Effects of Distance and Grouping on Visual Attention for Static and Dynamic Displays

A Thesis
Presented to

The Faculty of the Department of Electrical and Computer Engineering
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In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Electrical Engineering

by

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to

Bahar *&* ***Sait Gönen***

For your help, and love;

You are the people who made me what I am today

Hayatta en hakiki mürşit ilimdir.

“The true guide in life is science.”

Gazi Mareşal Mustafa Kemal Atatürk

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An Abstract of a Thesis
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Abstract

Naturally, our visual system receives a staggering amount of information from the environment. Mechanisms are needed to filter irrelevant information and select the most significant for our task. Since the static stimuli have been intensely researched, we are focusing mainly on dynamic stimuli. The goal of this research was to investigate the deployment of exogenous attention to the dynamic stimuli forming perceptual groups. We conducted three experiments both in dynamic and in static conditions with novel features. Particularly, we examined how attention spreads within or outside of a moving object and how perceptual grouping by color and motion affects the allocation of attention. The results demonstrate clearly the effects of distance, color and motion on the allocation of visual attention. Exogenous attention follows the reference frame moving with the stimulus. Also the exogenous attention is allocated not just to the cued element but also to all elements forming the group.

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Chapter 1

Introduction

1.1 Statement of the Problem

Every single moment we see hundreds of items, their sizes, their shapes, their distances to each other, and to us, thousands of objects whether standing still or in motion. We continuously allocate our attention, focus to what is relevant and respond accordingly. The selection mechanism for the visual attention seems effortless. We do not notice the activity of these ongoing mechanisms. Still, obtaining the essential, and filtering the remaining is not a simple process. Several mechanisms of this process are still largely unknown.

The input to our eyes is not always static. Our visual attention is often allocated to moving objects. Almost all the studies of how attention is allocated have used static stimuli and neglected the true nature of ecological vision. Even though several mechanisms may be shared in processing static and dynamic stimuli, it is a generally accepted fact that there are also different systems involved with dynamic vision. The main purpose of this study is to understand how attention is allocated to moving targets.

1.2 Goals of the Thesis

Here we extended the study reviewed in Chapter 2.6 with the following specific goals:

- We investigated how cue-target proximity influences the allocation of attention by changing the distance between the cue and the target in a moving object.

In the next two goals, we generalized “object effects” to perceptual groups and investigated whether attention is allocated to all elements of a perceptual group or if the allocation is specific to the cued element.

- Perceptual grouping by color was examined by using moving objects with the same versus different colors.
- Perceptual grouping by motion was examined using objects moving with the same versus different directions.

1.3 Significance

Out of all the senses humans possess, vision is the most important and the dominant one due to its high feedback to the brain from the external world. Everyday we see hundreds of people, recognizing faces, identifying several traffic signs, appreciate many forms of beauty. Without effort, several tasks are accomplished. This result is not due to the simplicity of the assignments, but due to the state-of-art complex structure of the vision system.

If one has interest towards visual science, the most central questions would lead to the study of the visual attention and to the investigation of perceptual groups. There are many objects in our environment but we selectively attend to a subset of those objects. As an example, we can say that when crossing a street, instead of the pedestrians walking on the sidewalk, we attend only to traffic. In a lecture, our attention compels us to listen to the professor.

Since the natural environment contains moving objects, it is important to understand how attention is allocated to moving stimuli. Moreover, our visual system groups stimuli following common features such as color and motion. Due to this natural tendency for grouping, it is also important to understand whether attentional processes apply to groups as effectively as to individual elements constituting the groups.

The problem of perceptual organization is essential for a broad understanding of vision science. During early 20th century, pioneers of Gestalt psychology started to ask first organizational questions. After the decrease of the Gestalt-boom, perception and the perceptual organization received less attention probably due to other developments in vision science (e.g., single cell recordings by Hubel & Wiesel, 1959 or the linear system approach by Campbell & Robson, 1968).

According to Palmer (2003), the key to understand the problem of mid-level vision is the perceptual organization, and the necessary information to understand vision after the linear and single cell structure of V1. Palmer believes that Gestalt approach is the bridge between the low-level and mid-level vision.

The mechanisms under the visual system are important also for the reverse engineering of the brain. Still a simple, trivial task for the human eye can be almost impossible for a machine to replicate it.

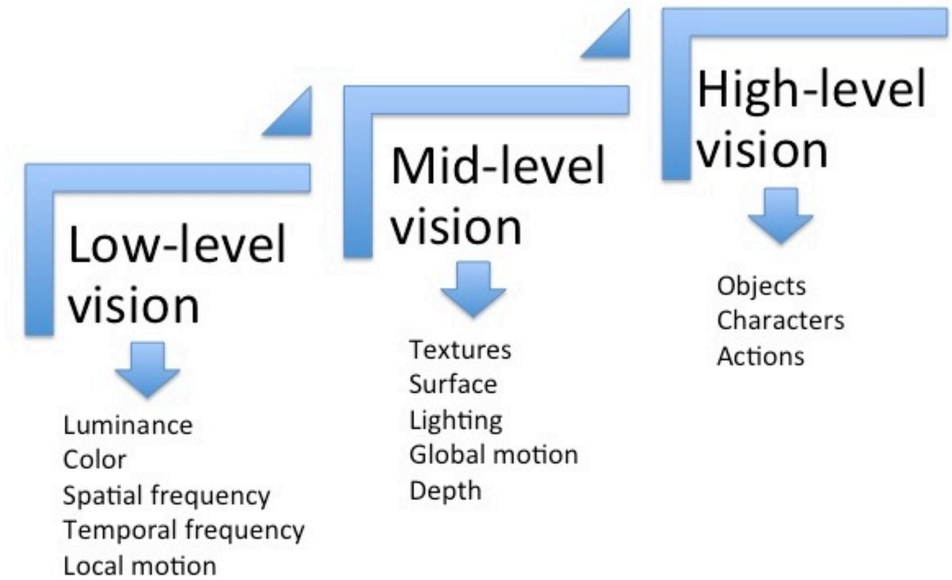

Fig 1.1: Levels of vision can be divided into three subfields: low-level vision (concerned with the derivation of image characteristics from the retinal image), mid-level vision (concerned with the integration of the characteristics into the perceptual organization), and high-level vision (concerned with the functional side of the perceptual organization).

1.4 Organization of the Thesis

This thesis is organized in 6 chapters. The remaining part of the thesis is categorized as follows:

- Chapter 2 presents the required background about the Gestalt theory, perception, perceptual organization, principles of grouping, attention, its' mechanisms and components, the pioneering study of Egly et al. and a previous related study conducted in our lab.
- Chapter 3 describes the first experiment's methods, results, statistical analysis and discussions, which explores the effect of cue-target distance in the validly cued object.
- Chapter 4 presents the second experiment's methods, results, statistical analysis and discussions, which explores the effect of color grouping.

- Chapter 5 reports the third experiment's methods, results, statistical analysis and discussions, which explores the effect of motion.
- Chapter 6 provides the general summary, conclusion, and suggestions for future research.

Chapter 2

Background

2.1 Gestalt Theory

The concept of Gestalt is first introduced by Christian von Ehrenfels. The Gestalt theory has conceptual roots in theories by David Hume, Immanuel Kant, Johan Wolfgang von Goethe, David Hartley, and Ernst Mach. Max Wertheimer firstly proposed the Gestalt psychology. Both the theories of the mind and the brain, Gestalt approach is that the brain is a whole and analog, having parallel working tendencies, in other words the brain is holistic. It can be even said that the mechanisms are not linear. The famous phrase by Kurt Koffka often used to describe the Gestalt theory: *"The whole is greater than the sum of its parts."* In German, Gestalt means "shape" or "form." The contrast between the approaches of the behaviorists and Gestaltists is that the behaviorists try to understand the elements of the processes but the Gestalt scientists are much more interested with the general organization of the whole system.

Koffka, Wertheimer, and Köhler looked to the objects by considering their background, within their own environment for their proper perception, for a better global construct. The holistic approach introduced by these Gestalt scientists defined the principles of perception. Although the Gestalt theory is a generally accepted source, several critics for Gestalt theory still exist for being only descriptive. Prägnanz, which is the indispensable principle of the Gestalt laws of grouping, is the concept of categorizing our experience in a regular, simple, symmetrical manner.

2.2 What is Perception?

Perception is the collected, categorized and analyzed information obtained from all the senses. The sensory inputs are the essential materials in order to perceive the environment. Beside the sound, touch, taste, body balance, acceleration, gravity etc., the visual perception, which is only the sub-category of the whole perception of the brain, is the process of creating the inner statement of the visible stimuli.

The general approach is to categorize the visual perceptual operations into two main subsets: bottom-up (data-driven) and top-down processes. In the bottom-up processing, from the retina to the visual cortex, each step in the visual pathway is responsible for a more complex analysis than the previous step. In the top-down processing, the whole visible stimuli are more useful for the understanding of the small parts via the prior knowledge and the past experience. As an example, we can think of a difficult handwriting with ambiguous words: Complete sentences usually help the reader by giving crucial contextual aid.

2.3 Perceptual Organization and Gestalt Laws of Grouping

To recognize the world, to give a meaning, Gestalt organization is used to describe and explain several illusions including the waterfall illusion or the rabbit-duck illusion. Another example is the Kanizsa triangle, which is just a floating triangle having no existence in reality. The human brain has the tendency to complete the images to a "whole."

The principles of grouping or "Gestalt laws of grouping" are organized into 7 main categories: proximity, similarity, closure, symmetry, good continuation (continuity), common fate, and good form (good Gestalt). Additional categories are also introduced over time.

- **Proximity:** This principle states that, if all the rest features are equal, the perception tries to group the stimuli being closer than the rest.
- **Similarity:** According to the principle, if the seen stimuli resemble each other; the perception tends to group that part as same objects (groups), and if the case is the opposite, than the different ones as different objects.
- **Closure:** In this principle, the mind tries to complete the objects that it processes, even though it's incomplete, obscured, partially hidden. With this ability to complete things by filling in, we have less missing information. The closure principle has also survival role in hunting and escaping in the nature.
- **Symmetry:** This organization principle states that the mind always tries to categorize the visible stimuli into symmetrical even groups.
- **Continuity:** This principle, also called "good continuation" creates a differentiation when there is a visual overlap on the allocated object or space. Lines or curves that follow abrupt changes are organized and grouped in a way that would make meanings.
- **Common Fate:** As understood from its name, the common fate principle suggests that when visual stimuli move in the same direction, they are considered as a single group. A flock of birds is the perfect example for the common fate condition. Hundreds of birds are perceived as a unified whole.

- **Good Form:** This phenomena makes the world we perceive in a way more simplistic, eliminated from its complexity and regularly patterned. This law is also called “the law of Prägnanz”.

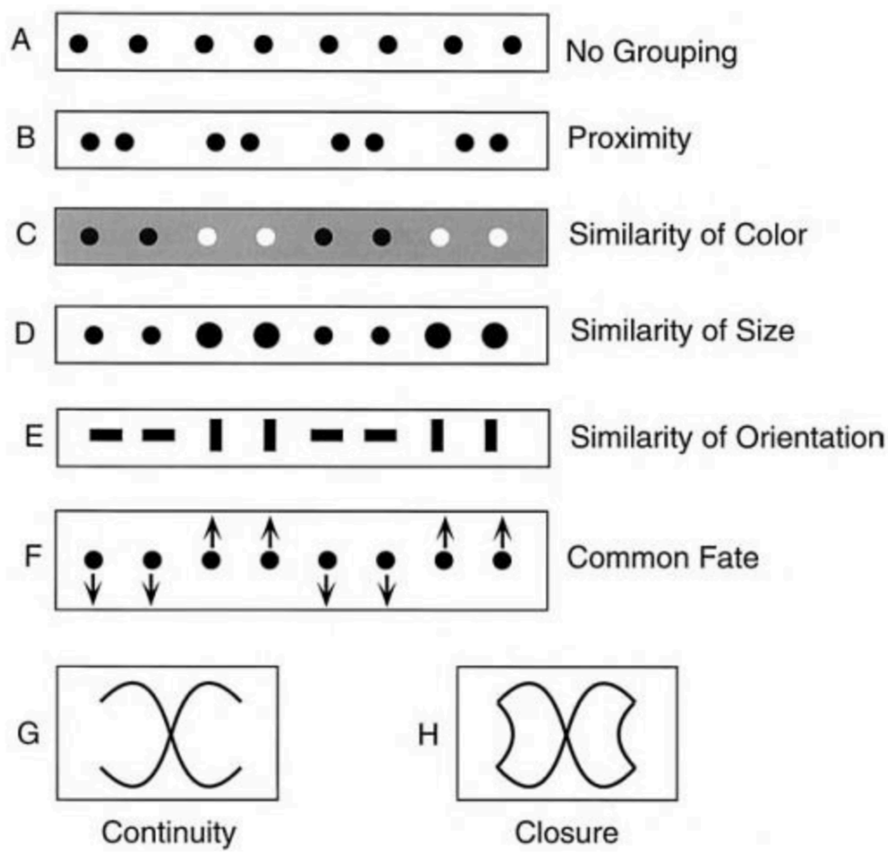

Fig. 2.1: Wertheimer’s classical principles of grouping.

