Studies of Visual Attention

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Aim

The experiment proposed to study the effect of sustained visual attention in an effective visual field of 40 degrees, in cued and uncued conditions with different set-sizes.

Methods

The participants had a normal contrast and visual acuity with normal ocular/general health. The experiments were performed both for central (0 - 20degrees) and peripheral (>20 – 50 degrees) visual fields. The targets were presented with valid and invalid cued conditions in different set-sizes of 500, 1000 and 2000. The targets were Gabor gratings oriented at 90 or 180deg subtending a minimum angle of resolution (MAR) ranging from 1.5-10minarc at 25cm. The spatial frequency of the Gabor ranged from 1- 29cycles/degrees and contrast from 20-100%. The observer had to identify the Gabor with horizontal grating and register the response. The accuracy and the reaction times for the targets were evaluated.

Results

The central targets had lower reaction times and high accuracy compared to the peripheral targets. There was a significantly increasing eccentricity effect as the

targets were displayed much peripherally. It was less with presentation of valid sustained cues but it was not eliminated. The diminishing contrast of the target had a significant increase in reaction times and reduced accuracy. The effect of increasing number of items in the display didn't show any significant increase in reaction time, i.e. there was no "set-size effect" seen both central and peripheral targets.

The valid cues improved the performance with lower reaction times, compared to the neutral cued conditions, in each of the different experiments and resulted in an improved accuracy in both the central and peripheral visual field.

Conclusion

Visual attention is affected by contrast, target size and spatial gratings. Reaction time is high and accuracy less for low contrast targets, high spatial frequency and larger set-size, except for set-size 2000 in the central field where it was seen that the reaction times were reduced. The effect is consistent in both central and peripheral visual fields. The set-size also has an effect on the reaction times and on accuracy. The effects are more pronounced in the peripheral visual field.

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Dedication

This thesis is dedicated to my parents.

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Acronyms and short forms used

2AFC:	**2-** Applied- Force- Choice
CPD:	Cycles Per Degree
CTOA:	Cue Target Onset Asynchrony
MAR:	Minimum Angle of Resolution
N:	Noise
ROC Curve:	Receiver Operating Characteristic Curve
RT:	Reaction Time
S:	Signal
SOA:	Stimulus Object Asynchrony
SDT:	Signal Detection Theory

1. Introduction

According to William James (1890),

"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. Focalization, concentration, of consciousness is of its essence. It implies withdrawal from some things in order to deal effectively with others, and *is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreutheit in German"*(James, 1890).

In this chapter I briefly review a few aspects of attention.

1.1 Introduction to Visual Attention

The origin of the word attention is a Latin word "attenti" (Itti, Reese & Tsotsos, 2005). Attention involves cognition to extract relevant information from the environment and process it. "Activating" attention to detect a target, "orienting" attention to "suppress" irrelevant stimuli at all unattended locations by "locking" attention at the point of interest are essential components of attention (Downing & Pinker, 1985, Hung & Ciuffreda, 2002, Posner, Walker, Friedrich & Rafal, 1987, Rafal & Posner, 1987, Steinman & Steinman, 2002, Yantis & Jonides, 1984). Other essential components involve the ability to "maintain attentional focus" at a point and later "disengage" to resume information processing anew at a different location (Hung & Ciuffreda, 2002, Mackeben & Nakayama, 1993, Nakayama, 1990, Ratcliff & Morrow, 1988).

1.2 A Short Historical Overview of Visual Attention

Though minimally discussed in the initial history, some eminent scholars like Aristotle, Lucretius, and Descartes, observed and reported the existence of attention(Hatfield, 1998, Itti et al., 2005). It was in the 1st century BC when direct attention and "enhanced clarity" of a perceptible target associated with keen examination, were first reported by Lucretius (Hatfield, 1998). Hobbes (1655) had claimed that it is not possible to engage a pre-occupied sense organ with other to obtain two different images from the action of both (Itti et al., 2005). It was Herman Von Helmholtz who experimentally showed an independent existence of attentional and ocular focus, for the first time, with the point of attentional focus being equally efficient like the fovea (Hatfield, 1998, Wright & Ward, 2008). Hering, on the other hand, proposed a contradictory theory that claimed a possibility to attend two points simultaneously at a moment, one at fixation and other at attentional focus (Itti et al., 2005). The complex relationship between focused attention and eccentricity at the attended locations are important areas of recent studies (Cameron, Tai & Carrasco, 2002, Carrasco & Frieder, 1997, Carrasco, Penpeci-Talgar & Eckstein, 2000, Carrasco & Yeshurun, 1998).

Titchener believed that attentional focus enhanced the clarity whereas Kulpe thought it to be discriminability (Titchener, 1908, Wright & Ward, 2008). Wundt (1874) claimed attentional focus was dependent on the observer's levels of consciousness (Kohonen, 2002). Wolfe (1740) established that the spatial expanse of attention decreased with increased visual attention. With further research, Eriksen introduced the "zoom lens" theory (Eriksen & St James, 1986, Pashler, 1998). According to the zoom lens theory, the center of the attentional focus worked as a zoom-lens with highest efficiency with a voluntary and variable spread of attentional focus (Eriksen & St James, 1986).

1.3 A Brief introduction to Broadbent's model of Attention and Feature Integration theory

A number of studies concentrated on the field of attention, based on auditory signals, were started in the middle of this century. The field of visual attention is vast and a lot of models have been introduced and discussed (Broadbent, 1958, Broadbent, 1982, Bundesen, 1990, Grossberg, 1975, Grossberg, 1976, Shiffrin & Schneider, 1977, Treisman, 1969, Treisman & Gelade, 1980, Wolfe, 2003, Wolfe, Cave & Franzel, 1989). The discussion here is confined to the Broadbent's model and the Feature Integration Theory due to the scope of the experiment (Broadbent, 1958, Broadbent, 1982, Treisman, 1969, Treisman & Gelade, 1980)

Poulton and Cherry introduced the first model of information processing where concepts of selective attending and shadowing were discussed (Cherry, 1953, Poulton, 1953). The data from the experiment by Poulton and Cherry was analyzed by Broadbent and the first comprehensive model of attention based on the behavioral data was introduced (Broadbent, 1958, Pashler, 1998). The concepts of serial and parallel search and a filtering "bottleneck" were discussed in this model (Broadbent, 1958, Hung & Ciuffreda, 2002). Stimulus at a given time were claimed to be processed in parallel. The information stimulus is differentiated on the basis of its physical features. The stimulus information is retained for sometime before processing after it enters the sensory buffer. The successive input being temporarily retained in the buffer, the preceding stimulus input goes through the filter. The stimulus that doesn't pass through this filter is lost at this point from the processing system (Broadbent, 1958, Hung & Ciuffreda, 2002). The filter, allowing one stimulus at a time, aids a smooth working of a limited capacity mechanism system (Broadbent, 1958).

A "breakthrough" of selective unattended stimulus through the filter was later reported in some studies which was not consistent with Broadbent's findings

(Moray, 1959, Wood & Cowan, 1995). Broadbent later proposed a "modified theory of attention" wherein he introduced a term "pigeon holing" to discuss the "break through" through the filter selective for blocking unattended stimuli (Broadbent, 1981, Broadbent, 1982, Styles, 2006).

Treisman studied unattended stimulus and introduced a simple model of visual attention consisting of a pre-attentive and an attentive stage (Treisman, 1969). The model consisted of a filter to reduce the effectivity of the unattended stimuli. The pre-attentive subsystem was considered to have unlimited processing capacity as stimuli in this level underwent parallel processing. This maintained the system efficiency, irrespective of the number of display items (Treisman, 1969). The results from her model showed inconsistency with Broadbent's model by registering some unattended stimulus selectively and indicated the presence of a parallel processing at a later stage than what Broadbent proposed (Styles, 2006, Treisman, 1969). This was followed by the introduction of the late selection models.

