6,192) = 4.421$, $p < .043$] and 5 [$F(6,192) = 3.844$, $p < .004$]. Post-hoc comparisons showed no reliable pattern that would suggest that the probe was more accurately reported when its location was cued.

		probe location						
		1	2	3	4	5	6	7
cue position	1	635	632	634	627	614	626	646
	2	607	659	636	622	605	604	624
	3	632	647	647	631	636	661	645
	4	638	612	643	651	643	640	626
	5	636	611	621	647	605	619	653
	6	628	616	615	622	647	622	615
	7	625	649	616	600	602	635	635

Table 3.4. Mean response times (in ms) for each combination of probe location and cue position.

Regarding possible reasons for this result, it seems unlikely that the cue did not capture attention since it was of the same size and color as in Experiment I. Potentially the nature of the probe and/or its timing were not adequate to measure attention, or the additional task in Experiment II may have bound too much of the participants' attentional resources so that they were not able to exert attention in the performance of the discrimination task. Further implications will be discussed later. This unexpected result made the following analyses difficult.

3.3.4 Continuity effect

3.3.4.1 Response times

A repeated measures ANOVA was performed on the response times from probe location 7 when position 6 was cued (and vice versa) as well as the data from probe location 5 when position 4 was cued (and vice versa). The factors were "block" (1-4), "continuity" (continuous segment, non-continuous segment), "field" (upper, lower) and "object" (eight, cross) showed main effects for "block" [$F(3,96) = 37.962$, $p < .001$] and "object" [$F(1,32) = 23.629$, $p < .001$], but no main effects for "field" [$F(1,32) = .393$, p = N/S] and "continuity" [$F(1,32) = 1.337$, p = N/S]. Surprisingly, the continuity effect from Experiment I disappeared. There was no significant difference in response time to the target whether there was an occluding segment between the cue and the probe (mean = 625ms) or not (mean = 645ms). In this experiment the occluding segment had no effect on attention. Other than expected the response times were even longer when no occluding segment was between cue and target than when there was one. The reason for that must be due to the change of the task (from probe reporting to probe discrimination) or the addition of a second task, because these were the two major changes between Experiment I and II.

3.3.4.2 Accuracy

The same analysis as for response times was done for accuracy rates. There were no main effects for any of the factors and none of the interactions turned out to be significant. Participants were equally accurate in all four blocks, equally accurate whether there was an occluding segment between the cue and the probe or not, equally accurate in the upper and lower visual field and equally accurate whether the probe was presented on the "eight" or the "cross".

3.3.5 Field effect

The analysis of the field effect included the same factors as in Experiment I: "cued location", "cued field", "probe location" and "probe field", but also included the factors "block" (1-4) and "object" (eight, cross). For the factors "cued location" as well as "probe location" the six locations besides the center location were paired up by their relative position to the occlusion. They had the three levels "front" (pos 4 and 5), "back" (pos 6 and 7) and "extreme locations" (pos 2 and 3). "Cued field" and "probe field" had two levels, "upper" (pos 2, 4 and 6) and "lower" (pos 3, 5 and 7). Position 1 was not included in the analysis, since it is the center position and in this case can be considered neutral.

3.3.5.1 Response times

There was no main effect of "cued field" [F(1,32) = .294, p = N/S] which showed that there was no difference in response time whether the cue was presented in the upper or the lower visual field. There was also no main effect of "probe field" [F(1,32) = .159, p = N/S] which showed that participants responded equally fast to probes presented in the upper and the lower visual field regardless of the cue position. The interaction of "cued field" and "probe field" wasn't significant either [F(1,32) = .324,

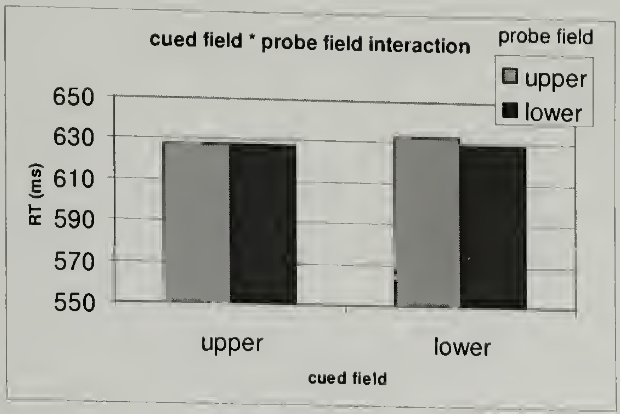

Figure 3.4. There was neither a main effect of "cued field" nor "probe field", nor was there an interaction.

p = N/S] showing that there was no difference in response time whether cue and probe were in the same field or in different fields. In contrast to Experiment I there was no difference in response time between the upper and the lower visual field. However, since it is not clear if the probe was measuring attention adequately it is not possible to tell if the field effect was indeed eliminated.