In the Fig 2.1, Wertheimer’s classical principal of grouping can be seen. The photo is taken from Vision Science: Photons to Phenomenology, by S.E. Palmer, 1999, p. 258, Cambridge, MA: MIT Press. Several factors are identified by the Gestalt psychologists to be perceived several inputs as groups.

2.4 What is Attention?

Before going to any more details, the main concept of attention should be discussed. Although it is very obvious and intuitive, it is also vague. As some examples we can give:

Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. (James, 1890, pp. 403-404)

People talk about attention with great familiarity and confidence. They speak of it as something whose existence is a brute fact of their daily experience and therefore something about which they know a great deal, with no debt to attention researchers. (Pashler, 1998, p. 1)

Pashler (1998) described the key aspects of attention as selectivity (ability to process some stimuli instead of others), capacity limitation (a limit for simultaneous (parallel) processing), and effort (sense of exertion).

2.5 Mechanisms of Visual Attention

In this section, the aforementioned three mechanisms of visual attention will be briefly discussed: selectivity, capacity limitation and sense of exertion. The starting point to study selectivity is visual search and Treisman et al.'s "feature integration theory" (Treisman & Gelade, 1980). The paradigm is that the subject is presented with a target stimulus and distractor stimuli. The display size (the number of stimuli) varies from trial to trial. The subject's task is to decide whether the target is present or not as rapidly and accurately possible. The decision duration is graphed as a function of display size.

The search rate (slope of the graph) measured in terms of time per display item is one of the important characteristics of the function. Treisman and her colleague Gelade proposed the parallel and serial modes of visual search. According to the feature integration theory, if the function increases only a little bit (rate < 10 ms/item) by increasing the number of stimuli, it is assumed that all the items are searched simultaneously…"parallel". On the contrary, if the function gives a linear increase (rate > 10 ms/item), it is assumed that all the items are searched "serially" (Muller & Krummenacher, 2006).

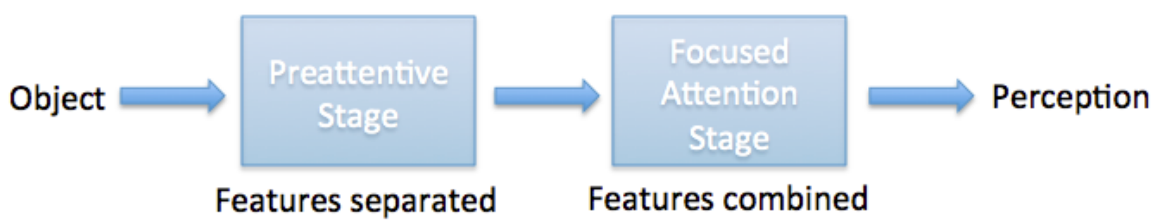

Fig 2.2: Flow Diagram of Feature Integration Theory

To conclude selective attention, we can say that it allows us to focus on what is relevant and filter the rest. Integration of elementary visual features is one main role of the visual attention but the process of these elementary visual features is also modulated within the visual system (Chaudhuri, 1990; Prinzmetal, Presti, & Posner, 1986).

Another key mechanism of visual attention is the capacity limitation, which is the limit of the parallel processing discussed above. This capacity concept is highly related with visual short-term memory (VSTM), and even though VSTM is mainly responsible for the process of perceptual and cognitive functions, having supports by very broad brain regions, its' storage capacity is very limited. The experiments to measure the VSTM capacity limitations generally use a paradigm in which the subjects see sample display containing a variable of colored discs. After some retention period, subjects see a probe; the task is generally to decide whether the probed disk matches to one of the sample disks in location or in color (Todd & Marois, 2004).

The third mechanism that needs to be discussed is the sense of exertion (effort) due to visual attention. It is widely known that when an object or an area is attended, the efficiency of the process increases. Attention is known to be directed either voluntary (endogenous control) or automatically, (exogenous control). In the endogenous control, attention is allocated (Yantis, 2000). The brain activity produced by these two types of attentional shift is believed to be completely different from each other (Gazzaniga, Ivry, Mangun, 2002). Although different mechanisms produce different brain activities, from the neurological point of view, the neural maps for the exogenous and endogenous attention, the common ground is that there is an overlap (Rosen et al., 1999).

2.6 Attentional Selection Theories

Many studies indicate that the operation of visual attention is maintained on two main bases: space-based and object-based information (Abrams & Law, 2000; Duncan, 1984; Egly, Driver, & Rafal. 1994; Egly, Driver, Rafal, & Starrveveld, 1994; Iani, Nicoletti, Rubichi, & Umilta, 2001; Lamy & Egeth, 2002). The evidence for space-based attention is obtained via visual cuing studies (Shulman, Remington, & McLean, 1979; Tsal, 1983; B.A. Eriksen & Eriksen, 1974; Hillyard, Vogel, & Luck, 1998; LaBerge, 1995; Mangun, 1995; I.P. Posner & Petersen, 1990; M.I. Posner & Dehaene, 1994). The evidence for object-based attention is also strong (Baylis & Driver, 1993; Duncan, 1984; Egly, Driver, et al., 1994; Egly, Driver, Rafal, et al., 1994; Hübner & Backer, 1999; Iani et al., 2001; Lamy and Egeth, 2002; Lamy and Tsal, 2000; Moore et al., 1998; Tipper & Weaver, 1998; Vecera, 1994).

2.6.1 Object-based Attention and its Mechanisms

One of the processes of selectivity is object-based attention. Based on the objects' relevance, independent of their spatial locations, objects (or perceptual groups) are selected for further processing. Several factors affect object-based attention: e.g.: perceptual load, stimulus onset asynchrony, and recent experience.

According to Cosman and de Wit, performance increases with a low perceptual load (Cosman and Vecera, 2012; de Wit, Kentridge, et al., 2009). The examination of the object-based attention with even very low perceptual load results in irrelevant features of objects being ignored. During flanker experiments, many objects features are wrongly combined due to belonging to the same perceptual grouping (Richard, Lee et al. 2008).

It is found that the object-based attention performs better with short stimulus onset asynchronies. Even though there is no exact number for short and long stimulus onset asynchronies, Chen & Cave (2008) concluded that with longer stimulus onset asynchronies, attention could be overridden. Duncan (1984) found a contradictory result, his experiments revealed object-based effects with even 50 ms stimulus onset asynchronies.

If subjects showed no object-based component with an object, it is generally considered that this very same object would not show the object-based component of the visual attention at all. This feature is called the recent experience (Daelli et al. 2010).

There are 3 main mechanisms proposed for object-based attention: sensory enhancement, attentional prioritization, and attentional shift:

- Assumption of the **sensory enhancement** theory (Drummond and Shomstein, 2010; Chen and Cave, 2006; Awh et al., 2001) is that, attention spreads all of its resources to the cued object's area. The spread of attention even includes the occluded and overlapped parts. By this mechanism, the processing of the objects' features is facilitated. The representation of the spatial resolution and the contrast sensitivity of the cued object become clearer in memory. Evidence of sensory enhancement comes from single cell recordings and fMRI studies.
- **Attentional prioritization**, as its name explains, prioritizes the order of objects or locations for the visual attention to allocate (Shomstein and Yantis, 2008; Shomstein and Behrmann, 2008, Richard et al., 2008). As in the case of a cued object, the allocation process will start with the cued object, which will result a better recall of that object's qualities.
- **Attentional shift** which occurs to use more source for a desired object and (and or) to decrease unwanted efforts in irrelevant inputs. Theories are competing each other about how attentional shift works (Lamy and Egeth, 2002; Posner and Peterson, 1990; Brown and Denney, 2007). Endogenous and exogenous attentional shifts use different attentional resources in order to function efficiently.

2.6.2 Use of Dynamic Stimuli

The main challenge in object-based attention studies is the differentiation of cuing effects of the objects vs. the effects coming from their locations if the stimuli are dynamic instead of static. The problem was solved by cuing both the object, and its location and then within different trials, detecting the target at the original location, and at the new location. The comparison of these two trials allows separating the objects effects from the spatial effects. The idea is that if the system works only with respect to the target's spatial locations; then the benefits or the costs due to the movement will not be observable. If it were the opposite, than the benefits and the costs would be still observable. The spatial cuing effects would be examined without their spatial cuing effects (Abrams & Dobkin, 1994; Behrmann & Tipper, 1999; Christ et al., 2002; Gibson & Egeth, 1994; Kahneman et al., 1992; Lamy & Tsal, 2000; McCrae & Abrams, 2001; Müller & von Mühlenen, 1996; Ro & Rafal, 1999; Soto & Blanco, 2004; Tipper & Behrmann, 1996; Tipper et al., 1991; Tipper, Jordan, & Weaver, 1999; Tipper et al., 1994; Umiltà et al., 1995; Vivas, Humphreys, & Fuentes, 2008; Weaver, Lupiáñez, & Watson, 1998). This method was mainly used for Inhibition of Return studies but several studies were made to examine the facilitatory effects as well (Lamy & Tsal, 2000; Soto & Blanco, 2004, Ro & Rafal, 1999).

Lamy & Tsal (2000), Soto & Blanco (2004) showed that effects of attention exist in moving stimuli as well. In their stimuli, comparing the distance to understand the spatial effects of cuing; the distance between the cue and the cued object was shorter than the distance between the cue and the uncued object. These findings create the possible additional influence of the spatial effects to the objects effects observed in these studies. In Ro & Rafal's (1999) work, spatial effects were compared to equidistant within-object and between-objects effects, and the facilitatory effects of exogenous cues were reported.

2.6.3 Space-based Attention

The second mode of selection in visual attention is the space-based (location-based) attention, which selects by location instead of objects. Because of the movement of the visual attention in the visual field and then the selection way of the stimuli, several researchers used the "spotlight" metaphor (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Posner, 1980; Posner, Snyder, & Davidson, 1980), the "zoom lenses" metaphor (Eriksen & St James, 1986; Eriksen & Yeh, 1985) for the space-based attention. The evidence obtained from visual cuing experiments shows that attention needs more time for allocation as the distance between the cue and the target increases (Shulman et al., 1979; Tsal, 1983; Brown et al. 2006).

2.6.4 Literature Review. Egly et al. (1994)

In this section, Egly, Driver, and Rafal's (1994) study is discussed. The main novelty about Egly et al.'s research is that with only few exceptions, (Kramer & Jacobson, 1991 etc.) almost all the previous studies were made with different paradigms to measure object-based and space-based components of visual attention. One single paradigm was used effectively in Egly et al.'s stimuli to examine both object-based and space-based components. The purpose of their experiment was to understand how cuing one end of an object changes the processing of the remaining of that object.

As the stimuli, two outline rectangles above and below the fixation point were used in the experiment. The task of the subject was to detect a target presented at of any four ends of the two rectangles by pressing a button in the joystick as soon as possible. After the initial display of the rectangles for 200 ms, the cue is presented for 100 ms; the cue is followed by the cue-onset-asynchrony period of 200 ms. The COA ends with the target presentation. The three options are: valid – if the target and the cue are presented at the same end of a rectangle-, invalid within – if the target and the cue are presented inside the same rectangle but at different ends-, invalid between – if the target is displayed inside the different object.