Treisman with Gelade had also introduced another model, "The Feature Integration Theory" that discussed focused attention (Treisman & Gelade, 1980) This model had a pre-attentive serial processing stage following an parallel processing automatic stage. It claimed that targets that differ in multiple dimensions like color, shape, size, etc., i.e. conjunction targets required serial processing. Unlike the automatic stage, in the serial processing stage each item in display underwent processing one by one leading to an slower processing with increased number of items in display (Treisman & Gelade, 1980).

Deutsch and Deutsch introduced a late selection model and they claimed that after complete processing of the stimulus, only the most significant information is selected. The level of signals determines which signal is most significant. Late selection models are also proposed by Duncan, Norman, Moray and Mac Kay (Deutsch & Deutsch, 1963, Duncan, 1980, Itti, Reese & Tsotsos, 2008, Moray & O'Brien, 1967, Norman, 1968, Styles, 2006).

1.4 Overt and Covert Attention

Attention can be oriented either by looking directly at the target (Overt attention) or without looking towards the target, i.e. no visible movement of the head and gaze (Covert attention) (Posner, 1980). James (1896) and Mackeben and Nakayama (1989) discussed the possibility of orienting attention without eye-movements i.e. covert attention (Itti et al., 2005). Wundt (1874) mentioned that knowledge about the target location, enhances the reaction time (Wright & Ward, 2008, Wundt, 1874, Wundt, 1912).

A typical experiment involving "covert attention" usually includes cues around a central fixation point for foveal fixation (Posner, 1980). A pre-cue precedes the target display. The delay between the cue and the target display is the cue-target-onset-asynchrony (CTOA) (Posner, 1980). A CTOA less than 220ms is significant as this is the minimum time required to program and carry out a regular saccade (Fischer & Ramsperger, 1984, Fischer & Weber, 1993).

1.4.1 Endogenous & Exogenous cues

The cues to a target may be either symbolic or direct so that they result in a voluntary or involuntary orienting of attention respectively.

1.4.1.1 Direct cues

Direct cues are presented either as underlines, outline or flickering boxes or a bar at the expected target location. It is also known as stimulus driven cue, extrinsic-cue (Jonides, 1981), involuntary-cue (Milner, 1974) or exogenous-cue(Jonides, 1981). This causes a target location to be registered due to the conspicuous cues at the target location. Therefore, the cue drives attention to the required target location, resulting into a "bottom-up" effect (Posner, Snyder & Davidson, 1980). The bottom-up attention effect can result only if there lays a salient item within distractors.

1.4.1.2 Symbolic cues

These are central arrows that point towards the target location. These are also known as central-cues, intrinsic-cues (Posner, 1978), voluntary-cues (Milner,

1974) or bottom up or endogenous-cues (Jonides, 1981). Cognition is essential for efficiently identifying the target location and thereby executing a task as the cue simply points towards the target location (Jonides, 1981). Therefore, the symbolic-cue results in a "goal driven" or "top-down" (Posner, 1978) attentional shift. Though validity of a cue are found to enhance the reaction times and accuracy, these cues can completely ignored intentionally by an observer, unlike an exogenous cue (Jonides, 1981). The maximum effectivity of a symbolic-cue is at a cue-target-onset-asynchrony (CTOA) of 300ms that sustains up to 2sec (Muller & Findlay, 1988, Wright & Ward, 2008). The efficiency of sustained attention depends on observation and therefore differs for each individual (Hatfield, 1998). The efficiency of both goal and stimulus driven processing is directly related to the levels of consciousness and awareness of an observer (Jonides, 1981, Muller & Rabbitt, 1989, Posner, 1978). The goal and the stimulus driven cues can be presented as three different kinds of cues to direct attention towards the target location. A cue is valid/ correct when the target appears at a cued location, invalid/ wrong when the target appears at a zone other than where the cue points to, and neutral when the cue gives no clue. A neutral cue is essential as a baseline data to compare data from cued trials and a cost benefit analysis (Wright & Ward, 2008). It can also be used as a warning that the target is about to appear (Fischer & Ramsperger, 1984). A valid-cued trial always generate a faster response (Eriksen & Hoffmen, 1972a, Eriksen & Hoffmen, 1972b) as it promptly shifts attention to the cued locations, thereby indicating a benefit in the cost-benefit analysis and increased accuracy(Bashinski & Bacharach, 1980, Henderson, 1991). An invalid cue points to a wrong target location leading to a system realignment, thereby resulting in a higher target detection time (Posner, 1978).

1.5 Conclusion

From a moment of initial focusing at a point of interest, registering it and then resuming focus at another point, attention plays an essential part. Attention plays an essential component of vision without which there will be no directionality of vision.

Though minimally discussed in the initial history, some eminent scholars observed and reported the existence of attention. The experimental phase began following the first experiment by Cherry and Poulton using auditory stimulus in 1953. Broadbent analyzed the data from this experiment to introduce the first behavioral model of attention. Soon, a series of experiments by various researchers followed and Treisman introduced her model of attention. This model, like a few other models of that time, did not exhibit consistent results with the predictions of Broadbent's model. Triesman's model indicated the presence of the parallel processing at a later stage than that predicted by Broadbent. Broadbent introduced a modified model of attention in 1980. Treisman and

Gelade introduced a modified model with a pre-attentive and an attentive stage involving a parallel and a serial processing respectively. The serial processing, unlike the parallel processing involved one by one analysis of the target features, and thereby was affected by the increased number of targets in display. Attention can be classified as covert and overt attention based on eye/ head movements involved during orienting attention towards a target. In case a target location is known, reaction time for both covert and overt attention is enhanced. The location can be indicated with cues. Based on the location of a cue, the cues were classified as exogenous and endogenous. The cues when valid enhance responses, whereas invalid cues decline performance in any experiment involving visual search.

1.6 Thesis Objectives

Previous studies using transient cues have indicated the presence of an "eccentricity effect" for targets presented in the peripheral visual field. Sustained cues have not been extensively used in such studies. In this thesis I will study visual attention using sustained cues up to a visual field eccentricity of 40degees. The experiments will be conducted using neutral, valid and invalid cued conditions for different set-sizes.

To summarize, this thesis will facilitate a better understanding of the mechanisms of sustained visual attention in the central and the peripheral fields by providing answers for the following questions:

1. How does visual attention change in central and peripheral fields?
2. How does the contrast affect visual attention?
3. Do cue and its validity make any difference?
4. Does set-size affect visual search?
5. Can the results be validated with the Theory of Signal Detection?

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2. Methodology

2.1 Study design

The experiment(s) were psychophysical tests to analyze the capacity of the central and peripheral retina to detect and discriminate between the presented targets. This prospective study had six participants. The study was cleared for ethics by the Office of Research Ethics at the University of Waterloo for all experimental protocols. The nature and purpose of the study was explained prior to the experiment to every participant.

2.2 Study Participants

Six participants were recruited from the graduate and undergraduate student community and the ages ranged between 16 - 30 years. There were four females and two males. The average age was 27.5 years.

2.3 Inclusion and Exclusion Criteria

The study demanded participants to have best corrected visual acuity (BCVA) of 1MAR and normal contrast acuity. Exclusion criteria were presence of any ocular disease or degeneration, history of corneal refractive surgery and systemic or topical medications that may affect attention.

All participants were recruited using standard protocols for enrolment of normal subjects with normal general health. These included a detailed history, thorough vision assessment with LogMar chart and contrast acuity with a Vistek® chart and a slit lamp examination to rule out any ocular disease.

The participant within the inclusion criteria was provided with an introduction / enrolment form, with a designated number. An information and consent letter was also given to each participant.

2.4 The Experiment

All tests included only the right eye of the participant. The viewing distance of the monitor was set at 25cm. A chin and headrest with a band was provided to keep the head stable and to avoid undesired movements. The monitor was enclosed within a black box with its sides extending up to the chinrest to limit the visual field to a 40deg radius from the point of fixation. This also limited the extraneous light falling on the monitor in order to enhance the display and to minimize stray light noise and glare.