3.3.5.2 Accuracy

The same analysis (including the same factors) as for response times was conducted for probe accuracy rates. There were no main effects except for the one for "probefield" [$F(1,32) = 5.943$, $p < .021$]. Probes from the upper field (mean = .978) were more accurately reported than probes from the lower field (mean = .969). Thus there still seems to be some bias in favor of the upper visual field. There was also an interaction of "cue field" and "probe field" [$F(1,32) = 5.155$, $p < .030$]. Figure 3.5 shows that probes from the field in which the cue appeared were more accurately reported than probes from the uncued field.

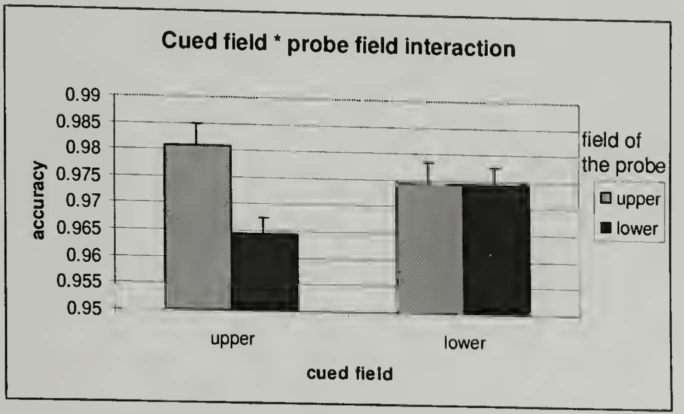

Figure 3.5. There was a main effect of "probe field", which shows that probes from the upper visual field were more accurately reported than probes form the lower field. The interaction shows, that when the cue was in the upper visual field, probes from the upper field were more accurately reported than probes from the lower visual field. When the cue was in the lower visual field, probes from both field were reported equally accurately.

3.3.6 Object effect

A repeated measures ANOVA with factors "block" (1-4), "cue position" (1-7), "probe location" (1-7) and "object" (eight, cross) was done for response times and accuracy rates:

3.3.6.1 Response times

As the preliminary analysis already suggested, there was a main effect of "object" [$F(1,32) = 53.788$, $p < .001$] showing that responses to the probe were slower on the "eight" (mean = 688ms) than on the "cross" (mean = 571ms). The interaction of "object" and "block" was also significant [$F(3,96) = 6.818$, $p < .014$] suggesting different learning rates for the two different objects.

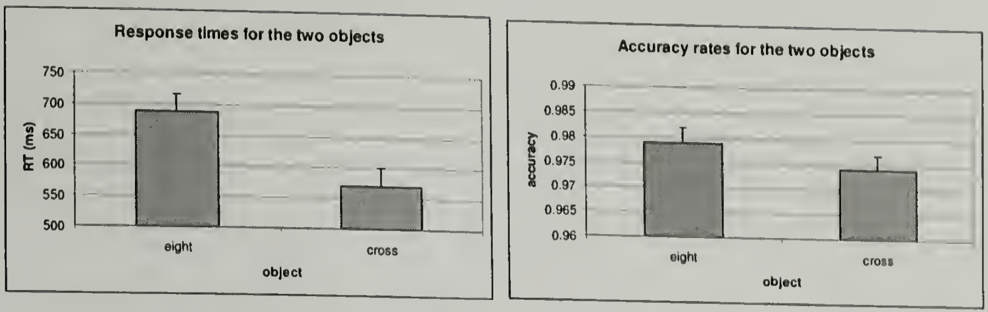

Figure 3.6. Participants responded slower and more accurately to probes on the "eight", but responded faster and less accurately to probes on the "cross".

3.3.6.2 Accuracy

The analysis for accuracy rates showed also a main effect [$F(1,32) = 4.275$, $p < .047$], but in the other direction: responses to the probe were more accurate when it was presented on the "eight" (mean = 0.979) than on the "cross" (mean = 0.974). Other than for resposne times the interaction of "object" and "block" was not significant [$F(3,96) = .359$, p = N/S]. A possible explanation for the different speed-accuracy trade-offs for the "eight" and the "cross" is given in the Conclusions section.