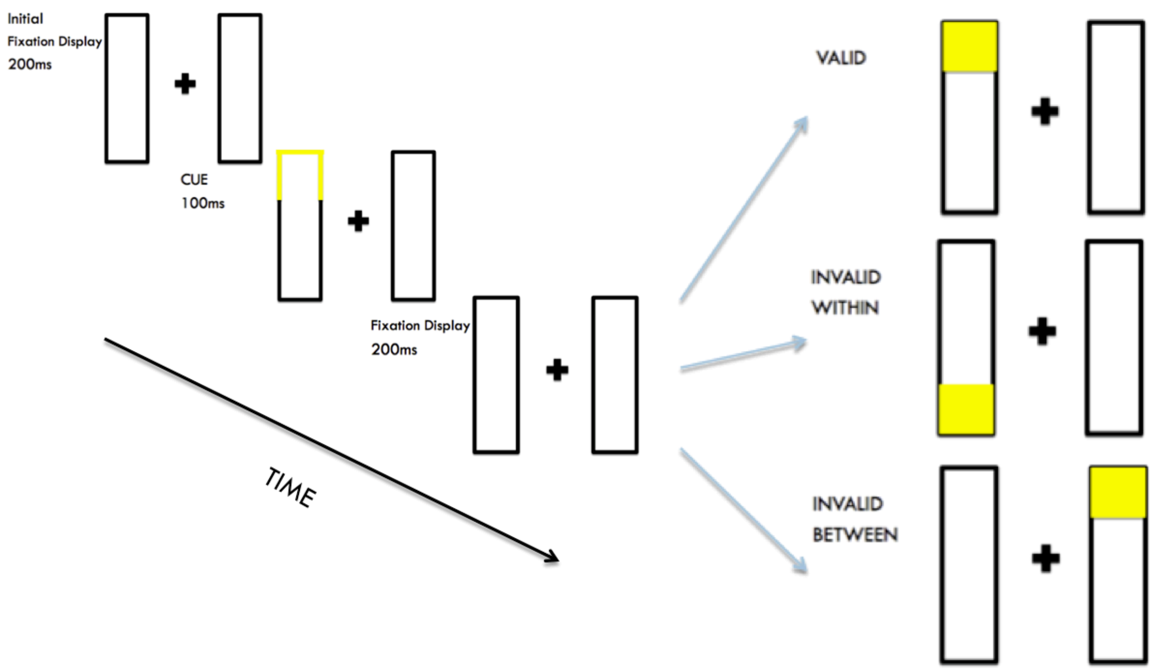

Fig 2.3: Egly et al. stimuli. Typical sequence of events within trials.

Each trial started with an initial fixation cross and the two rectangles for 200 ms. The possible locations for the two rectangles were either to the left or to the right of the fixation or above and below the fixation. The superimposition of the cue lasted for 100 ms. After the cue disappeared and the colored end of the rectangle returned to its original color, another fixation display with only fixation cross was followed for 200 ms. The last step of each trial was the target presentation until the subject response on the joystick or for 2000 ms if no response was recorded.

The target was at the cued end on 75 % of the trials, on the remaining 25 %, the target was at an uncued end. The “invalid between” and “the invalid within” conditions (see Fig 2.3) were equally likely on the 25 % of the trials. There were also catch trials, in which no target was shown in order to prevent any anticipatory responses.

The fastest response was for the “valid” condition (324 ms). This is due to conventional valid cuing with short stimulus onset asynchrony (less than 250 ms) providing a facilitatory effect (Klein, 2000). The reaction time to detect the “invalid between” condition (371 ms) was significantly larger than the “invalid within” condition (358 ms) even though the physical distance from the cue to these two target options were the same. This result gives rise to the following claim:

Even though the results showed both object-based component and the space-based component of the visual attention within the same task, the object-based part of visual attention was much stronger compared to the space-based part because the physical distance between the cue and the within-the-same-object target was equal to the distance between the cue and the inside-the-other-object target. The fact that the “valid” condition (324 ms) required significantly less time than the “invalid between” condition is the evidence for the space-based attention. The shift of attention inside an attended object created a cost due to a location change. Later studies agree that space-based attention and object-based attention can’t be studied as mutually exclusive (Egly, Driver, & Rafal, 1994).

2.6.5 Cue - Target Asynchrony and Inhibition of Return

In order to study the dynamic mechanisms of visual attention, the concept of inhibition of return must be clearly understood. Discovered by Posner and Cohen (1984), this concept causes visual attention to shift from its original location or its original object to explore new, previously unattended locations or objects after 200-300 ms of attending any object. Inhibition of return guides the visual mechanism to attend a new place or object even though the eyes are fixated to an initial point. It is because of the notion of inhibition of return that the dynamic case of visual attention experiment results is completely different compared to the static display experiments. As stated in the definition above, inhibition of return has both object and location based components. Cue-response paradigms are used to detect and measure this phenomenon.

The study by Klein (2000) shows that the inhibitory effect of attention is seen for cue-target asynchrony larger than 300 msec. As seen above, for smaller cue-target asynchronies, a facilitatory effect takes place, which leads to faster responses to targets at the cued locations. Our experiments have short cue-target delays and promote the facilitatory effect for cued items. Fig 2.4 shows both the inhibitory and facilitatory effects for cued and uncued stimuli due to short and long cue-target-onset-asynchronies. The graph is redrawn from Klein R. (2000)'s work.

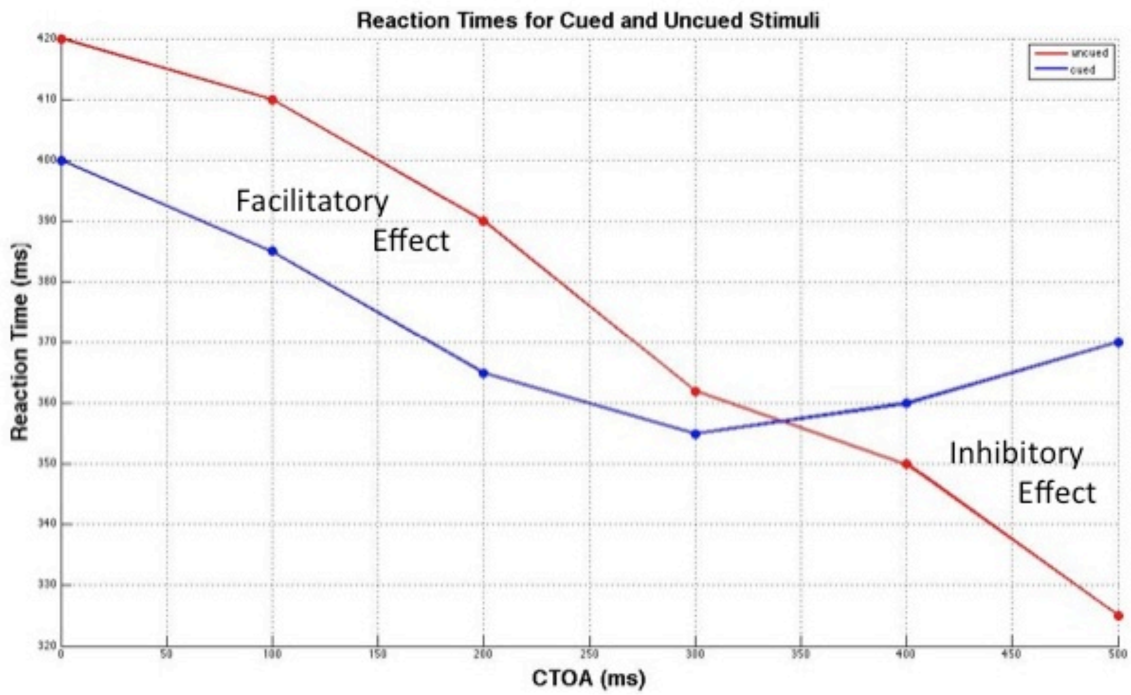

Fig 2.4 Inhibitory and facilitatory effect for cued and uncued stimuli due to short and long CTOAs.

2.7 Attentional Processes: Endogenous Attention vs. Exogenous Attention

Generally, attentional orienting is divided into two main categories: endogenous attention and exogenous attention (Posner, 1980; Jonides, 1981; Weichselgartner & Sperling, 1987; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Cheal & Lyon, 1991; Egeth & Yantis, 1997). Endogenous (top-down) attention is the controlled, allocated by voluntary control to a stimulus (e.g. an object) or location. Exogenous (bottom-up) is the involuntary, reflexive component of the visual attention. It is relatively faster compared to endogenous attention.

The general paradigm to examine endogenous and exogenous attention is Posner's cueing paradigm (Posner, 1980; Posner & Cohen, 1984), in which a peripheral target is preceded by a peripheral or a central cue. The endogenous attention is allocated by the central cue (e.g. an arrow) marking the possible location of the target. Generally the cued locations require less time to detect compared with the uncued locations, leading a conclusion that the endogenous attention was shifted to the cued location.

In the exogenous processing, instead of a central cue, an abrupt onset cue is presented at one of the target locations. The cue is not predictive for the location of the target. The cue, being abrupt onset creates an automatic attraction for the attention. As in the endogenous attention, the cued locations require less time to detect compared with the uncued locations.

2.8 Previous Study. Allocation of Attention for Dynamic Stimuli

The aim of this study (Hallal & Öğmen, 2011) was to understand how attention is allocated to moving objects. Egly et al. (1994) stimuli were modified in order to introduce motion. To keep eccentricity constant, stimuli rotated around a virtual circle of fixed radius. A new target, "Invalid Space", was added in the dynamic condition in order to analyze the effects of shifting attention to a spatial location that coincided with the location of the cue. Half of the dynamic trials were clockwise and the other half was counterclockwise rotation. The rotation speed was 40°/s in polar coordinates. In other words, one single turn of the arcs would require 9 seconds. The "Valid" target was adjacent to the cue location.

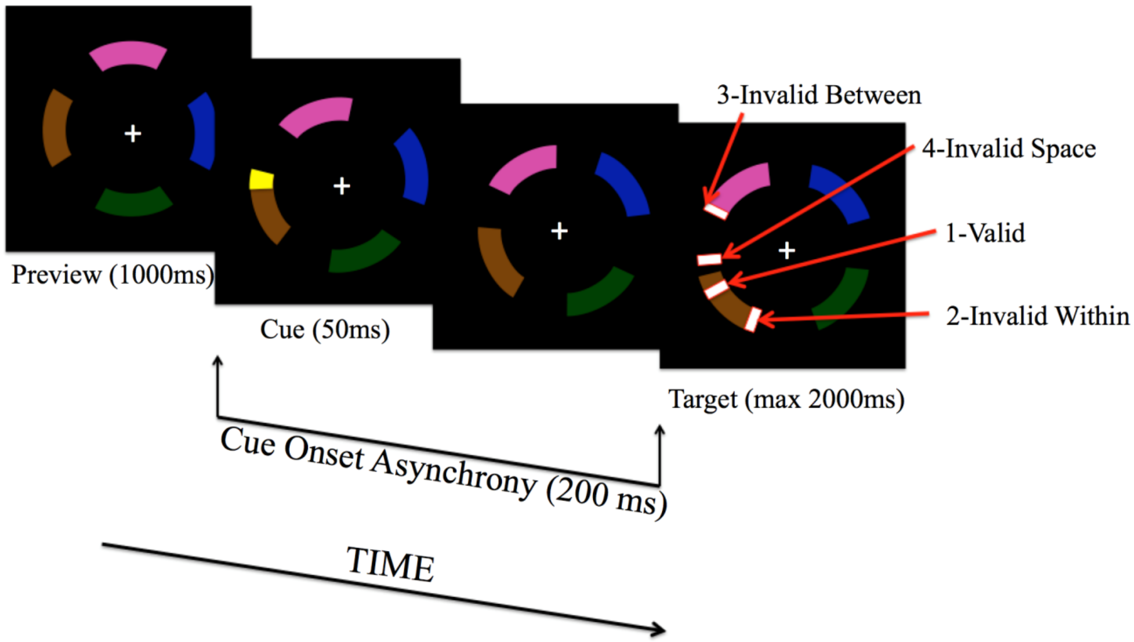

Fig. 2.5: Representation of allocation of attention for dynamic stimuli. Typical sequence of events within trials. After the preview of the rectangles for 1000 ms, the cue is presented for 50 ms; the cue-onset-asynchrony period is 200 ms. The COA ends with the target presentation.

Each trial started with the preview of four arcs, which lasted 1000 ms. In the static condition, the arcs remained stationary during the preview period. In the dynamic condition, the arcs rotated either clockwise or counterclockwise, selected randomly in each trial. Half of the dynamic trials were clockwise and the other half was counterclockwise rotation. There were four different initial starting positions of the arcs. The angles for these were 0, 90, 180, and 270. The 90 degrees of increment may seem intuitive but this number was found by the addition of the angular extent of one single arc to the spacing between them. After the preview, the cue was presented for 50 ms in one of the 2 edges of a randomly selected arc from 4 arcs, as a total, the cue can be located in one of the 8 edges. The cue is followed by a cue-onset-asynchrony (COA) period of 200 ms. Following the COA, the target was presented. The three options are: valid – if the target and the cue are presented at the same end of an arc-, invalid within – if the target and the cue are presented inside the same arc but at different ends-, invalid between – if the target is displayed inside different arcs.