The experiment involved covert attention and therefore, a fixation point was provided at the center of the display and fixation was continually monitored with a webcam.

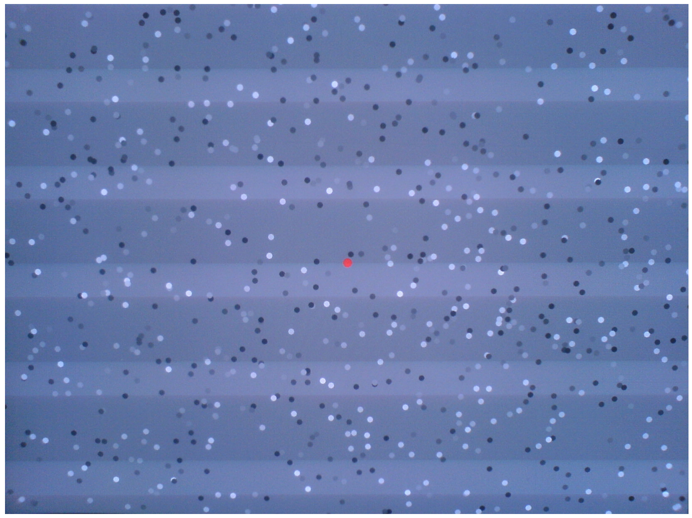

Figure 2-1: The display screen with the central point for fixation.

2.4.1 Procedures for data generation

The experiment involved two out of the three procedures of the theory of SDT. The participants underwent practice trials in the first 2 or 3 sessions, of 1 hour duration, until the responses were consistent. An experiment with a small sample size demand consistent data for analysis from the participants. Therefore 2-3 sessions of practice experimental trials were essential in order to minimize learning effects, monitor the false alarms, fixation losses and response variability.

2.4.2 Yes/No Procedure

The yes/no procedure involve a long series of trials, usually greater than 300 trials in each session, in which observers must register the presence or absence of the signals in each trial. The trials have a combination of noise (N) or noise added to a signal (SN). Each trial of the experiment begins with an indicator such as a sound, cue, etc. and the observer also knows the proportion of signal-noise and signal in the display trial-set. The Yes/No method also facilitates plotting a Receiver Operating Characteristic (ROC) curve with the proportions of hits and false alarms obtained at different criterion locations.

2.4.3 2-Applied- Force- Choice (2AFC) procedure

The method for the target display for this experiment was a combination of Yes/No and 2AFC. The random presentation of targets has been claimed to be efficient in reducing bias in responses (Ulrich & Miller, 2004). The 2 AFC process proves to be an ideal method to assess sensitivity since it is independent of criterion fluctuations. This procedure can efficiently estimate both absolute threshold for a detection task and difference threshold for a discrimination task, thereby resulting in a high-level of performance. A 2AFC discrimination task uses 2 stimuli, one as a baseline and other comparison. Each of the targets is presented randomly in each trial. The comparison stimulus differs from the baseline in a particular parameter (Ulrich & Miller, 2004). The observer has to report the presence or absence of the target in each trial and, therefore the observer's criterion effects are reduced compared to that in a Yes/No experiment. So, this can be used as a measure of sensitivity.

A 2 AFC Fixed Stimuli Methods cannot separate the sensory and attentional effects which is possible with a Yes/No Method. The Yes/No Method is based on subjective criterion. Thus, a combination of a 2-AFC method and the Yes/No method may be necessary in order to differentiate genuine sensitivity effects from both attentional effects and criterion effects (Skoyles & Skottun, 2008).

2.5 Display set-up

2.5.1 The computer monitor display settings

The experiment was programmed on Matlab (The MathWorks, Inc.) and the display and data collection was achieved using the Generator Cambridge Research System – Visual Stimulus Generator (CRS Ltd.). The target was displayed on a Sony Trinitron monitor with a refresh rate of 100fps and resolution 1280x780 pixels. The standard display was a grayscale background with 1000 scattered, static random dots. The monitor with the "standard display" was calibrated daily before starting the experiment with a photometer to 53cd/m^2.

2.5.2 Field of target display – the useful field of vision

The visual field to be studied was chosen on basis of the useful field of vision (UFOV®). The operational definition identifies an eccentric field within 35 degree as the useful field of vision. While stationary, one uses only near peripheral vision, i.e. 20° - 35° radius field from fovea. (Ball & Owsley, 1993, Owsley, Ball &

Keeton, 1995) Though experiments involving cortical magnification measurements have been done beyond 40deg periphery, but visual attention experiments cues have not been done up to a 40 degree eccentricity (Carrasco & Frieder, 1997, Carrasco & Yeshurun, 1998, Rovamo, Virsu, Laurinen & Hyvarinen, 1982). This study extends the measurement of visual attention for a useful field of vision of 40 degrees.

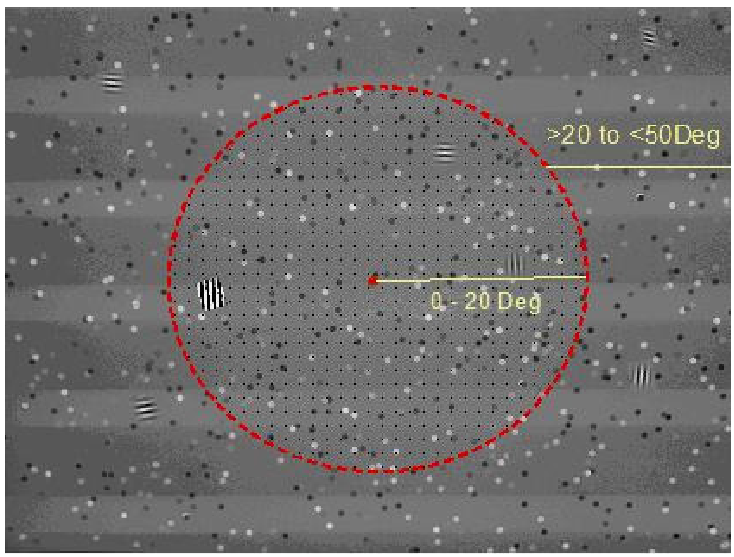

Figure 2-2: Central and Peripheral
Field Distribution on the monitor

The visual attention fields of the eyes are circular. Therefore, visual field was divided as four imaginary concentric circles set at 10°, 20°, 30° and 40° from the red fixation point at the center of the monitor. The targets were then randomly presented between the imaginary rings in central 0° to 20° from fovea and >20° to <50° in the visual field (Figure 2-2). The design of presentation of targets was similar to the one used by Eimer (2000). The responses in his experiment were consistent with the zoom lens model (Eriksen & St James, 1986) of visual attention and predicted that the central rings are included in the attentional focus if the outermost ring is attended (Eimer, 2000).

The targets in the central zone underwent testing five times at five random central locations and four times at eight random locations in the peripheral zone. The responses were considered valid only when the response was correctly registered 3 times or more. The target was displayed as a loop of **6** frames.

2.5.3 Frames and features

The frames included provision for a red dot for fixation at the center to impose a "fixed viewing" condition and respond to targets displayed at random locations in the monitor without moving the eyes, i.e. using "covert attention". Alerting, orienting and search for target detection are essential functions of attention (Posner, 1980). The entire set of frames presented had a set of random dots with a fixation spot. The display monitor with the randomly scattered random dots acted as a cluttered display on which the targets appeared. The background display was cluttered with either 500, 1000 or 2000 random dots.

2.5.4 Fixation and Ready-alert frame

Ocular fixation helps in forming the target image at the fovea, i.e. "foveation". The visual analysis involving hyper-acuity occur fundamentally at the fovea but peripheral retina responds mostly to detection of motion, brightness changes and sudden appearance of new objects.