3.3.7 Same object and different object boundaries

As in Experiment I, planned comparisons of single probe locations were conducted in order to test the effect of boundaries that separate one part of an object from another as well as boundaries that separate two objects from each other. A repeated measures ANOVA on the data from probe locations 4, 5, 6, and 7 when position 1 was cued contained the factors "block" (1-4), "field" (upper, lower), "boundary" (present, not present) and "object" (eight, cross). Again, there was a main effect of "block" [$F(3,96) = 41.580$, $p < .001$] reflecting a learning effect from block 1 to block 4.

3.3.7.1 Response times

As expected there was no main effect of "field" [$F(1,32) = .049$, p = N/S] but also no main effect of "boundary" [$F(1,32) = .458$, p = N/S]. In contrast to Experiment I the presence of a boundary between the cue and the probe had no effect on attention. There was a main effect of "object" [F(1,32) = 25.994, p < .001]. As in the overall analysis it took participants longer to respond to the arrow when it was presented on the "eight" (mean = 680ms) than on the "cross" (577ms). Of particular interest was the interaction between "boundary" and "object". The boundary between the cue and the probe in the "eight" was of a different nature than in the "cross". In the "eight" the boundary separated two parts of the same object, while in the the "cross" it separated two different objects, namely the two rectangular shapes that constitute the "cross". If the same-object advantage for attention held for an object so strongly "bent" like the "eight", the RT to the probe at location 6 should be faster in the "eight" than in the "cross". However, the interaction was not significant [F(3,96) = 1.127, p = N/S] nor was any other interaction.

3.3.7.2 Accuracy

The same analysis was done for accuracy rates. None of the main effects was significant. Probes were reported equally accurately regardless of the block, the field and the object. Similar to the result that was obtained for response times, there was no difference in accuracy whether there was a boundary between the cue and the probe or not. The interaction between "object" and "boundary" wasn't significant either. Two explanations for this non-result can be given:

1. The "eight" is indeed bent too strongly and attention doesn't flow from the cued location to the probe location (at least not in the given time).

2. The two rectangular shapes which constitute the "cross" are not represented as two different objects but one "cross"-object.

However, considering that the cue didn't seem to be effective, this analysis is not conclusive.

3.3.8 Object-background boundaries (cue outside)

In order to test the effect of boundaries which separate an object from its background, response times to probes outside an object were compared to those to probes inside an object. Experiment I showed an effect for this kind of boundary only in the upper, but not the lower visual field. This could have been due to the general field effect which was observed in Experiment I. In Experiment II there was no field effect, thus this kind of boundary should be effective in both the upper and the lower visual field. A repeated measures ANOVA with factors "block" (1-4), "cue position" (position 2, 3), "probe field" (left, right) and "boundary" (present, not present) was conducted. This combination of factors allows a comparison of the response times from probe locations 4 and 6, when position 2 is cued and probe locations 5 and 7 when position 3 is cued. In the "eight" there is no boundary between the cue and the probe, in the "cross" there is a boundary.

3.3.8.1 Response times

The main effect of "boundary" [$F(1,32) = 35.147$, $p < .001$] showed a reversed pattern than expected: when no boundary was present the response times were even slower (mean 692ms) than when a boundary was present (mean = 561ms). However, this result is confounded with the very dominant object effect. The "no boundary" condition only exists in the "eight" while the "boundary" condition only exists in the "cross". The general object effect may have overruled the boundary effect.

3.3.8.2 Accuracy

The main effect of "boundary" was marginally significant [$F(1,32) = 3.710$, $p < .063$]. In contrast to the results for response times, the results for accuracy rates showed the expected pattern. When the cue and the probe were not separated by a boundary the accuracy in the probe task was higher (mean = .983) than when they were separated (mean = .972).

3.3.9 Object-background boundaries (cue inside)

3.3.9.1 Response times

In the analyses above the cue was outside the object and the probes inside. A similar analysis was conducted for the case in which it was vice versa (when the cue was inside the object and the probe outside). A repeated measures ANOVA with factors "block" (1-4), "horizontal position of the cue" (positions 4 and 6, positions 5 and 7) "vertical position of the cue" (positions 5 and 6, positions 4 and 7), "probe location" (location 2, 3) and "boundary" (present, not present) was conducted. Besides "block" the only other main effect that was significant was "boundary" [$F(1,32) = 65.853$, $p < .001$] but again, contrary to expectations, it took participants longer to respond to the probe when no boundary was present (mean = 686ms) than when a boundary was present (mean 560ms).