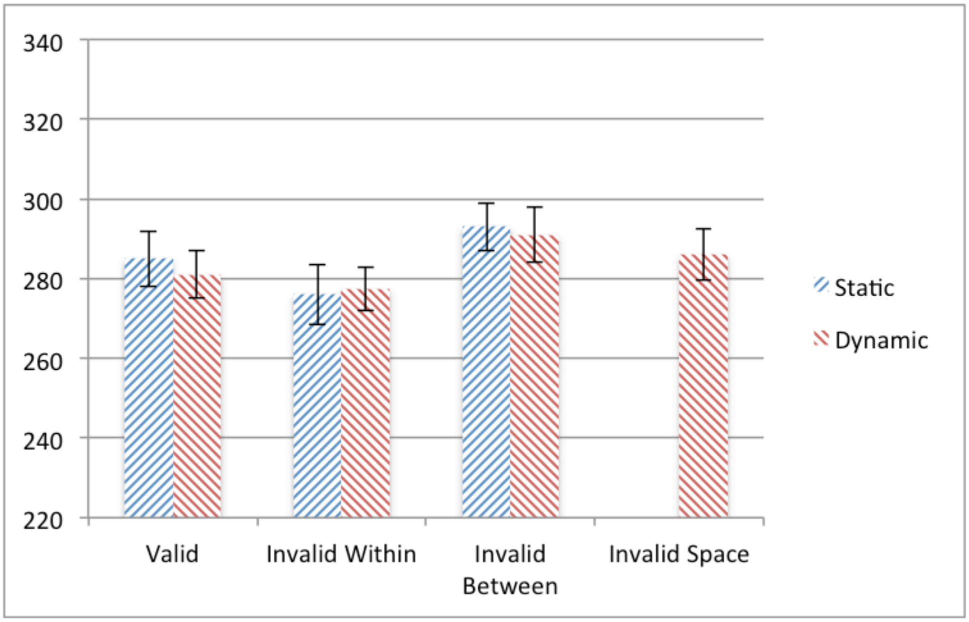

Fig 2.6: Reaction times ± standard errors for within-object and between-object shifts of attention for each stimulus condition tested in allocation of attention for dynamic and static stimuli.

The task of the observer was the same as that of the Egly et al. (1994) study: To press the button as soon as the target is detected. Fifteen students volunteered from the University of Houston. All had normal or corrected-to-normal vision by self-report, and were naïve to the purpose of the experiment. Fig 2.6 shows the reaction times ± standard errors for different target options. The data here are shown as a function of both motion and validity conditions.

For all the target conditions except invalid space, there was no significant difference between moving and static stimuli ($F\ [1,14]=0.110$, $p=0.745$, $\eta_p^2=0.008$). The cue-target relationship had a significant effect ($F\ [2,28]=26.925$, $p<0.001$, $\eta_p^2=0.836$).

The interaction between these two main factors was not significant (F [2,28]=1.922, p=0.165, η_p^2=0.348).

For the static condition, repeated-measures ANOVA showed that the location of the target with respect to the cue has a significant effect on RT's (F [2,28]=18.35; p<0.0001, η_p^2 =0.762). In pre-planned comparisons, a significant effect of object was found (invalid within vs. invalid between: *t* (14)=-7.055, p=0.0001, d=1.821). This result replicated several previous findings. A significant effect of location within the cued object was found (valid vs. invalid within: *t* (14)=4.172; p=0.001, d=1.077). Surprisingly, Reaction Times for invalid within are shorter than those for valid. The reason for this was not clear; it may be due to an inhibitory effect exerted by the cue at its location. Other studies typically highlighted only the edges of the rectangle, while we presented a filled square cue (the reason for our choice of filled square was to provide an effective cue for the invalid space condition).

For the dynamic condition, repeated-measures ANOVA showed that the location of the target with respect to the cue has a significant effect on RT's (F (3,42)=10.07; p<0.0001, η_p^2 =0.836). In pre-planned comparisons, a significant effect of object was found (invalid within vs. invalid between: *t* (14)=-4.249, p=0.001, d=1.097). No significant effect of location within the cued object was reported (valid vs. invalid within: *t* (14)=0.779; p=0.449, d=0.201). To understand the location-based effect, invalid space and the valid conditions were compared, and a significant effect of object vs. space was obtained (valid vs. invalid space *t* (14)=-2.244; p=0.042, d=0.579). Also the difference between the invalid between and invalid space was significant too (*t* (14)=-2.985; p=0.001, d=0.77075).

In the static condition, the object effect was indicated by the advantage of a target stimulus positioned inside the attended object relative to a target at the same distance from the cue but positioned outside the attended object (Reaction time required to detect the invalid within is less than the invalid between). In the dynamic condition, only object effect was shown due to the clear cost between the invalid between and the invalid within.

Taken together, the results showed that the allocation of attention for dynamic stimuli follows both low-level (space effect) and higher level (perceptual grouping into objects) factors. For both static and dynamic stimuli, the attention was allocated to the whole “arc” instead of a limited location of the cue.

Chapter 3

Effect of Cue-Target Distance on the Allocation of Attention

3.1 Aims

Since moving objects constitute a crucial aspect of our ecological environment, we analyzed the allocation of attention to moving targets. In particular, we focused on spatial and "object-based" components of attention and how perceptual grouping determines object-level units.

Previous studies have shown that short cue-target delays facilitate target detection (Duncan, 1984; Klein, 2000; Christ, 2002), for static stimuli, the cue attracts attention to the entire cued-object and for dynamic stimuli, the cue attracts attention to both cued object and cued spatial location (Christ, 2002). The present experiment extends these studies by investigating how attention is allocated to stimuli spread over space but still located inside an object. The main factor in this experiment is the cue-target distance.

To conclude the goals of the experiment, we ask the following questions;

- How is attention allocated to moving targets?
- What is the effect of cue-target distance in the allocation of attention for dynamic and static stimuli?

3.2 Methods

The goal of this experiment is to explore the effect of cue-target distance by adding several target options inside "the same object" condition. Six target options (including catch trials) for dynamic and five target options for static case are investigated.

Our hypothesis is that an increase in the cue-target distance in “the same object” would require more time to detect.

3.2.1 Participants

All experiments reported in this paper were conducted according to a protocol approved by the University of Houston Committee for the Protection of Human Subjects, in accordance with the federal regulations, 45 CFR 46, the ethical principles established by the Belmont Report, and the principles expressed in the Declaration of Helsinki. Twelve students from the University of Houston participated in this experiment. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Participants provided written informed consent approved by the University of Houston Committee for the Protection of Human Subjects.

3.2.2 General Apparatus

Stimuli were presented on a 20-inch NANAO FlexScan color monitor in a dark room, with a black background. The resolution of the display was set to 656 X 492 pixels with a 100 Hz frame rate. Generation of the stimuli was made possible by a video card (Visual Stimulus Generator; VSG 2/3) manufactured by Cambridge Research Systems. A fixed head and chin rest was set to a distance of 1 meter away from the display monitor. The screen size was approximately 23° X 17.5° and each pixel corresponded to 1.7 arcmin. Reaction times were measured by a joystick device interfaced to the VSG board.

3.2.3 General Procedure

Egly et al.'s (1994) experiment was modified in order to allow the whole stimulus to rotate around a circle of fixed radius. The fixation point was a white plus sign (+) placed in the center of the monitor. Stimuli consisted of four arcs rotating around the fixation point (Fig 3.2). Their size in polar coordinates was set to 52.5˚, the spacing between them 37.5˚(respectively 7˚and 5˚visual angles), the height of each arc from the fixation point to their edge was 14˚(1.52˚visual angle). The angular extent of each arc and the spacing between the arcs added up to 90˚so that the 4 arcs divided the circle equally.

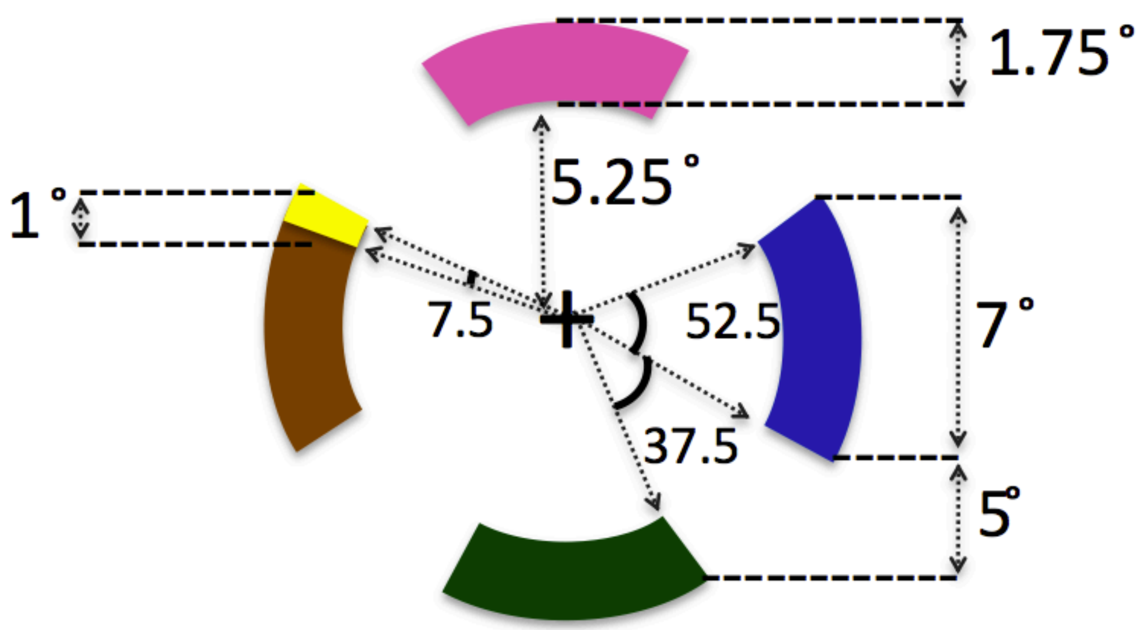

Fig 3.1 The "Arc's" dimensions in visual angle, the height, the width, and the spacing shown.

The size of the cue and the target in polar coordinates were 7.5˚(1˚visual angle). As an addition to Egly's target options: "Invalid Within Near, Invalid Within Far, and Invalid Space" were added in the dynamic condition. The "Valid" target appeared in the same end of the same arc as the cue, but slightly shifted to avoid the exact spatial overlap between the cue and the target. The “Invalid Within Far” and “Invalid Within Near” targets appeared within the same object. “Invalid Within Far” and “Invalid Within Near” options were separated by 7.5˚. “Invalid Within Near” was closest to the cue and “Invalid Within Far” was the farthest to the cue. The “Invalid Between” target appeared in a different object, but equidistant from the cue with “Invalid Within Far”. The “Invalid Space” target appeared outside the cued object. At the dynamic case, the targets either went with the object (“Valid”, “Invalid Within Near”, and “Invalid Within Far” conditions) or it stayed at its initial place for the entire target duration.

The task of the observer, while fixing his/her eyes to the fixation cross was to press a joystick button as soon as the target appeared in order to measure the reaction times.

The amount of time for the duration of

- The preview (4 arcs only) was set to 1000 ms,
- The cue for 50 ms,
- The cue onset asynchrony (the time at which cue was present for) for 200 ms,
- The maximum target duration was set to 2000 ms.