Frame No.	Purpose	Target Shown over the background	Duration
1.	Fixation	●	3000 ms
2.	Ready	+	500 ms
3.	Cues	↑←↓→	60 ms
4.	Post cue	No target	60 ms
5.	Target	Conjunction target	100 ms
6.	Response	Nothing	1000

Table 2-1: Display slides in each trial

The first screen had a central circular (●) fixation spot of 0.50° angular subtense to maintain fixation at all times during the experiment. The observer had to look straight towards the dot with the right eye at all times during the test. Fixation was monitored with a webcam to ensure no ocular movements. Due to the foveal-fixation on the red spot in the center, the other points on the monitor corresponded to fixed retinal locations. It was followed by the second frame for

500ms to alert the observer that the target was about to appear. At this point the central circular target changed into a plus (+) sign.

The third frames displayed the cue for 60ms followed by the fourth frame. The fourth was a blank "post-cue" frame of 60ms duration. These two frames were used only with the experiments involving cued targets. As mentioned in section 1.4, cue target onset asynchrony (CTOA) if restricted to <220ms prevents any saccadic movement by the observer to view a peripheral target (Fischer & Ramsperger, 1984, Fischer & Weber, 1993).

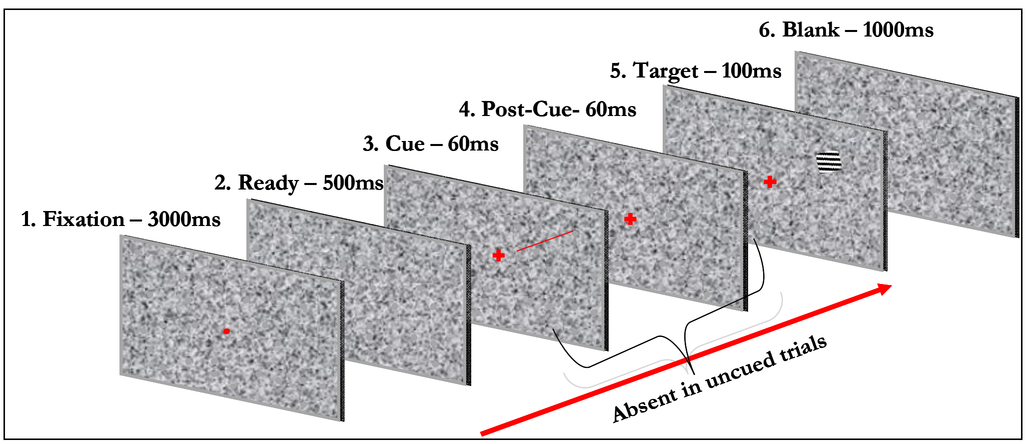

Figure 2-3: Frames in order of display on the monitor

Effect of a goal-driven attention is maximal when the time between the cue and target onset known as the cue target onset asynchrony (CTOA) is 300ms and it increases further up to an increase of CTOA to 2 sec (Wright & Ward, 2008). The effect of a cue is directly proportional to the validity for symbolic cues (Muller & Rabbitt, 1989, Posner, 1978).

The cues used for the experiment were neutral, valid and invalid. The neutral cues provided no information about the target location, the valid cues correctly guided the observer to the targets and the invalid cues wrongly indicated the target direction that caused a delay in detection of a target. Targets cued by symbolic cues have been found to improve performance by efficient allocation of the processing resources towards the target location (Gottlob, 1999, Jonides, 1981, Lambert, Spencer & Mohindra, 1987). The drawback of using symbolic cues is that these can be ignored intentionally when found to be misleading (Jonides, 1981, Krose & Julesz, 1989, Muller & Humphreys, 1991). Therefore the cues were set as 75% invalid and 25% valid cues, i.e. 1 out of 4 cues were valid. This was done to keep the observers attending to the cues. The fifth frame was displayed for 100ms and contained a Gabor patch. The target for every trial was randomly picked from an array of Gabor patches of type1 and type2 targets discussed under Types of targets section 2.8.

The sixth frame was the response frame, a blank frame that was displayed for 1000ms. The observer had to detect the orientation and register the response quickly else after a lapse of 1000ms the computer automatically considered the target as not seen. Once the response was registered the observer was again led to the first frame.

2.6 Target design

The target for detection and discrimination was a Gabor patch, a sinusoidal grating enveloped by Gaussian window. It is close to a target in the natural visual environment because unlike the sharp visible edges of a square target, which results in the presentation of high spatial frequencies, it has fuzzy edges that merge with the background.

Stimuli are primarily processed on account of functionally independent dimensions, e.g. color, size, shape, etc. (Bashinski & Bacharach, 1980, Nakayama & Mackeben, 1989, Posner, 1980, Posner, Snyder & Davidson, 1980). "Dimension" of a target can be described as its independent attribute i.e. physical characteristics and "feature" represents an amount of that characteristic i.e. a value on a dimension (Treisman, 1969). In this experiment size, contrast and orientation are the "dimensions" and the various MAR values of sizes, percentage of contrast and orientations as 90 and 180 are the features. Attention combines the various features of a target and helps to perceive it as a single object (Treisman & Gelade, 1980).

2.7 Target Parameters

The targets in this experiment were conjunction targets, i.e. targets with a combination of three different "dimensions" which are the physical characteristics of a target namely size, spatial gratings, grating orientation and contrast. Each dimension was then split as five different "features" which are values for each dimension on a scale. Therefore, targets were combinations of [5 Size x 5 spatial-gratings x grating orientation x 5 contrast].

2.7.1 Spatial Frequency and Contrast

Detection and discrimination are the two major tasks performed by the visual system. To detect a grating it is essential that the gratings can be resolved. The contrast sensitivity function (CSF) for a human observer has the highest sensitivity and is in the mid spatial frequency range. Sensitivity drops off steeply for the high spatial frequencies, therefore, with the higher spatial frequency the visibility of a target drops (Atchinson & Smith, 2000). Moreover, towards the periphery the sampling rate of the retina drops down due to its anatomical/physiological characteristics. The optical interpretation of a grating by the visual system is accurate, but the under sampling of the retinal image can cause retinal aliasing thus resulting in the perception of a lower frequency (De Valois & De Valois, 1988, Pointer & Hess, 1989, Robson & Graham, 1981).

2.7.2 Grating orientation

The central vision acuity and resolution are better for horizontal and vertical than oblique orientations (Atchinson & Smith, 2000), known as the "oblique effect". The oblique effect is significantly reduced at eccentricities of 8 to 18 degrees (Campbell & Maffei, 1974, Maffei & Campbell, 1970) and beyond this eccentricity, the meridional resolution effect takes over (Berkley, Kitterle & Watkins, 1975). At 25 to 30 degrees the resolution limit is found to be two times higher for horizontal gratings compared to vertical and oblique gratings (Rovamo et al., 1982). To avoid a profound oblique effect, 180deg and 90deg, i.e., horizontal and vertical, orientations for spatial gratings were chosen.

2.7.3 Size of the target (Visual Angle/ Minimum angle of Resolution)

The visual angle subtended at the fovea by a target determines its resolution. Resolution performance declines as we move to the peripheral visual field. However, foveal and peripheral performance can be equated by compensating the peripheral stimulus with a cortical magnification factor in order to balance the decrease in sampling density towards periphery (Hubel & Wiesel, 1968). Peripheral magnification rate, expressed as $E2$, is extremely variable depending on the task (Rovamo & Virsu, 1979), therefore, no cortical magnification correction was considered for the targets in the experiment.

The target size was designed to be viewed at 25 cm. The target parameters were:

S. No	Gabor gratings	Contrast	Size (Visual Angle)
1	1 CPD	20%	1.5
2	5 CPD	40%	3
3	10 CPD	60%	4
4	20 CPD	80%	6
5	29 CPD	100%	10

Figure 2-4: Target Parameters

2.8 Types of targets

The targets used for the experiment were split into two types depending on the dimensions that were used to obtain the conjunction target.