3.3.9.2 Accuracy

The same analysis for accuracy rates showed no main effect of "boundary" [$F(1,32) = 1.792$, p = N/S]. When the cue was inside the object and the probe outside the effect of the boundary (which was observed for accuracy rates when it was vice versa) disappeared.

3.4 Conclusion

In Experiment II the response times to probes at the cued location were not different from those to probes from locations that were not cued. Similar results were obtained for accuracy rates. Even though there was a main effect of "cue position"

in the analysis of the accuracy rates, there was no evidence that the probe from the cued location was more accurately reported than from other locations. Possible explanations for this result include the following: the cue did not attract attention, the probe did not measure attention properly, or another factor prevented the exertion of attentional resources in the discrimination task. Since the same cue was effective in Experiment I, it is unlikely that the cue was not effective in Experiment II. Probe discrimination tasks have been successfully used in research on visual attention (e.g. Hoffman and Nelson, 1981; Davis and Driver, 1997; Mounts, 2000), including arrow probes (Mogg et al., 2004). Thus it is also unlikely that the probe didn't measure attention properly. However, Posner et al., 1980) found not only faster response times for a detection task than a discrimination task, but also a smaller effect size for the discrimination task. They analyzed response times as a function of uncertainty of the probe position and explained these results with an "internal lookup" process that requires additional time. In the current experiment, it may be that the effect size was too small to be detected. If this was the case, a detection task should reveal attentional differences between the probe locations.
Another explanation for equal response times and accuracy rates of cued and uncued locations is that the additional task could have prevented the application of attention in this task. This option will be discussed in detail in Chapter 4.

Since it is not certain whether participants used attentional resources in the discrimination task at all, it is difficult to draw reliable conclusions from the results. Although, response times were not affected by any of the boundaries, the analysis of accuracy rates showed a marginal effect of the boundaries that separated the object from its background (though this was only true when the cue was outside and the probe was inside the object, but not vice versa). Likewise the occluding segment had no effect whatsoever, neither on response times nor on accuracy rates. If participants truly did not employ attention in the discrimination task, it is not surprising that the above mentioned effects were not observed.

It is noteworthy, however, that the response times to probes on the "eight" were about 100ms longer than those to probes on the "cross". Accuracy rates in contrast were better for the "eight" than for the "cross". This pattern suggests that participants made a different speed-accuracy trade-off for the two objects. Probes presented on the "eight" were reported slower but more accurately, while probes being presented on the "cross" were reported faster but less accurately.

There are 3 main differences between the "cross" and the "eight":

1. The cross covers a smaller area than the eight.

2. The total length of the lines that compose the object is shorter for the cross than the eight.

3. The cross is composed of two objects, while the eight is one single object.

The first two differences seem to be the most likely explanations for the faster response times to the probes on the "cross" in contrast to the "eight". The smaller size and the smaller circumference may have made it easier for participants to build up and maintain a representation of the "cross" than of the "eight". This may have led them to respond faster (since the task was to respond as quickly as possible) to the "cross". Faster responses are usually less accurate, which is exactly what the results show. Since the "eight" required more time to process, responses became "automatically" more accurate. However, this post-hoc explanation is more speculative than explanatory.

CHAPTER 4
CONCLUSION

4.1 General Discussion

The purpose of Experiment I was to investigate if and how different kinds of boundaries affect the allocation of attention as well as its temporal implications. Experiment I showed expected and unexpected results. The fact that a cue facilitates information processing at its location was expected, as was the fact that attention stays within an area bordered by lines, rather than crossing them. The preference for the upper visual field and the finding that an occluding segment hampers the spread of attention from one part of an object to another (continuity effect) were not expected. While the field effect seemed to be a result of the experimental design, the continuity effect contradicted the findings of others. Thus Experiment II was conducted in order to remove artifacts that may have altered the pattern of results, to replicate the expected results from Experiment I and to uncover expected effects that were not observed. These goals were partially achieved, but other unexpected effects occurred and raised new questions.

In Experiment I, the probe at the cued location was most frequently reported on the majority of the trials. This means that the cue successfully directed attention to the location where it appeared and facilitated information processing from this location. Thus, in Experiment II, it was expected that response times to the probe that appeared at the cued location would be faster than the response times to other probes and that participants would be more accurate reporting the probe from a cued location in contrast to locations that were not cued. Such an advantage for the cued location was not observed in Experiment II, neither for response times nor for accuracy rates. There are several explanations possible for this result:

1. **Effectiveness of the cue:** The cue was not effective and didn't draw attention to the location where it appeared. This explanation is unlikely since in Experiment II exactly the same cue was used as it was in Experiment I in which the cue was effective.