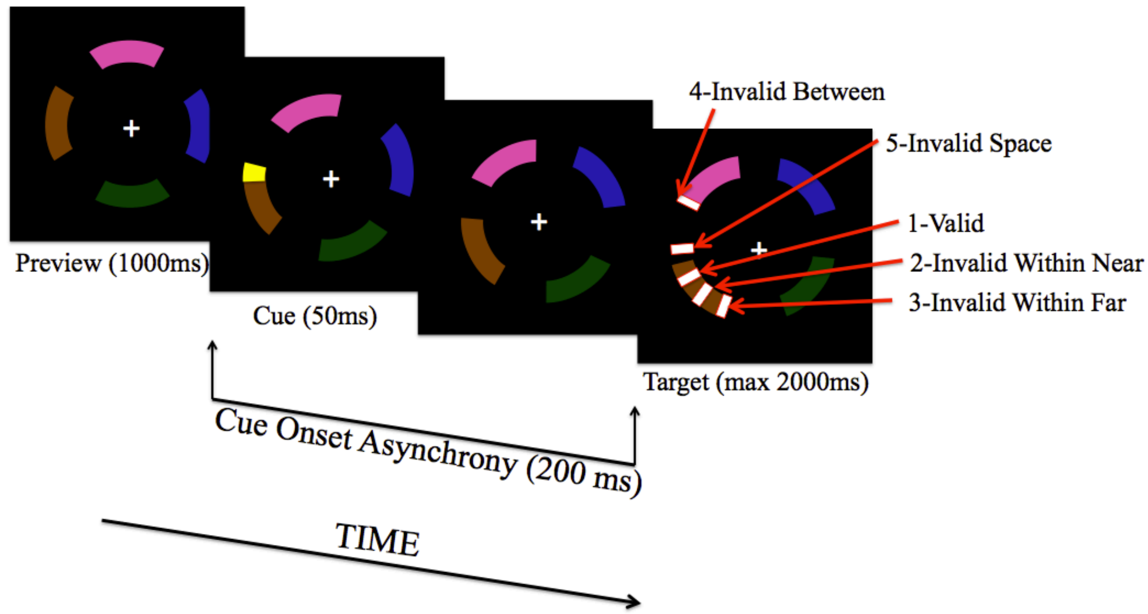

Fig 3.2 Schematic representation of the stimuli in the effect of cue-target distance experiment. Typical sequence of events within trials.

In the dynamic condition, each frame was shown for 50 ms, and the corresponding displacement of arch for each frame was set to 2° (polar). The arc speed with these parameters was 0.04 polar°/ ms. In other words, one complete turn of the arcs required 9 seconds.

The dynamic and static stimuli were blocked separately. Within each block, all target conditions were presented in random order. In the dynamic condition, the arcs rotated either clockwise or counterclockwise, selected randomly in each trial. Half of the dynamic trials were clockwise and the other half was counterclockwise rotation. The starting positions of the arcs were such that the midpoints of the arcs were on the cardinal axes. After the preview, the cue was presented for 50 ms in one of the 2 edges of a randomly selected arc. Thus, there were 8 possible locations for the cue. Following the cue-onset-asynchrony (COA) period of 200 ms, the target was presented. The number of trials for all cases can be seen in the table below. The aforementioned trials constituted one session, and each subject completed 5 sessions giving a total of 1800 trials for the both static and dynamic conditions. The cue was not predictive considering the locations of the target conditions. Before recording the data for every subject, practice trials were performed for training purposes: For practice trials, 60 valid, 60 invalid within far, 60 invalid within near, 60 invalid between and 60 catch trials were run for static case. In the dynamic case, the numbers were same with an addition of 60 invalid space.

Comparing the reaction times of Invalid Within Far and Invalid Within Near, we were able to understand the effect of the distance between the cue and the target for the dynamic case.

Table 3.1 Number of trials for each subject in static and dynamic cases in the effect of cue-target distance experiment.

	STATIC	DYNAMIC
Total number of trials	360	360
Valid	72	60
Invalid Within Far	72	60
Invalid Within Near	72	60
Invalid Between	72	60
Invalid Space	0	60
Catch Trials	72	60

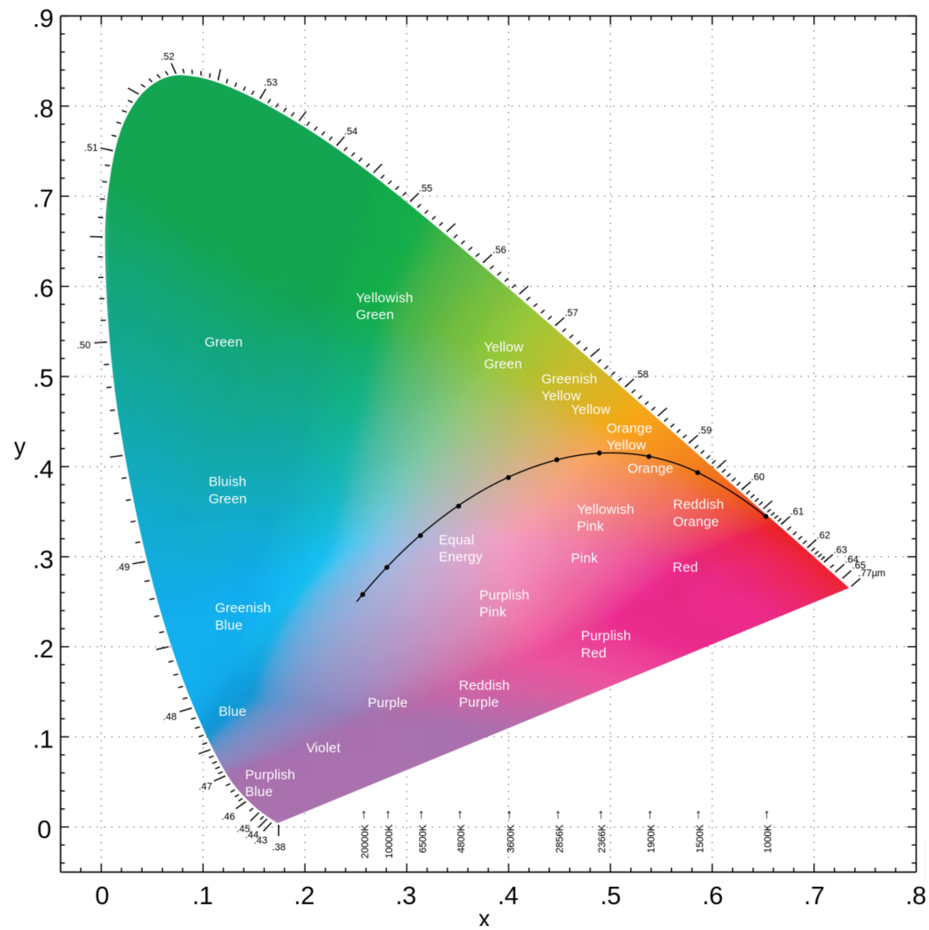

Fig 3.3 C.I.E 1931 Chromaticity Diagram

We used the CIE 1931 XYZ color space; preset 4 different set of numbers for 4 different colors. The chromaticity diagram can be seen in Fig 3.3 (taken from Smith et al. 1931-32) The formula below was used to form a color wheel, separating available colors in 180 degrees, where α and β were offsets, and θ was the coefficient for the wheel, i was reserved as a simplified input for the color selection. For the experiment, we used 0.2044 for α, 0.48085 for β, and 0.2 for θ. i values for the 4 arcs were: 30, 75, 120, and 165. Z was kept constant for the four arcs with a value of 2.0 cd/m^2. These figures leaded to blue, green, brown and pink respectively. The arcs were displayed with different colors to make each arc visually distinct from the others. This minimized the possibility of confusing the arcs with each other when they were rotating. The background color was black by giving X, Y, and Z all 0. The cue and the target were both white having X = 0.2044, Y=0.48085 and Z =20.0 cd/m^2. We predicted that because of proximity to the cue, Invalid Within Near would require less time to be detected compared to Invalid Within Far.

$$X = \alpha + \theta * \cos(2*i*\pi/180) \text{ and} \tag{3.1}$$

$$Y = \beta + \theta * \sin(2*i*\pi/180), \tag{3.2}$$

$$Z = \text{desired luminance } (cd/m^2).$$

3.3 Results and Statistical Analysis

Mean reaction times and standard errors were compared. Reaction times less than 150 ms and greater than 1000 ms were excluded from all analysis. 1.3 % data were excluded from analysis. Reaction time data were analyzed by two-factor repeated measures ANOVA (with Huynh-Feldt correction for sphericity, as necessary) and with pre-planned paired t-tests depending on the comparisons in order to test significance.

In the Fig 3.4, mean reaction times ± standard errors are shown for both dynamic and static cases. Accuracy in catch trials was % 96.5 or higher.

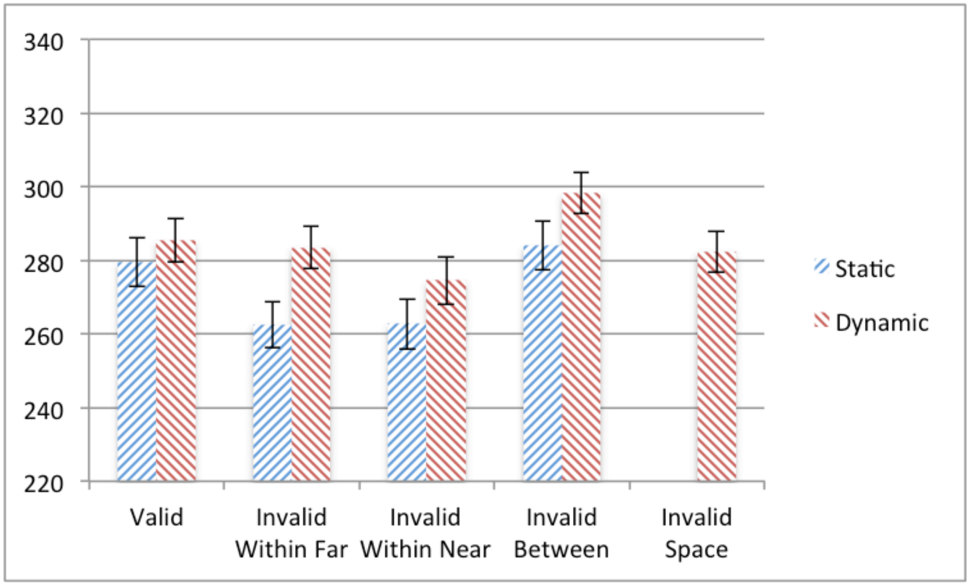

Fig 3.4 Mean Reaction Times ± Standard Errors for within-object and between-object shifts of attention for each stimulus condition tested in the effect of cue-target distance experiment for dynamic and static cases.

Each case (dynamic and static) is investigated for the validity by repeated measures ANOVA. Main effect of validity was significant for both cases: F [1,11] = 10.131, p=0.003, η_p^2 =0.773 for the static case and F [1,11] = 6.78, p=0.011, η_p^2 =0.771 for the dynamic case. In order to understand the object-based and the space-based components, the cost to shift attention within the object, and between objects were analyzed.

In the static condition, a significant object effect was observed due to the significant difference between the invalid within far (262.6ms), and the invalid between (283.9 ms) conditions (*t (11)=-5.870, p=0.001, d=1.69461*). Mean reaction time difference was 21.3 ms. The required time for the detection of invalid between was also the largest than any other conditions. On the other hand, inside object effect, which can be considered as space-based effect inside the object, was not observed. The mean reaction time difference between the invalid within far (262.6 ms) and the invalid within near (262.7 ms) conditions was not significant (*t (11)=-0.006, p=0.996, d=0.016*). Both invalid within far and invalid within near conditions were significantly smaller than the valid condition (*t (11)=2.76, p=0.019, d=0.7968* and *t (11)=3.098, p=0.010, d=0.8941* respectively). Previous studies showed shorter reaction times for valid compared to invalid within condition (Brown et al., 2001; Brown, Denney, 2007; Christ et al., 2002; Egly et al., 1994; Iani et al., 2001; Vecera, 1994). The difference in our results may be due to an inhibitory effect exerted by the cue at its location. The cue-invalid within far distance was 3.9˚. In Egly et al.'s work, this number was 8˚; in Brown et al.'s work, it was 4.19 ˚. These studies typically highlighted only the edges of the rectangle, while we presented a filled square cue (the reason for our choice of filled square was to provide an effective cue for the invalid space condition).

In the dynamic condition also, the object effect was significant. The significant difference between the invalid within far (283.5 ms) and the invalid between (298.2) conditions was 14.7 ms (*t (11)=-3.364, p=0.006, d=0.9711*). As in the static case, the difference between the invalid within far and the invalid within near conditions was not significant (*t (11)=1.919, p=0.081, d=0.081*). The significant difference between the invalid space (282.4 ms) and the invalid between (298.2 ms) conditions indicated a space effect (*t (11)=3.455, p=0.005, d=0.9974*). The cost to shift (engage) to another object from space could cause this 15.8 ms difference. The difference between the valid and the invalid within near was significant (*t (11)=2.794, p=0.017, d=0.8064*). However, in contrast with our hypothesis, the difference between the valid and the invalid within far was not significant (*t (11)=0.357, p=0.728, d=0.1029*). This can be due to the spread inhibitory effect of the cue discussed above. The cue-invalid within far distance in the dynamic case increased due to the motion. Instead of 3.9˚, it was 9.9˚(150 x 0.04+3.9).