2.8.1 Type 1

This set of targets was designed with combination of five different spatial gratings and five sizes and two different orientations (Section 2.7). The contrast was constant for these targets.

2.8.2 Type 2

This set of the conjunction targets (section 2.7) was designed with combination of five different contrast levels, 5 spatial gratings, 5 sizes and two different orientations.

2.9 Target presentation

The observer looked for a pre-defined target presented between the distractors, which acted as clutter. Visual search was used for target presentation because it is the most common method to study visual attention.

2.9.1 Method of constant stimuli

The classical psychophysical methods that can be used for stimulus presentation are the method of constant stimuli, method of limits or method of adjustment.

The method of constant stimuli uses a set of more than 5 stimuli, with threshold located within 50% of the range. The lower end of the stimulus can almost never be detected and highest always detected. A minimum of 100 trials are essential in each session. The Yes/No responses help to a plot the psychometric curve that relates the physical stimulus to the sensation. This method with random target presentation can minimize the "errors of habituation" or "error of expectation" that are seen with the method of limits or the method of adjustment.

2.10 Experiment protocol for data collection

The study was split into different experiments on the basis of either type of targets, cue or the set-size.

2.10.1 Different cues

On the display monitor the target, followed by a pre-cue, was presented at a random location. A neutral, valid or an invalid cue directed attention to the desired location. The observer registered the responses in the different cued conditions.

Sustained cues can be intentionally ignored by an observer and that can affect the response data (Wright & Ward, 2008). Therefore, repeated instructions to voluntarily attend to the cues were provided to the observers. Moreover, to keep the observer actively and voluntarily attend to the invalid cues, valid and invalid cues were presented together in a proportion of 1:4 so that for every 4 trials, one valid and three invalid cues could be shown. It has been shown that partially valid cues also enhance attention, therefore such cues were also incorporated to study the effects (Krose & Julesz, 1989).

2.10.2 Different set-sizes

The display on the monitor was cluttered with random dots as distractors. The distractors with the target stimuli comprise a set-size, which was altered as 500random-dots+target stimulus, 1000random-dots+target stimulus, 2000random-dots+target stimulus and the experiment was done in cued, uncued and neutral cued conditions.

2.10.3 Different targets

The experiments with different set-sizes and cues were done for targets of type1 and type2 (see sections **2.8.1 & 2.8.2**) respectively.

2.11 Data Collection

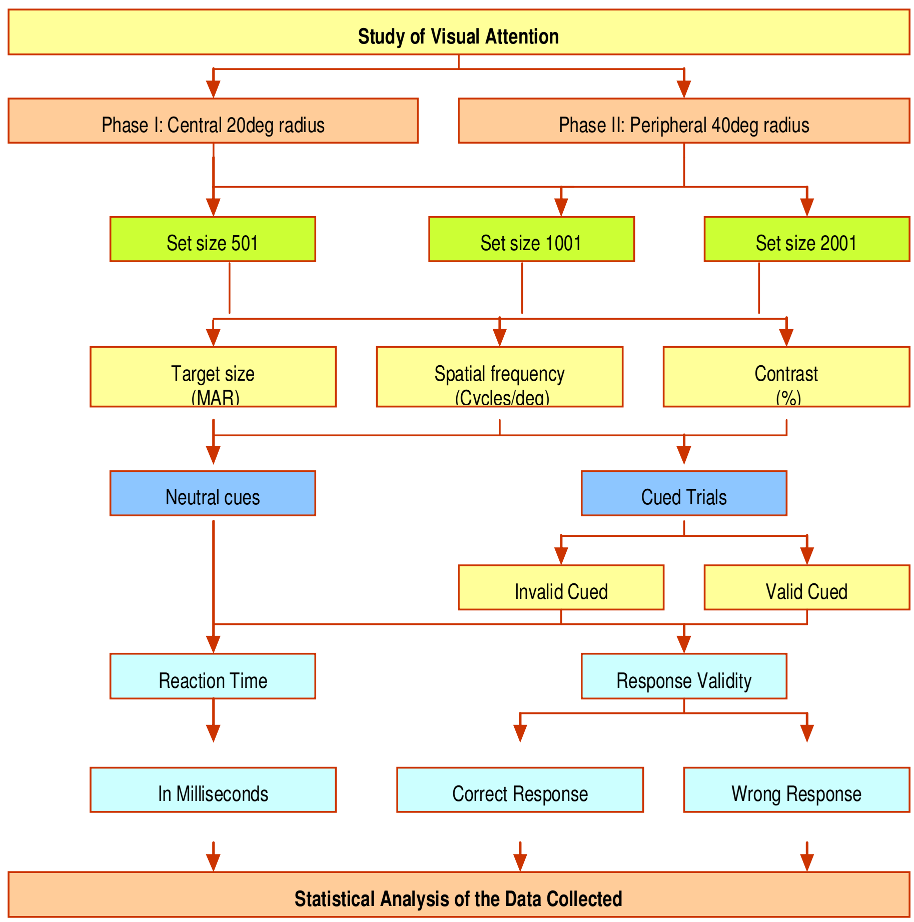

Figure 2-5: Flowchart of the protocol

Each session comprised of 300 trials and a keypad was provided to register the response. Once a target stimulus was presented, the observer responded as whether the target was detected or not-detected. If the stimulus was not detected, no button on the key-pad was pressed. It was automatically registered as undetected target and assigned a "-1". If the target was seen, the observer had to register the direction of grating orientation, vertical or horizontal and press the left button for the vertical grating and right for the horizontal one.

The response was then analyzed by the program and assigned a "0" for a wrong response, and "1" for a positive response. No feedback was given to the subject (in any condition) with respect to whether the response was correct or incorrect.

2.12 Data Analysis

2.12.1 Sample size considerations

All the experiments in this study included a very small sample size that required each observer to undergo a large number of trials.

All subjects included were trained observers from the vision science graduate student population. The reliability for data was tested for each subject by performing initial practice experimental trials until responses were found to be consistent for and within each individual for most trial sessions.

Data averaging and estimation of trends, done for such data can overrule to hide the significant but small and individual effects when the numbers of trials are less. This typically happens with a large sample size that involves fewer trials. A high intra-observer difference returns a considerably different pooled data compared to individual data (Movshon & Kiorpes, 1988).

2.12.2 Statistics

A response was analyzed in terms of its accuracy and reaction time. Reaction time was measured from the point when the cue was presented or the ready sign was flashed, up to the point when the observer pressed the button to register the target. It was measured in millisecond (ms). Accuracy was determined by targets correctly detected or not-detected.

Data analysis was done with Student's t-test, 2 or 3 way ANOVA and Bonferroni methods. The significance levels were set at $p<0.05$ for Student's t-test, 2 or 3 way ANOVA and <0.005 for Bonferroni methods respectively.

One of the experiments being small sampled, tests of analyzing inter observer trends, namely -Altman-Bland plot, linear regression plots and Correlation of Repeatability were used. The other test used was t-test with unequal variance to monitor mean reaction time difference that could indicate if there was a difference between the data from the two observers.

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3. Visual Attention as a Function of Eccentricity

3.1 Abstract

The aim of the study was to analyze the effect of the eccentricity, on visual attention, when targets were presented up to 47degrees eccentricity. The secondary aim was to study the effect of sustained attention and set size on the eccentricity effect. Four participants, with normal vision and contrast acuity, were included in this study. Targets were displayed on a Sony Trinitron monitor, with 100fps and 1028x780pixel resolution. Targets with 25 different combinations of visual angle and spatial frequency were presented at the central 20deg and peripheral 20- 40deg with and without sustained cues. The reaction times and accuracy were assessed. The presence of an eccentricity effect was confirmed with the significant difference between the reaction times and accuracy differences for the targets in center and periphery. The eccentricity effect was reduced significantly by the sustained cues but could not be completely abolished. The set-size had an effect on the visual search implying the presence of a serial processing involved for the conjunction targets.