2. **Adequacy of the probe:** The cue *did* direct attention to the cued location, but the probe was not adequate to measure attention. However, probe discrimination tasks have been used successfully by many others (e.g. Hoffman and Nelson, 1981; Davis and Driver, 1997; Mounts, 2000) even with arrow probes (Mogg et al., 2004, see also Mou et al. 2001).

3. **Timing:** The cue *did* direct attention to the cued location and the probe *was* adequate to measure attention but the SOA (the time between stimulus onset and probe onset) was not long enough to allow attention to spread over the object. However, in Experiment II the SOA was held constant at 80ms while in Experiment I effects on attention were observed with an SOA of 53ms. In addition to that e.g. Kim & Cave (1995) found effects on attention with an SOA of 60ms.

4. **Probe task:** The cue *did* direct direct attention to the cued location and the probe *was* adequate to measure attention but the nature of the probe task didn't require participants to spread their attention over the whole object. Even though it has been shown that attention can spread *automatically* over surfaces (He and Nakayama, 1995), the probe discrimination task could have encouraged participants to shift attention from the cued location to the location where the probe actually appeared, rather than spreading it over the whole object.

However, in this case, the location where the probe appeared should have still received more attention than other locations, resulting in shorter response times to the probe. This was clearly not the case.

5. **Size of the probe:** The cue *did* direct attention to the cued location and the discrimination task *was* adequate to measure attention but the probe was too large (and easy to detect) that the discrimination task was too easy for the participants. It's possible that participants did not have to exert attentional resources in order to perform the task. The probes covered an area between 0.5 square degrees at the center and 1.5 square degrees at locations 2 and 3. Others used smaller probes (e.g. Kim and Cave, 1995 used a probe of the size of 0.48 square degrees, Hoffman and Nelson, 1981 a probe of the size of 0.04 square degrees).

6. **Priority of the two tasks:** The cue *did* direct attention to the cued location and the probe *was* adequate to measure attention, but the priority of the two tasks was chosen poorly. The primary task was to memorize and later report the identity of the object. The secondary task was to identify the probe. Participants may have first encoded the identity of the object and maintained it in a short term memory buffer before they performed the probe discrimination task. Thus they may have used the majority of their attention to perform the object recognition task instead of the probe discrimination task. An indicator for this explanation is the fact that the response times were longer (mean of 668ms) than in other experiments that used a probe discrimination task (e.g. Posner et al., 1980 found mean response times of 450-500ms). Switching the order of the two tasks and telling the participants that the probe discrimination task is more important than the object recognition task would require participants to prioritize the probe discrimination task and attend more strongly to the probe.

7. **Second task:** It may be that not only the priority of the tasks influenced participants' distribution of attention between the object recognition task and the probe discrimination task, but also the addition of the second task itself. The addition of the second task may have overstrained the participants. Assuming that attention is a limited resource, participants may have used the majority of their attentional resources in order to perform the primary task of identifying the object and maintaining its representation until they were asked to report it. It was easy to identify the object as the "cross" or th "eight" but since the two flips of each object only differ slightly, the task required a lot of attention to accurately identify the object correctly. Thus, at the time when the probe task had to be performed, no (or only little) attention was to be allocated to this task.

The last explanation is consistent with the Load Theory proposed by Lavie, Hirst, deFockert & Viding (2004). The authors showed that cognitive functions like working memory and dual-task-coordination can affect attention.

In order to demonstrate the effect of working memory load, they combined a recognition memory task with a flanker response-competition task: participants either had to memorize a set of six digits (high memory load) or only one digit (low memory load) while they had to report the identity of a target letter under the presence of a distractor letter. They found that distractor letters had a larger influence in the high-load condition than in the low-load condition, i.e. response times to the target letter under the presence of a distractor were slower in the high-load condition than in the low-load condition.

Similarly they showed that dual-task-coordination can influence the performance in the flanker task. In a second experiment they manipulated the number of tasks the participant had to perform at a time (two tasks, one task) by having the participant perform the two tasks simultaneously (like in the experiment described above) or perform them serially. Distractor effects were larger in the dual-task condition than in the one task condition, i.e. response times to the target letter in the presence of a distractor were slower in the dual-task condition than in the one task condition.