A 2 factor (motion vs. validity) repeated measures ANOVA was conducted to examine the effects of motion and different validity conditions. The effect of motion was significant (F (1,11)=6,842, p=0.024, η_p^2 =0.364). No significant interactions were observed between the "inside-object-distance" (Invalid within far and invalid within near) vs. "motion" (static and dynamic), (F (1,11)=2,876, p=0.118, η_p^2 =0.161).

3.4 Discussion

We investigated the effect of cue-target distance on the allocation of attention both for dynamic and static stimuli. As seen from Fig 3.3, intuitively first thing that took our "attention" is that observers were remarkably faster in detecting targets under static condition in comparison with the dynamic condition. For both static and dynamic stimuli, we were able to observe both object and space effects significantly. The exogenous attention was captured and spread to the whole arc (object) instead of the location of the cue within the object. This result can be considered as an addition to the prior studies supporting the operation of visual attention on both object-based and space-based levels (Abrams, Law, 2000; Duncan, 1984; Egly et al. 1994; Iani, Rafal et al., 2001; Lamy, Egeth, 2002).

Shifts of attention within objects, being always faster than between objects, even though the within-object and the between-object distances were equal, showed the "traditional" object-based facilitation and supported several pioneering studies of object-based views of the visual attention (Egly et al., 1994; Brown et al., 2006; Lamy, Egeth, 2002; Moore et al., 1998; Vecera, 1994). On the other hand, if we look from the location point of view, space effects were only present in the dynamic stimuli. The significant difference between the invalid space and the invalid between supports the cost to “engage” to an object. The different outcomes for static and dynamic stimuli leaded us to think that the movement of stimuli is a highly dependent factor on the allocation of attention. The fact that the allocation occurs by following the motion of the stimuli, the non-retinotopic frame is respected in the dynamic stimuli as opposed to a purely retinotopic reference frame.

Our hypothesis was that an increase in the cue-target distance in “the same object” would require more time to detect. Although only for the dynamic case, and even though the difference is not significant, the invalid within far condition needed more time to be detected compared with the invalid within near condition.

Chapter 4

Effect of Color Grouping on the Allocation of Attention

4.1 Aims

As discussed also in Chapter 3, the main purpose of this experiment is also to have a better understanding for the allocation of attention in dynamic stimuli. As an extension to the previous experiment, we measured the effect of grouping by color in the allocation of attention. Taken together, the results of the previous experiment showed that the allocation of attention for dynamic stimuli follows both low-level (space effect) and higher level (object effect) factors. As stated in Chapter 2, the similarity of color is a very powerful Gestalt grouping principle. According to the principle, if all the rest features are equal, the perception tries to group the stimuli being similar than the rest. While previous studies suggested that attention is allocated to objects, these studies did not clearly define the object concept. How is an object defined? Assume that a stimulus consists of multiple disks and that a subset of these disks is grouped by color. When attention is allocated to an "object", is it allocated only to one of the grouped disks, or to the entire group? The experiments presented in this chapter aim to answer this question. Here, we extended these studies with the following specific aim: effect of color grouping on the allocation of attention using moving objects with the same versus different colors.

4.2 Methods

The goal of this experiment is to investigate the effect of grouping by color on the allocation of attention. Our prediction is that color grouping has a facilitatory effect for the “other” object compared to the ungrouped condition. In brief, we believe that reaction time needed to detect the same color case will be less than the different color option. The stimulus of Chapter 3 was modified to investigate the role of perceptual grouping by color in the allocation of exogenous attention. In order to study grouping by color, the colors assigned to the arcs were such that, in each trial, two randomly selected arcs had the same color while the other two had different colors.

4.2.1 Participants

The author and 11 naïve observers having normal or corrected to normal vision participated in the experiment. The number of subjects was kept same as the previous experiment.

4.2.2 General Apparatus

The apparatus was identical to that described in Chapter 3.

4.2.3 General Procedure

The stimuli was identical to the one described in Chapter 3 with the following exceptions:

- There was no invalid within near or invalid within far, only one single invalid within (here, invalid within far condition is used for the invalid within condition) which was in the same object with the cue.
- Randomly chosen two out of four arcs were selected with the same color. The remaining two arcs were also set randomly with two other random colors. Via this color grouping, the cued item and the item in which the target appears can have the

same or different color. As in Chapter 3, C.I.E. 1931 XYZ was used for color. For the color randomization, three random numbers between 0 & 180 were generated. They were not allowed to be equal or be close as 30. First generated number was used for 2 arcs chosen randomly from 4 arcs. The remaining 2 numbers were used for the 3rd and the 4th arcs. The 3 randomly generated numbers were put as i value, α, β, and θ were kept the same as in Chapter 3.

$$X = \alpha + \theta * \cos(2*i*\pi/180) \text{ and} \tag{4.1}$$

$$Y = \beta + \theta * \sin(2*i*\pi/180). \tag{4.2}$$

- If two consecutive arcs had the same color, the invalid between option would become "the invalid between same color." In the other case, if two consecutive arcs had different colors, the invalid between option would become "the invalid between different color."
- Half of the invalid between trials were "the invalid between same color," the remaining half were "the invalid between different color."

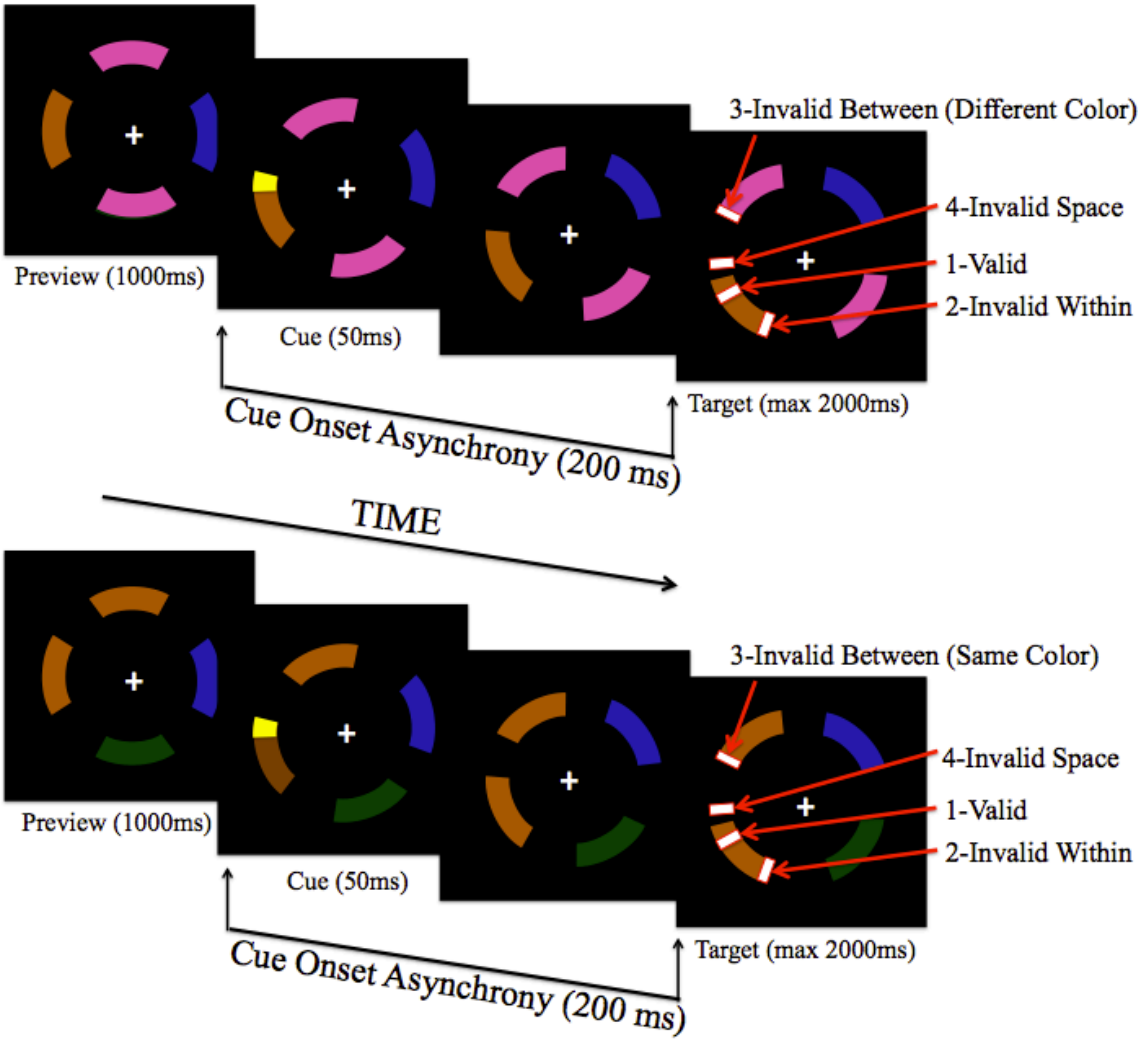

Fig 4.1 Schematic representation of the stimuli in the effect of color grouping experiment. Typical sequence of events within trials.

The task of the observer was the same as in the previous chapter. The time duration of the preview, cue, COA, and the target were exactly same as in the previous chapter.

Trials of all target options were presented in random order. Each dynamic case was repeated for clockwise and counterclockwise rotation. The number of trials for all cases can be seen in the table below. The aforementioned trials constituted one session, and each subject completed 5 sessions giving a total of 1800 and 1200 trials for the static and dynamic conditions, respectively. Before recording the data for every subject, practice trials were performed for training purposes: For practice trials, 60 valid, 60 invalid within, 30 invalid between same color, 30 invalid between different color and 60 catch trials were run for static case. In the dynamic case, the numbers were same with an addition of 60 invalid space.

Comparing the reaction times of invalid between same color and invalid between different color conditions, we were able to examine whether attention is allocated to the entire group or only to the cued element.

Table 4.1 Number of trials for each subject in static and dynamic case in the effect of color grouping experiment

	STATIC	DYNAMIC
Total number of trials	360	240
Valid	97	48
Invalid Within	97	48
Invalid Between (Same Color)	49	24
Invalid Between (Different Color)	49	24
Invalid Space	0	48
Catch Trials	68	48

4.3 Results and Statistical Analysis

Mean reaction times and standard errors were compared. Reaction times less than 150 ms and greater than 1000 ms were excluded (0.6 %) from all analysis. Accuracy in catch trials was % 96.1 or higher. Reaction time data were analyzed by two-factor repeated measures ANOVA (with Huynh-Feldt correction for sphericity, as necessary) and with pre-planned paired t-tests depending on the comparisons in order to test significance.

In the Fig 4.2 below, mean reaction times ± standard errors are shown for both dynamic and static cases. Also the comparison between the same color and different color conditions can be seen.

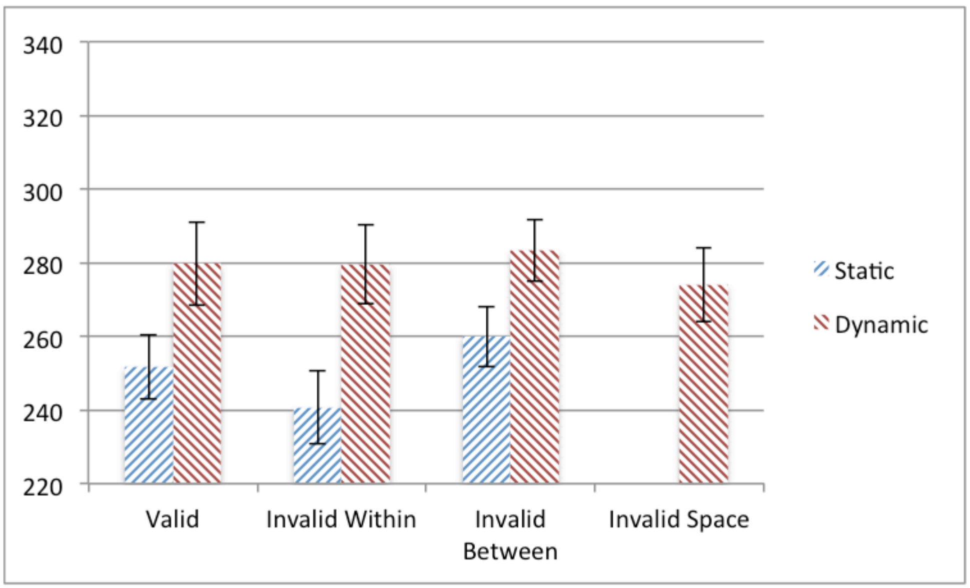

Fig 4.2 Mean Reaction Times ± Standard Errors for within-object and between-object shifts of attention for each stimulus condition tested in the effect of color grouping experiment for dynamic and static cases.