Keywords: Visual Attention, sustained attention, attention, eccentricity.

3.2 Introduction

Foveal representation dominates both the lateral geniculate body and the visual cortex. It is due to losing gradual grouping of photoreceptors onto a single ganglion cell towards the peripheral retina unlike the one to one relation in the central field. (De Valois & De Valois, 1988) These large receptive fields at the peripheral retina result into a "lateral masking" that affects target detection because of multiple stimulus processing by the same receptor cell (Breitmeyer, 1980). Therefore, in case of a high display density, a marked set-size effect should be expected (Breitmeyer & Ogmen, 2000, De Valois & De Valois, 1988).

Errors and reaction time latency are shown to increase with presentation of a target at a more eccentric location in presence of transient cues (Carrasco, Evert, Chang & Katz, 1995, Wolfe, 1994). Symbolic cues help in voluntarily orienting attention and a valid pre-cue reduces reaction time whereas an invalid symbolic cue deteriorates performance (Posner, 1980). This is shown to result in a delayed reaction time for both sustained and transient attention (Eimer, 1997, Eriksen & Hoffmen, 1972a, Eriksen & Hoffmen, 1972b). Literature on attention predicts an enhanced performance with an optimally timed sustained cue (Jonides, 1981, Muller & Rabbitt, 1989).

The hypotheses of this experiment include existence of an eccentricity effect that results in high reaction time and errors with increasing eccentricity of a target, enhanced responses for valid cued trials and deteriorating performance with increased set-sizes, especially more to the peripheral field.

3.3 Methods

Four participants, 3females and 1male, with normal general/ocular health and normal visual acuity with LogMar chart and normal contrast acuity, with a Vistek® chart, participated in the experiment. The method of the target display for the experiment was a combination of Yes/No and 2AFC procedure.

The experiment was programmed on Matlab (The MathWorks, Inc.) and used with the Cambridge Research System – Visual Stimulus Generator (CRS Ltd.). The target was displayed on a Sony Trinitron monitor with a refresh rate of 100fps and at resolution 1280x780 pixels. The standard background on the monitor was a static, grayscale display with 1000 scattered random dots, which was calibrated everyday before the experiment to set it to 53cd/m^2 with Color Cal from Cambridge Research System (CRS Ltd.).

The visual fields were split as two imaginary concentric circles set as central 0° to 20° from fovea and peripheral >20° to <50°. Overall, 1425 random trials of Gabor gratings were displayed at random locations at the center and the periphery. Each point was tested 5 times at each of the 5 random locations in the center and 4 times in each of the 8 peripheral locations. A response was considered valid and counted as valid only if it was seen more than 50% of the time, i.e. a minimum of 3 correct responses at each location. The responses were analyzed for reaction time and accuracy.

The targets subtended visual angle of ranging from 1.5-10 arc-minutes. Contrast was 100% and the Gabor gratings varied as 1, 5, 10, 20 or 29cycles/degree were used.

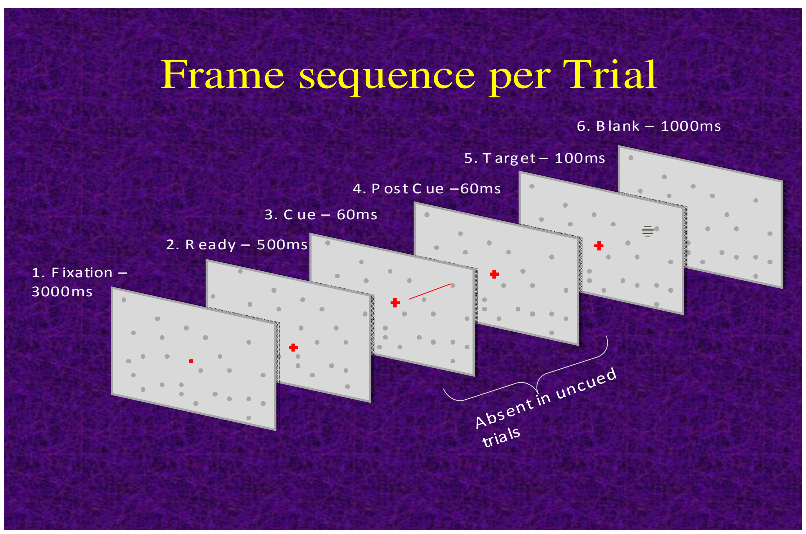

Figure 3-1: Presentation of trials

The trials were split into 250 trial blocks and presented over multiple sessions. Overall, 25 target combinations with variations in size and spatial frequency were used in the experiment. Then the experiment was repeated with valid and invalid cues with a standard static background with 1000 random dots and set-size was varied as 2000 and 500 random dots. The set-up included the display of slides as shown in Figure 3-1. The results were analyzed for effect of eccentricity, cues, set-size and target size on the reaction times and the errors.

3.4 Results

2.12.3 Effect of target eccentricity

The overall reaction time for the peripheral targets was higher than central targets. The mean reaction time was found to increase with increased eccentricity.

Analysis Category	Visual Field	Reaction Times on Standard Display 1000 random dots and Neutral cues
Reaction Time	Center	591.57
(ms)	Periphery	608.67
% Error	Center	29.45
	Periphery	37.32

Table 3-1: Observers mean reaction time and in center and periphery

The visual field was initially considered as central and peripheral visual fields. The mean reaction time for center was 591.58ms and periphery 608.67ms (Table 3-1). The number of errors significantly increased with more eccentric target presentation. The targets seen at all quadrants by the two observers were plotted. It was found that the least number of targets were seen towards the nasal/inferior visual field followed by the nasal/superior field. The difference between mean targets seen in the nasal and temporal fields was statistically significant using a student t-test.

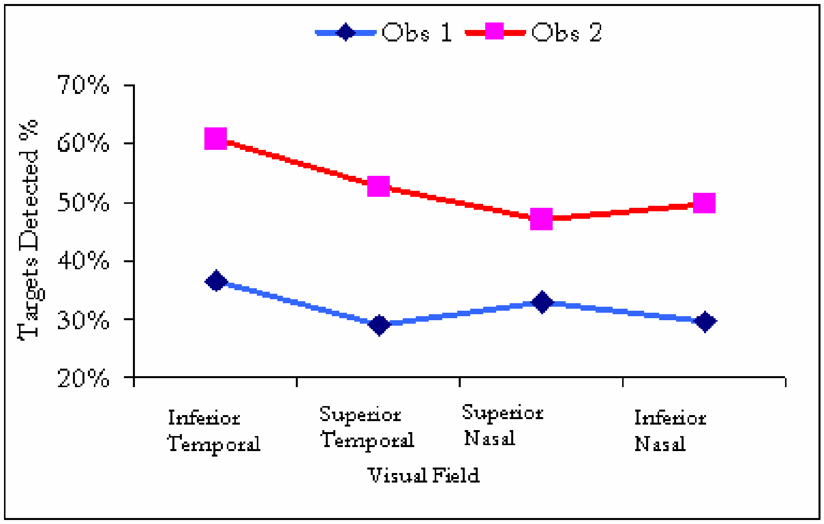

Figure 3-2: Target detection in the visual field in neutral cued conditions

Visual Field	Observer 1	Observer 2
Right Inferior Temporal	36	61
Right Superior Temporal	29	53
Left Superior Nasal	33	47
Left Inferior Nasal	30	50