These results can be directly related to the inconsistency that in Experiment I different probe locations received a different amount of attention but not in Experiment II. In Experiment I participants had to perform only one task (the selective attention task) and all attentional resources could have been used to perform this task. In Experiment II participants had to deal with two additional tasks: aside from the selective attention task (report the probes) they had to memorize the identity of the object and later report it (a memory recognition task) and they had to coordinate the memory task with the selective attention task (dual-task coordination). According to the Load Theory, participants in Experiment II had to deal with a much higher cognitive load than in Experiment I. This higher load may have bound attentional resources so that no or only little resources may have been left when the cue and subsequently the arrow probe appeared. Thus perhaps not enough attention was left that could have been spread over the object to facilitate the processing of the probe. Attention might also have been spread too broadly in doing the object recognition task so that the probe discrimination task measured the allocation of attention inappropriately.

Another goal of Experiment II was to eliminate the undesired preference of the upper visual field and the ceiling effect at the center location.
Response times to probes from the upper visual field were not different from those to probes from the lower visual field. However, the analysis of accuracy rates showed that probes from the upper field were more accurately reported than probes from the lower field. Thus, the field effect was not completely eliminated, even though

a non-alphanumerical probe and symmetrical objects were used. Possibly there is a natural preference of the upper visual field.
Response times to probes from all seven locations were equal, but the analysis of accuracy rates showed, that locations 1 and 4 were more accurately than probes from other locations. The strong advantage of the center probe, as it was observed in Experiment I, did not completely disappear. However, it remains unclear why the probe from location 4 received a similar advantage.
The results of Experiment II do not allow strong conclusions. If attentional resources were mainly bound to the additional tasks, it is difficult to tell if and how much attention was used to perform the probe task in Experiment II. Thus the non-results of Experiment II are not very meaningful.

Experiment I, however, showed that attention is influenced by the configuration of boundaries and that an occluding segment hampers the spread of attention from one part of an object to another. This is an indicator for the use of attentional resources, early on in perceptual processing. At the time when the probes from the seven different locations were processed, wither the two regions on either side of the occluding segment (location 7 when 6 was cued and vice versa) were not yet represented as belonging to the same object, or attention hadn't spread to the part on the other side of the occluding segment. If the two parts had been amodally integrated in the representation of the object, the location on the other side of the occluding part from the cue should have received a within object advantage.

Experiment I also showed the general influence of boundaries on attention. Probes were less frequently reported when a boundary separated the probe from the cue than when not. In accordance with the within-object advantage, attention seems to primarily cover an enclosed area before it spreads to areas that require the crossing of a boundary. However, the results of Experiment II are still inconclusive and the results from it still require clarification. Thus a follow-up experiment which could clear up the results will be proposed in the following section.

4.2 Future Research

4.2.1 Design

One explanation for why the probe from a cued location may not have received any advantage over other probes in Experiment II could be that participants used their attentional resources in order to perform the additional task of object recognition. If this was the case, an experiment involving no additional task (as Experiment I) should leave the participant all of his or her attentional resources to perform the probe task. Thus, a follow-up experiment (Experiment III) should not include this additional task.

It's possible that the probe was too large and thus the discrimination task was too easy for the participants. In Experiment III the probe size at all locations will be decreased in contrast to Experiment II. Sizes between 0.1 (for the center) and 0.5 square degrees (for locations 2 and 3) are reasonable.

Again, only the "eight" and the "cross" object will be used to keep the amount of structure in the upper and the lower visual field the same and to avoid any biases toward the one or the other field.

The procedure of Experiment III will be the same as in Experiment II, but with the exception of the object reporting task. After the fixation cross a cue will appear, then the arrow probe will appear and the participant has to respond as quickly as possible with a button press depending on the direction in which the arrow is pointed.

The timing will be same as in Experiment II.

4.2.2 Expectations

The arrow probe shouldn't encourage participants to *read* the probes as they did in Experiment I. Given that only the "eight" and the "cross" object will appear, neither the upper nor the lower visual field should receive any advantage over the other. The scaling of the size of the probes according to their eccentricity (as it was already done in Experiment II) should compensate for the better perception at the focus of the gaze in contrast to parafoveal locations. Thus response times to the center location should not be faster than to other locations.

In contrast to Experiment II, the participants should have a larger amount of unbound attentional resources (similar to Experiment I). Thus these resources should be exerted in order to perform the attention task. In order to find out about the influence of the different boundaries, the following contrasts will be made:

1. **Occlusion:** An occluding segment between cue and probe should slow down RT to the probe. The RT to location 6 when 7 is cued (and vice versa) should be slower than the RT to location 4 when 5 is cued (and vice versa).