Each case (dynamic and static) is investigated for the validity by one-way repeated measures ANOVA. Main effect of validity was significant for both cases: *F* [1,11] = 9.601, p=0.019, η_p^2=0.465, for the static case and *F* [1,11] = 70.880, p=0.001, η_p^2=0.761 for the dynamic case. The reaction time to detect static stimuli was significantly less than the reaction time to detect dynamic stimuli (*F* [1,11]=20.639, p=0.004, η_p^2=0.822).

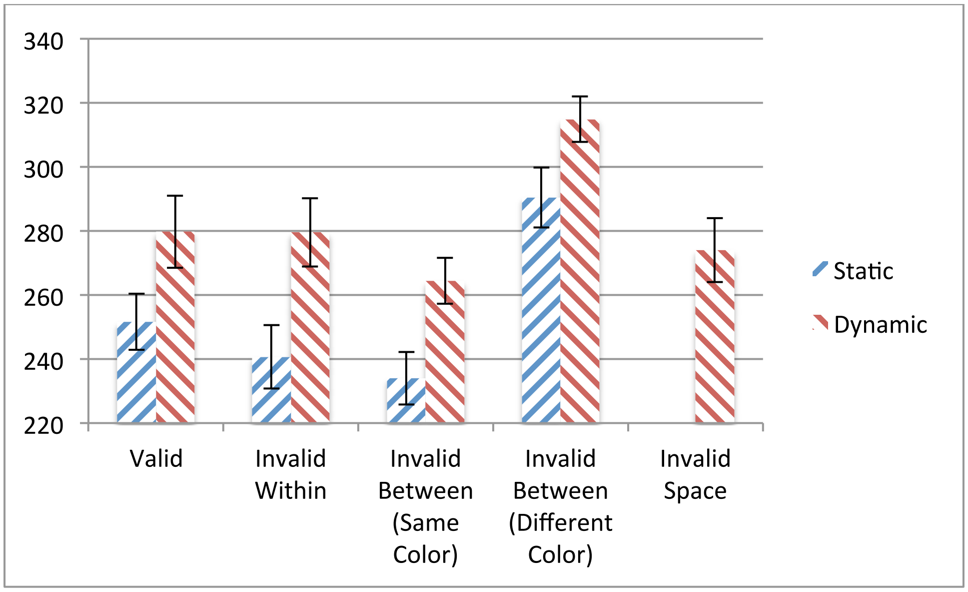

Fig 4.3 Mean Reaction Times ± Standard Errors for between-object shifts as a function of color grouping for each stimulus tested for both cases. (Same data as Fig. 4.2 except that Invalid Between condition is separated into Invalid Between Same Color and Invalid Between Different Color.)

Two-way repeated measures ANOVA with factors dynamic-static and validity (valid, invalid within, invalid between) showed significant difference between static and dynamic stimuli (F [1,11]=31.322, p<0.001, η_p^2=0.740). Cue validity and the interaction between the two factors were also significant (F [2,22]=15.501, p<0.001, η_p^2=0.585 and (F [2,22]=10.805, p=0.002, η_p^2=0.496, respectively).

In order to understand the object-based and the space-based components, the cost to shift attention within the object, and between objects was analyzed. In the static condition, a significant object effect was observed due to the significant difference between the invalid within (240.7 ms) and the invalid between (260 ms) conditions (*t (11)=-5.385, p=0.000, d=1.5554*). Mean reaction time difference was 19.3 ms. This result replicated prior studies (Egly, Driver, et al., 1994; Egly, Driver, Rafal, et al., 1994; Iani et al., 2001; Lamy and Egeth, 2002; Lamy and Tsal, 2000; Moore et al., 1998; Vecera, 1994). The required time for the detection of invalid between was also the largest than any other conditions, which again showed a strong object-effect. On the other hand, inside object effect, which can be considered as space-based effect inside the object, was not observed. The mean reaction time difference between valid (251.6 ms) and the invalid within (240.7 ms) conditions was not significant (*t (11)=3.488,* p=0.207, *d=1.0006*). Thus, we did not observe the within-object distance effect. This null finding was based on the analysis where same and different color cases were lumped together, forming the invalid within case. However, if the exogenous attention is affected by the grouping by color, than the invalid between same color case should be separated by the invalid within, and the difference between the invalid between same color and the invalid between different color should be significantly different, same color option generating faster reaction times compared to the different color option. As seen from Fig 4.4, the invalid between same color is significantly faster than the invalid between different color (*t* (11)=-4.698, p=0.001, d=1.35609). The difference between invalid between same color and invalid within showed no significance (*t (11)=1.988, p=0.082, d=0.40173*), however the difference became significant for the invalid between different color and invalid within (*t (11)=-9.995, p=0.002, d=3.1843*). Comparing the valid condition and the invalid between same color option, the difference was significant (*t (11)=7.309, p=0.000, d=2.11*).

In the dynamic condition, the object effect was not significant. When, same and different color invalid between cases were analyzed together, the difference between the invalid within (279.6 ms) and the invalid between (283 ms) conditions was only 3.4 ms (*t (11)=-1.160, p=1.000, d=0.3347*). A 2 factor (motion vs. color) repeated measures ANOVA was conducted to examine the effects of motion and same color vs. different color conditions. The effect of color grouping was significant (*F* (1,11)=8,210, *p*=0.029, η_p^2 *=0.929*). The effect of motion was also significant (*F* (1,11)=87,475, *p*=0, η_p^2=0.485). There was no interaction between grouping and motion (*F* (1,11)=0,132, *p*=0.729, η_p^2=0.016). Figure 4.3 shows the analysis when same color and different color, subcases of invalid between are separated. As in the static case, the difference between invalid between same color and invalid within showed no significance (*t (11)=1.976, p=0.084, d=0.4777*). Still consistent with the static case, the difference became significant for the invalid between different color and invalid within (*t (11)=-5.478, p=0.011, d=1.7235*). The significant difference between the invalid space (274 ms) and the invalid between (283 ms) conditions indicated a space effect (*t (11)=6.036*, *p*=0.01, *d*=1.742). The cost to shift (engage) to another object from space could cause this 9 ms difference. The retinotopic/spatiotopic effect of the cue was significant (invalid-space vs. invalid-between different-color, *t* (11)=-7.756, *p<0.001, d=2.2395*). The cue was more effective for the cued element of the group compared to retinotopic/spatiotopic cue (valid vs. invalid space: *t* (11)=4.761; *p=0.026, d=1.854*), but the cueing effect was not different when retinotopic/spatiotopic condition is compared to the other element in the cued group (invalid space vs. invalid-between same-color *t* (11)=1.049, p=0.317, d=0.3026). In contrast with the static condition, the valid condition and the invalid between same color option were not significantly different (*t (11)=1.650, p=0.127, d=0.476*).

The cue-invalid within distance was same as described in Chapter 3. The location of invalid within far in Chapter 2 is the same as the invalid within in Chapter 3.

4.4 Discussion

We examined the effect of color grouping on the allocation of attention both for dynamic and static stimuli. As seen from Figure 4.2 and 4.3 subjects were significantly faster in detecting targets in static stimuli compared to dynamic stimuli. For static stimuli, attention is allocated preferentially to objects, even when the object is spread out and grouped by color. For dynamic stimuli, the spatial location of the cue determines the allocation of the attention. The same grouping effect is observed for dynamic stimuli; however in this case the spatial location of the cue is also a significant attractor for attention. As in the previous chapter, the exogenous attention tracks the motion of the stimuli. The spatiotopic/retinotopic effect of the cue is much stronger compared to the effect of the cued element. Because of this finding, the biggest advantage goes to the cued stimulus. The comparison between the cue and the cued element becomes more significant if it is compared to the previous experiment.

According to our hypothesis, if grouping had an effect on the allocation of attention, there should have been facilitation for the invalid between same color condition. If there is no interaction between the allocation of attention and grouping by the color feature, than the reaction times for invalid between same color and for invalid between different color conditions should have been equal. The results and the statistical analysis clearly showed that grouping by color has a significant facilitatory role on the allocation of attention whether the stimuli is static or dynamic. The color grouping analysis results showed that reaction times for invalid between same color condition are significantly shorter than reaction times for invalid between different color condition.

Chapter 5

Effect of Motion on the Allocation of Attention

5.1 Aims

As stated in Chapter 3 and Chapter 4, the main goal of all the experiments is to understand the mechanisms for the allocation of attention in dynamic cases. The previous experiments gave clear results on the effects of cue-target distance and color grouping for the static and the dynamic stimuli. In addition to the main goal, we still seek the effect of grouping on the dynamic stimuli. This experiment's grouping feature is motion.

As being said in Chapter 2, the principle of common fate suggests that if the visual stimuli move in the same direction, they are considered as a single group. Similar to the example of bird flock, several disks going in the same direction will constitute one single group.

Extension of the previous studies and the previous chapter comes with grouping by motion. Perceptual grouping by motion is investigated using objects moving with the same versus different directions. We predict that grouping with motion will have a facilitatory effect compared to randomly chosen linear direction.

To conclude the aims of the experiment, we ask the following questions:

- How is attention allocated to moving targets?
- What is the effect of motion in the allocation of attention of attention for dynamic stimuli?

5.2 Methods

The goal of this experiment was to explore the effect of motion by introducing several target options inside different "disks". Five target options (including catch trials) were investigated. It was expected that having the cue and the target within the same group would facilitate the task, requiring less reaction time to allocate the attention.

5.2.1 Participants

The author and 11 naïve observers having normal or corrected to normal vision participated in the experiment. The number of subjects was kept same as the previous experiments.

5.2.2 General Apparatus

The apparatus was identical to that described in Chapter 3.

5.2.3 General Procedure

The stimuli consisted of six disks. All objects were circular disks with a diameter of 0.8° visual angle. As in the previous chapters, the fixation point was a white plus sign (+) placed in the center of the monitor. All the disks had a speed of 5 degrees per second for all trials. The interference of objects was not permitted during their linear trajectory movement. Objects' velocity remained identical even if they moved across each other.

As in the previous chapters, the CIE 1931 XYZ color space was chosen; the formula 3.1 was used to create the disks. For the experiment, we used 0.2044 for α, 0.48085 for β, and 0.2 for θ. For the i (angle) value, 30 degrees was used. The corresponding color was blue with a luminance of 4cd/m^2 (0.3044, 0.6541, 4). As in the previous chapters, background color was black (0,0) with a luminance of 0 cd/m^2.

The cue and the target were appeared on top of one disk having smaller diameters than the disks (see Fig 5.1). Their CIE color values were 0.2044, 0.48085 with a luminance value of 20 cd/m^2. Their colors correspond to white. The task of the observer, while fixing his/her eyes to the fixation cross was to press a joystick button as soon as the target appeared in order to measure the reaction times.

The amount of time for the duration of

- The preview (6 disks only) was set to 500 ms,
- The cue for 100 ms,
- The cue onset asynchrony for 200 ms,
- The maximum target duration was set to 1000 ms.

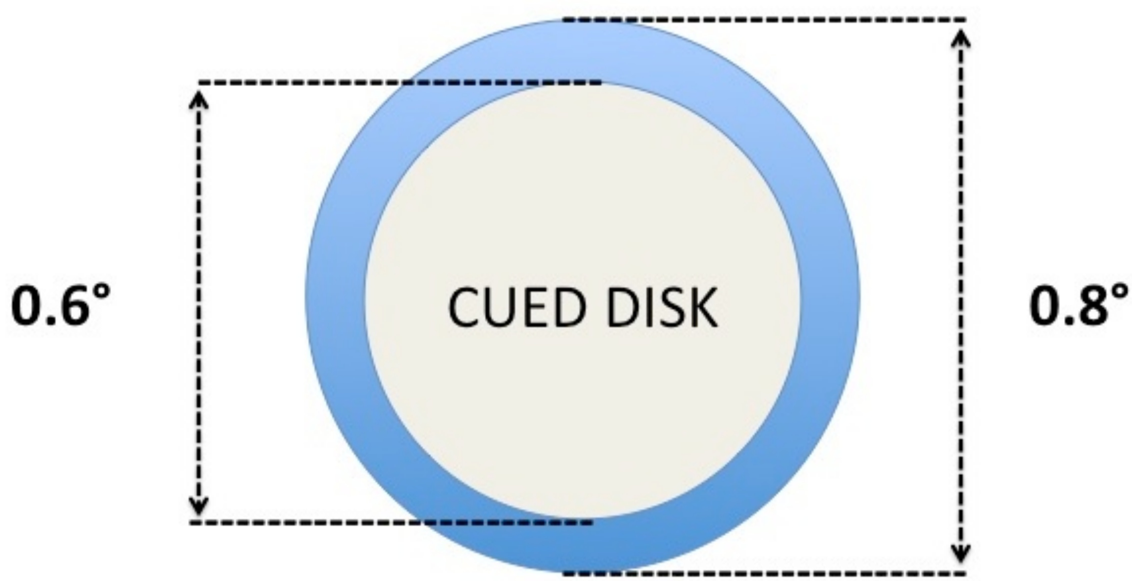

Fig 5.1 The "Disk's" and the cue's diameters in visual angle. In this figure, the cue is shown in beige color for easy detection purpose, in the actual stimuli, it is white.