Table 3-2: Percentage of Targets seen in the visual field in each quadrant

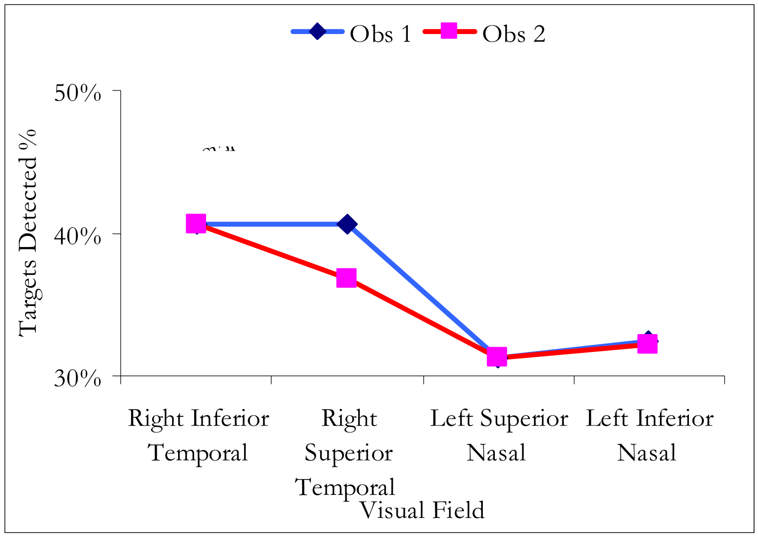

Figure 3-3: Targets detected in the visual field when presented with valid cues

3.4.1 Effect of cues and eccentricity

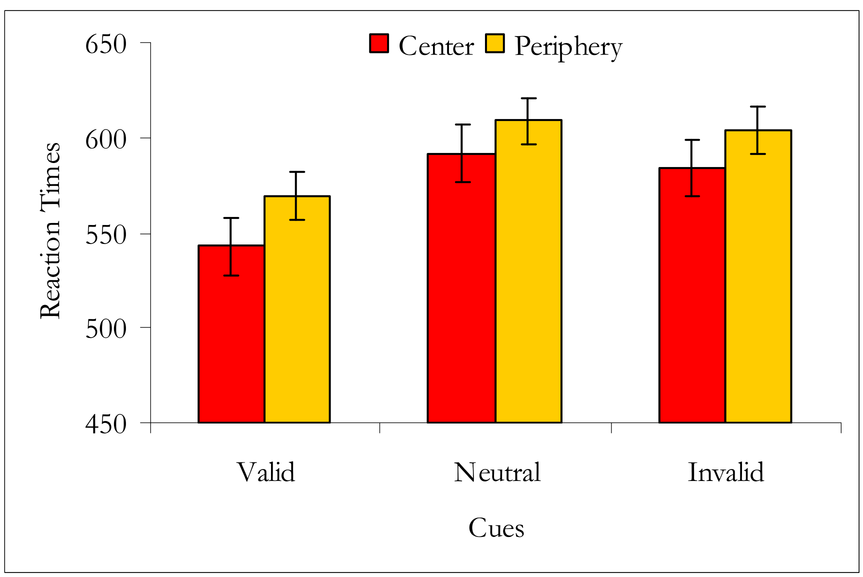

Figure 3-4: Observers Reaction time at center and periphery with cues

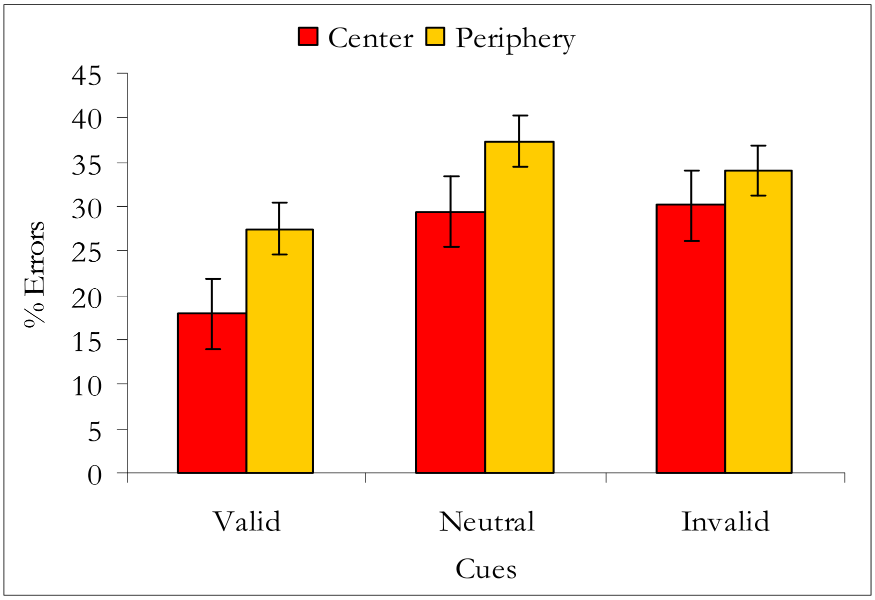

Figure 3-5: Observers Error% at center and periphery with cues

Analysis	Visual Field	1000-Valid cues	1000-Neutral cues	1000-invalid cues
Reaction Times	Center	542.91	591.57	583.99
	Periphery	568.92	608.67	603.68
% Error	Center	17.90	29.45	30.1169
	Periphery	27.53	37.32	34.06

Table 3-3: Mean reaction time in center and periphery with different cues

The overall mean reaction time and error for detected targets for valid-cued and invalid cued are shown in and based on eccentricity (Figure 3-4 and Figure 3-5). The valid cues significantly reduced the reaction times and the errors. The difference between reaction times, both for the valid compared to neutral cued and valid compared to invalid cued experiments, were statistically significant. In the overall field (0 -<50 degrees), the difference between the reaction time with different cues was analyzed. The average reaction time analyzed by splitting the field as central and peripheral also had significant p-values. (Table 3-4)

Zones	**Cues**	**Reaction Time p values**
Center	Valid and neutral	0.331
	Neutral and Invalid	0.307
	Valid and Invalid	0.709
Periphery	Valid and neutral	0.001
	Neutral and Invalid	0.049
	Valid and Invalid	0.0581

Table 3-4: P values for reaction time in center and periphery with different cues

Zones	**Cues**	**Responses P value**
center	Valid and neutral	<0.001
	Neutral and Invalid	0.917
	Valid and Invalid	<0.001
Periphery	Valid and neutral	<0.001
	Neutral and Invalid	0.068
	Valid and Invalid	0.003

Table 3-5: P values for correct responses center and periphery with different cues

Significant difference was seen between the mean reaction time for different cues in the peripheral zone, but not for the central zone. Therefore, the presence of the cue did affect an observer's response and reduce eccentricity effect. The difference between the correct responses associated with valid, invalid and neutral cued targets were significant with $p<0.05$ in all the cases, with the exception of the one in the central zone--proving that the cues do affect the response up to far periphery in the retina.

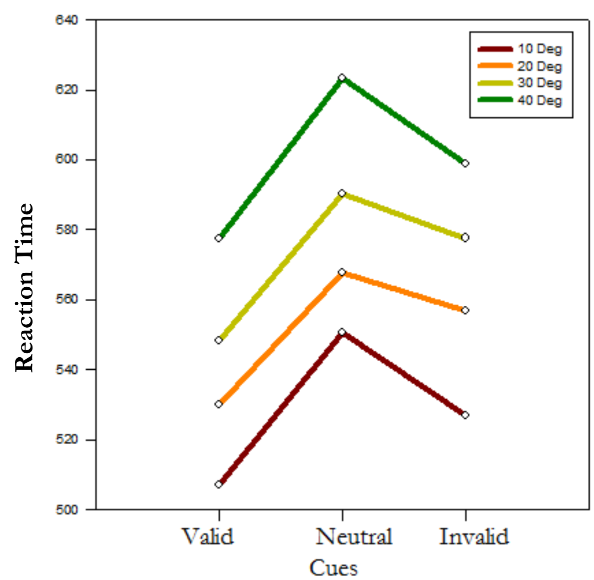

Figure 3-6: Cues and Eccentricity

A two-way ANOVA of reaction times, for the cue type [valid, neutral & invalid] x eccentricity [0 to <50] showed that the reaction times increased with cue validity [$F(2,24)=2.49, p>0.05$], and reduced eccentricity [$F(3,24)=3.86$, p<0.05]. There was no significant interaction between the cues and eccentricity, thereby suggesting that eccentricity and cues independently had effects on the reaction time.