2. **Inner boundaries:** A boundary between the cue and the probe should hamper attention. When the cue is in the center location, the RT to the probe at location 6 should be slower than to location 4. Likewise it should be slower to the probe at location 7 than at location 5.

3. **Outer boundaries:** A boundary between the cue and the probe should hamper attention. When the cue is at position 4 in the "cross", the RT to the probe at location 2 should be slower than when the cue is at position 4 in the "eight". And vice versa, when the cue is at position 2 in the "cross" the RT to location

4 should be slower than when the cue is at position 2 in the "eight". Similar results should be observed for locations 6 and 2 as well as locations 5 and 3 and 7 and 3.

4. **Inner vs. Outer boundaries:** Do different kinds of boundaries affect attention differently (does the boundary that separates the two segments of the cross have a different effect than the boundary that separates one segment from the background)? When the cue is at position 6 in the "cross", the RT to probes at location 1 and 2 will be compared. If the boundaries have an equal effect, no difference should be observed. If one of the boundaries receives any kind of priority, a difference should be observed. It is suspected that the background boundary is more important, because it discriminates the object from its environment. Thus the RT to the probe at location 2 should be slower than to location 1. Similar results are expected for the case when the cue is at position 4 in the "cross" as well as at position 5 in the "cross" (then RT to the probes at location 1 and 3 will be compared) and at position 7. The probes will be scaled according to their eccentricity. However, eccentricity might still have some effect on the response times. Thus the results of these comparisons must be interpreted carefully.

5. **Space vs. structure:** The stimuli allow a direct comparison of the effect of the spatial proximity of a probe and a cue and their "structural" proximity. When the cue is presented at location 4 in the "eight", the RT to the probes at locations 5 and 6 will be compared. Location 6 is spatially closer to the cue, but location 5 is "structurally" closer to the cue (i.e. the boundaries bordering the direct connection between location 4 and 5 put these two locations on the same segment). Thus if the RT to the probe at location 6 is faster than to the one at location 5, it can be concluded that spatial proximity dominates structural

proximity. If the probe at location 5 is faster reported than the probe at location 6, it can be concluded that structural proximity dominates spatial proximity. If the RTs are equal there is some evidence that attention moves along the object rather than directly moving from the cue to the probe: this is because the "distance on the object" between locations 4 and 5 is equal to the "distance on the object" between locations 4 and 6 along the object (refer to Figure 4.1). Similar comparisons will be made between location 4 and 7 when 5 is cued.

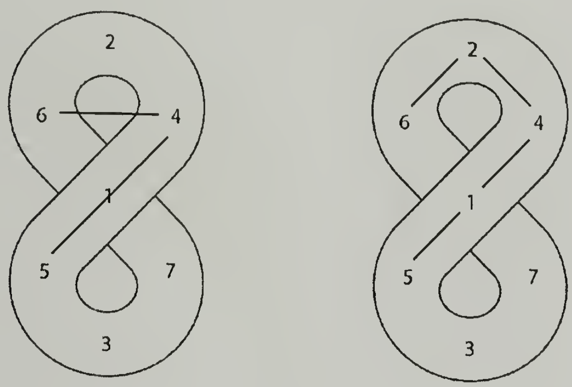

Figure 4.1. Left: location 6 is spatially closer to location 4 than location 5 (but 4 and 5 are located on the same segment, thus one can say they are "structurally" closer to each other). **Right:** Since the spatial distance between all probes is equal, locations 5 and 6 are equidistant from location 4 in terms of "distance on the object".

The results of this experiment should reveal the effects of different kinds of boundaries on attention, as well as confirm the finding from Experiment I that an occluding segment can hamper the movement of attention from one part of the occluded object to another part. This would mean that the within-object advantage can be influenced by an occluding segment.

BIBLIOGRAPHY

Avrahami, J. (1999). Objects of attention, objects of perception. *Perception & Psychophysics*, 61(8):1604–1612.

Bundesen, C., Habekost, T., and Kyllingsbæk, S. (2005). A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychological Review*, 112(2):291–328.

Castiello, U. and Umiltà, C. (1990). Size of the attentional focus and efficiency of processing. *Acta Psychologica*, 73:195–209.

Cepeda, N., Cave, K., Bichot, N., and Kim, M.-S. (1998). Spatial selection via feature-driven inhibition of distractor locations. *Perception & Psychophysics*, 60(5):727–746.