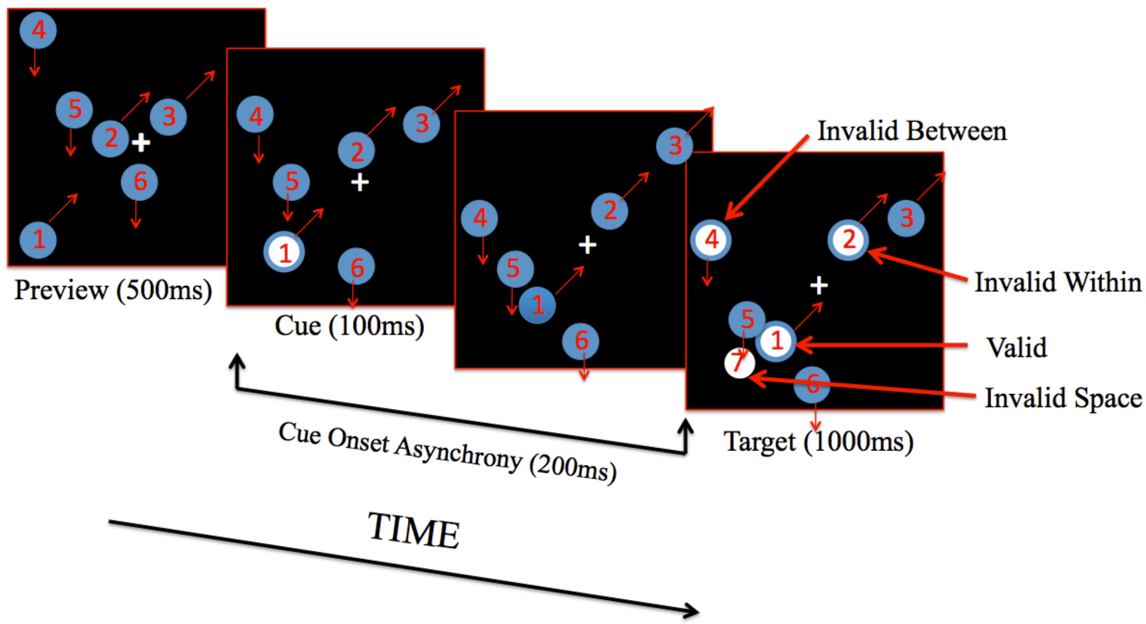

Fig 5.2 Schematic representation of the stimuli in the effect of motion grouping experiment. Typical sequence of events within trials.

Each trial started with the preview: Six disks with randomly chosen six starting positions, having two different randomly chosen linear trajectories started their motion. After the preview period of 500 ms, the cue, which was a smaller white disk, appeared in one of the disks and traveled with that disk for 100 ms. After the disappearance of the cue, there was an interval of 150 ms, which was basically like preview. Cue onset asynchrony was followed by the presentation of the target inside one randomly chosen disk. The cue and the target had exactly the same dimension, and color. The maximum duration of the target was set to 1000 ms, in which the subject had to press the joystick button.

The "Valid" target appeared in the same disk as the cue. The "Invalid Within" target appeared in the disk, which belonged to the same group as the disk having the cue. "Invalid Between" target appeared in the disk, which belonged to the opposite group as the disk having the cue. The last target option is the "Invalid Space", in which, the target did not appear in any disk, but appeared in the first location that cue appeared. This target option is valid from a space-based point of view. In order to remove any bias due to a space-based advantage, the total distance between the cue and the invalid within was set equal to the distance between the cue and the invalid between for all the trials.

Trials of all target options were presented in random order. The number of trials for all cases can be seen in the table below. Each trial was repeated 4 times. As a total, 4 target options x 60 x 4 made 960 trials. Before recording the data for every subject, 60 trials for each target option were performed for training purposes.

Comparing the reaction times of invalid within, invalid between, we were able to understand the effect of the motion grouping.

We predicted that because of being grouped by common motion, invalid within would require less time to be detected compared to invalid between.

Table 5.1 Number of trials for each subject in the effect of motion grouping experiment.

Total number of trials	240
Valid	48
Invalid Within	48
Invalid Between	48
Invalid Space	48
Catch Trials	48

5.3 Results and Statistical Analysis

Mean reaction times and standard errors were compared. Reaction times less than 150 ms and greater than 800 ms were excluded from all analysis. 1.7 % data were excluded from analysis. Reaction time data were analyzed by two-factor repeated measures ANOVA and with pre-planned t-tests depending on the comparisons in order to test significance. In the figure below, mean reaction times ± standard errors are shown. Accuracy in catch trials was % 95.1 or higher.

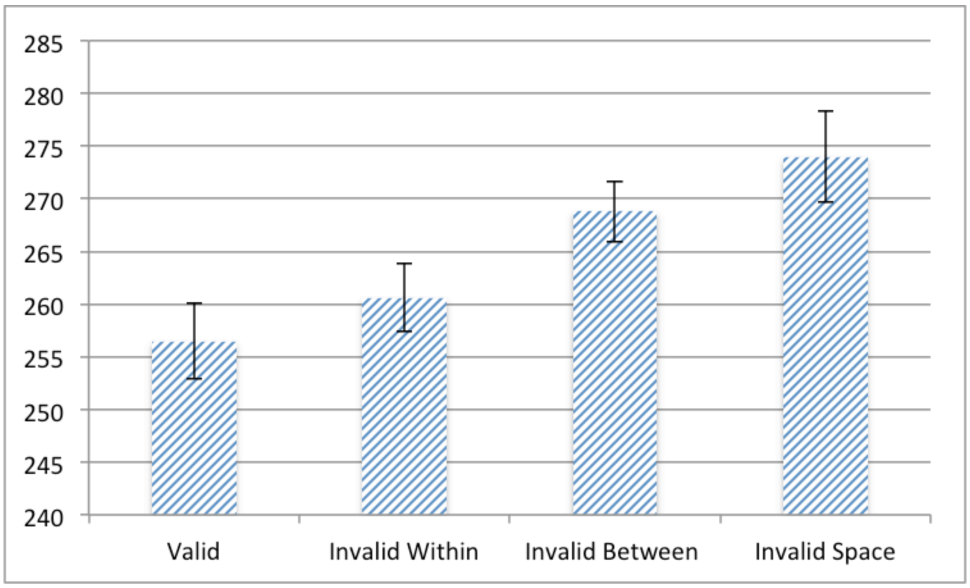

Fig 5.3 Mean Reaction Times ± Standard Errors for within-object and between-object shifts of attention for each stimulus condition tested in the effect of motion grouping experiment.

Main effect of validity was significant: *F (3,9)=11.589, p=0.002,* η_p^2 =0.794. In order to understand both components of the visual attention, to cost to shift within the group, and between groups were analyzed. Object effect was observed due to the significant difference (8.2 ms) between invalid within and invalid between (t (11)=-5.268, *p=0.000, d=1.5207*). The space-based effect was also present: The mean reaction time difference between the invalid within and the valid was significant (*t (11)=-3.231, p=0.008, d=0.9328*). As in the previous studies (Brown et al., 2001; Brown, Denney, 2007; Christ et al., 2002; Egly et al., 1994; Iani et al., 2001; Vecera, 1994), the valid condition was significantly the fastest compared to all condition. (*t (11)=-6.342, p=0.000, d=1.8307; t (11)=, p=0.015, d=1.1254* for invalid between, and invalid space respectively).

The difference between invalid space and invalid between was not significant (*t (11)=-0.769, p=0.458, d=0.2218*). The cost to shift (engage) from the group to the space didn't indicate a space-effect.

5.4 Discussion

We investigated the effect of motion grouping on the allocation of attention. As seen from Fig 5.3 subjects were significantly faster detecting valid targets compared to all other target options. Considering the difference between the valid and the invalid space, this signifies the overall object-based advantage compared to the space-based coordinate of the visual attention.

Re-stating our hypothesis, our predictions were that grouping by motion had a facilitatory role in detecting targets. The results showed that the targets being in the same group as the cue have been detected significantly faster compared to the ones that did not belong in the same group. Looking from a non-retinotopic point of view, considering that the cued disk receives more resources from exogenous attention, even though with the motion, the retinotopic and the spatiotopic locations are different than the original cue. The results and the statistical analysis proved that grouping by motion has a significant facilitatory role on the allocation of attention.

Chapter 6

General Discussion

6.1 General Discussion

We investigated how distance and grouping affect the visual attention for both static and dynamic displays and with this study; we clearly demonstrated the effects of cue-target distance, color and motion grouping on the deployment of exogenous attention.

In Chapter 3, we investigated cue-target distance on exogenous attention using dynamic and static stimuli. The hypothesis was that, reaction times of the target having closer distance to cue inside the same object would be smaller compared to the object far but still in the same object. Unfortunately neither in the static case, nor in the dynamic case, an inner-object (group) effect or location-based advantage was not present. Comparing the within-object shifts to the between-object shifts, the advantage of within shifts favored the object-based approach towards the main mechanisms of visual attention, as did many studies (Egly et al., 1994; Brown et al., 2006; Lamy, Egeth, 2002; Moore et al., 1998; Vecera, 1994).

In Chapter 4, the effects of color grouping on the allocation of attention were examined for both dynamic and static stimuli. The effects of color grouping were clearly demonstrated for both stimuli types. The interaction between grouping and the allocation of attention was demonstrated. It can be concluded that the color is very powerful for exogenous attention. In contrast with the previous experiment (chapter 3), only static stimuli showed both object and space effects. In the dynamic stimuli, the object effects were absent; the spatial location of the cue determined the allocation of attention.

In Chapter 5, the effects of motion grouping on the allocation of attention were tested. Both object-based and space-based advantages were observed. Also, the difference between the valid and the invalid space signified the overall object-based superiority over the space-based coordinate of the visual attention. The hypothesis of the experiments was that grouping by motion had a facilitatory role in detecting targets. The hypothesis holds. The targets being in the same group as the cue, were detected significantly faster compared to the ones that did belong in the other group.

In the previous study conducted in our laboratory, and in the first and the second experiments (Chapters 3 & 4), observers were remarkably faster in detecting targets under static condition in comparison with the dynamic condition. Considering that in the dynamic condition, the exogenous attention had to cross more distance, this might be due to the location-based component of the visual attention. Also this difference might be due to the fact that in the static case; purely retinotopic reference frame existed.

For both static and dynamic stimuli, several comparisons in the experiments showed the operation of exogenous attention on both object-based and space based coordinates. This fact is in line with several important researchers' work (Abrams & Law, 2000; Duncan, 1984; Egly et al. 1994; Iani, Rafal et al., 2001; Lamy, Egeth, 2002). The different outcomes for static and dynamic stimuli lead us to think that the movement of stimuli is a highly dependent factor on the allocation of attention even though several communalities exist between the static and the dynamic results.

In sum, I think that the allocation of attention is based abundantly on perceptual grouping. Recently the link between the allocation of attention and perceptual grouping is also cited in Boi et al. (2011). In their study, authors demonstrate that object-based reference frames defined by perceptual grouping affect the deployment of attention.

The allocation of visual attention reflects the logical approach towards the survival. The conclusion that the reference frame of exogenous attention respects the motion of the stimuli shows that the visual system clearly gives more importance to the present location of the target, compared to the previous locations of the target. The allocation of the attention to an entire perceptual group is more meaningful than to only target. Again in the survival, many times animals notice only a small part of their predators but complete the big picture.

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