Davis, G. and Driver, J. (1997). Spreading of visual attention to modally versus amodally completed regions. *Psychological Science*, 8(4):275–281.

Downing, C. and Pinker, S. (1985). The spatial structure of visual attention. In M. Posner and O. Marin, editors, *Mechanisms of attention: Attention and performance*, volume 11, pages 171–187. Erlbaum, Hillside, NJ.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, 113(4):501–517.

Egly, R., Driver, J., and Rafal, D. (1994). Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, 123(2):161–177.

Eriksen, C. and Hoffman, J. (1972a). Some characteristics of selective attention in visual perception determined by vocal reaction time. *Perception & Psychophysics*, 11(2):169–171.

Eriksen, C. and Hoffman, J. (1972b). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics*, 12(2-B):201–204.

Eriksen, C. and Hoffman, J. (1974). Selective attention: Noise suppression or signal enhancement? *Bulletin of the Psychonomic Society*, 4(6):587–589.

Goldsmith, M. and Yeari, M. (2003). Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *Journal of Experimental Psychology: Human Perception & Performance*, 29(5):897–918.

Haimson, C. and Behrmann, M. (2001). Cued visual attention does not distinguish between occluded and occluding objects. *Psychonomic Bulletin & Review*, 8(3):496–503.

He, Z. and Nakayama, K. (1995). Visual attention to surfaces in three-dimensional space. *Proceedings of the National Academy of Sciences*, 92:11155–11159.

Hoffman, J. and Nelson, B. (1981). Spatial selectivity in visual search. *Perception & Psychophysics*, 30(3):283–290.

Houtkamp, R., Spekreijse, H., and Roelfsema, P. (2003). A gradual spread of attention during mental curve tracing. *Perception & Psychophysics*, 65(7):1136–1144.

Huang, L. and Pashler, H. (2005). Attention capacity and task difficulty in visual search. *Cognition*, 94:B101–B111.

Itti, L. and Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts if visual attention. *Vision Research*, 40:1489–1506.

Jolicoeur, P., Ullman, S., and Mackay, M. (1986). Curve tracing: A possible basic operation in the perception of spatial relations. *Memory & Cognition*, 14(2):129–140.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long and A. Baddeley, editors, *Attention and performance IX*, pages 187–203. Erlbaum, Hillsdale, NJ.

Kim, M.-S. and Cave, K. (1995). Spatial attention in visual search for features and feature conjunction. *Psychological Science*, 6(6):376–380.

Klein, R., Kingstone, A., and Pontefract, A. (1992). Orienting of visual attention. In Rayner, K., editor, *Eye-movemnts and visual cognition: Scene perception and reading*, pages 46–65. Springer-Verlag, New York, NY.

Koch, C. and Ullman, S. (1985). Shifts in selective visual attention: towards the underlying neural circuitry. *Human Neurobiology*, 4:219–227.

LaBerge, D. (1995). *Attentional Processing*. Harvard University Press, Cambridge, Massachusetts.

Lavie, N., Hirst, A., de Fockert, J., and Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, 133(3):339–354.

Macquistan, A. (1997). Object-based allocation of visual attention in response to exogenous, but not endogenous, spatial precues. *Psychonomic Bulletin & Review*, 4(4):512–515.

Mogg, K., Philippot, P., and Bradley, B. (2004). Selective attention to angry faces in clinical social phobia. *Journal of Abnormal Psychology*, 113(1):160–165.

Moore, C., Yantis, S., and Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science*, 9(2):104–110.

Mounts, J. (2000). Evidence for suppressive mechanisms in attentional selection: Feature singletons produce inhibitory surrounds. *Perception & Psychophysics*, 62(5):969–983.

Pollatsek, A. and Digman, L. (1977). Dependent spatial channels in visual processing. *Cognitive Psychology*, 9:326–352.

Posner, M. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32:3–25.

Posner, M. and Snyder, C. (1975). Attention and cognitive control. In Solso, R., editor, *Information processing and cognition: The Loyola symposium*, pages 55–85. Erlbaum, Hillsdale, NJ.

Posner, M., Snyder, C., and Davidson, J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, 109(2):160–174.

Treisman, A. and Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12:97–136.

Tsal, Y. and Lavie, N. (1993). Location dominance in attending to color and shape. *Journal of Experimental Psychology: Human Perception and Performance*, 19(1):131–139.

Yantis, S. and Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception & Performance*, 10(5):601–621.