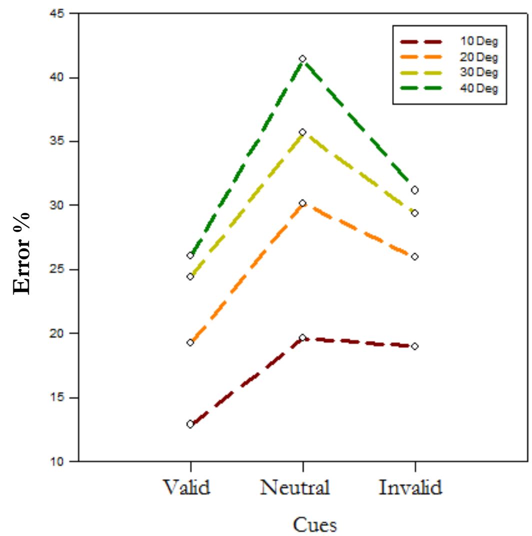

Figure 3-7: Error (%) Cues vs. Eccentricity

The two-way ANOVA for the errors also showed significantly reduced errors for cued targets as compared to the uncued targets and the main interactions were significantly related to each other. A two way ANOVA for errors, for the Cue type [valid, neutral & invalid] x eccentricity [0 to <50] showed significant reduction in errors with reduced eccentricity [$F(3,24)=3.08$, $p<0.05$ but not with cue validity [$F(2,24)=3.02$, $p>0.05$]. There was no significant interaction between the cues and eccentricity, thereby suggesting that eccentricity and cues independently had effects on the errors.

3.4.2 Search accuracy and time method to assess set-size effect

This method was introduced by Palmer in 1994(Palmer, 1994). The psychometric curves were plot based on visual angles and threshold was obtained for each set-size. For each set-size, the threshold was considered at 50% correct discrimination. On a log-log scale linear regression plots were obtained for set-size vs. threshold. The slopes had a very minute difference for the set-sizes.

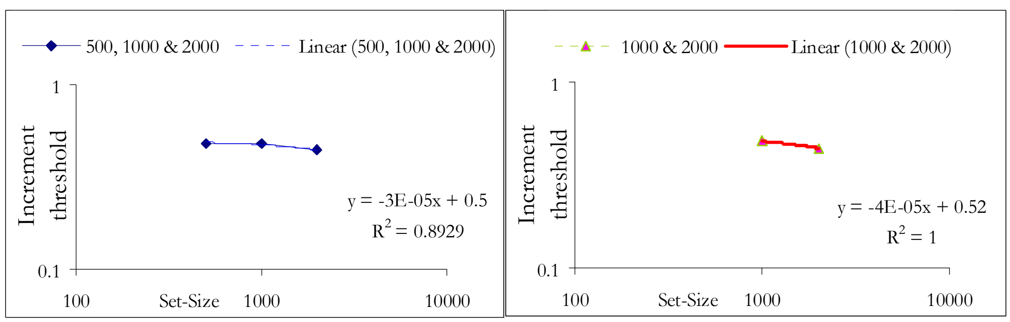

Figure 3-8: The slopes with different set-sizes

3.4.3 Effect of set-size with Eccentricity

The set size was varied as 500, 1000 and 2000 random dots on the monitor. The reaction time and errors were then analyzed as a function of eccentricity in each set size. Evident from Figure 3-9 and Figure 3-10, increasing set-size and eccentricity results in an increase of reaction time and errors. A two-way ANOVA for the effects of (set-size 500, 1000, 2000) x eccentricity (0 to <50) was done on the reaction time and the error. Reaction time reduced for smaller set-sizes [F (2,24)=24.21,p<0.05], and reduced eccentricity [F (3,24)=12.38, p<0.05]. The main effects had significant interactions.

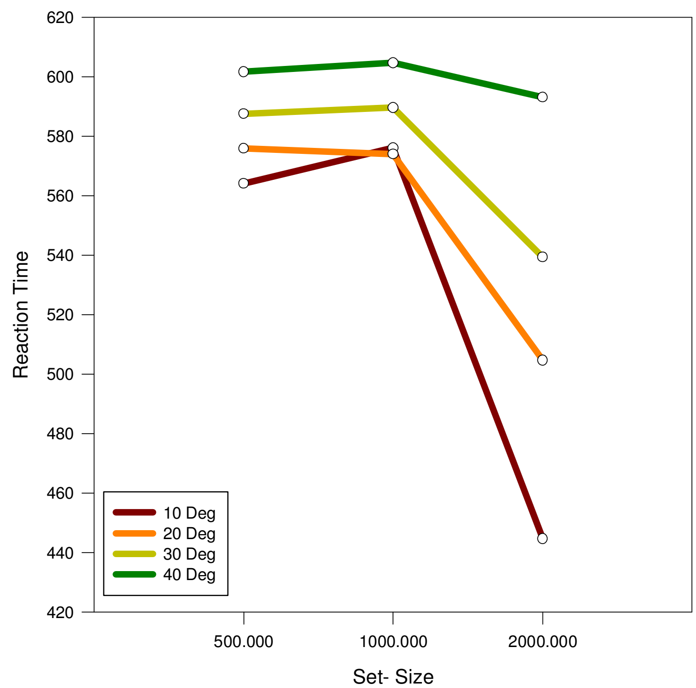

Figure 3-9: Reaction time Set-size and Eccentricity

Evident from Figure 3-9 and Figure 3-10, increasing set-size and eccentricity results in increase of reaction time and errors. A two way ANOVA for the effects of (set-size 500, 1000, 2000) x eccentricity [0 to <50]) was done on the reaction time and the error. Mean reaction time remained similar for the 500 and 1000 set-size but reduced for 2000 F (2,24)=24.21,p<0.05], and reduced eccentricity [F (3,24)=12.37, p<0.05]. The main effects had significant interactions.

The errors first increased with a higher set-size and later reduced with the set-size of 2000 random dots, F $(3,24)=27.7, p<0.05$], and reduced eccentricity [$F(2,24)=9.44$, $p<0.05$]. There was a significant interaction between the main effects, thereby suggesting that eccentricity and set-size had combined effects on errors.

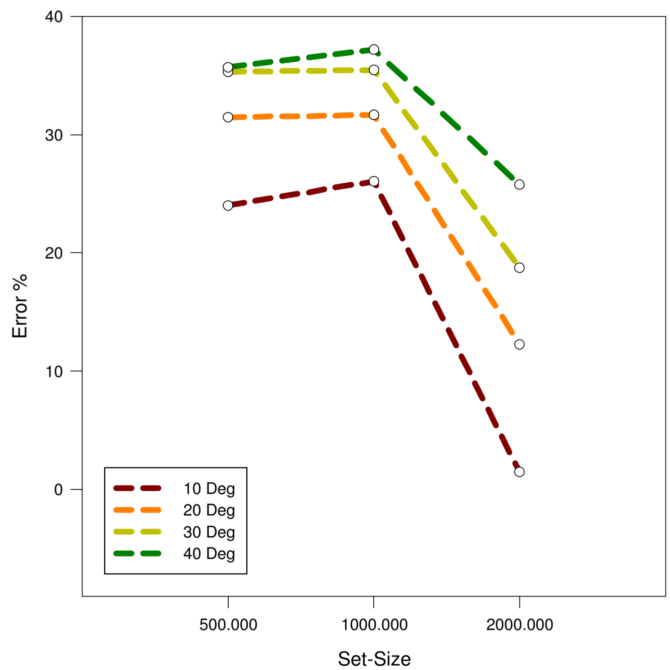

Figure 3-10: Error % Eccentricity vs. Set-size

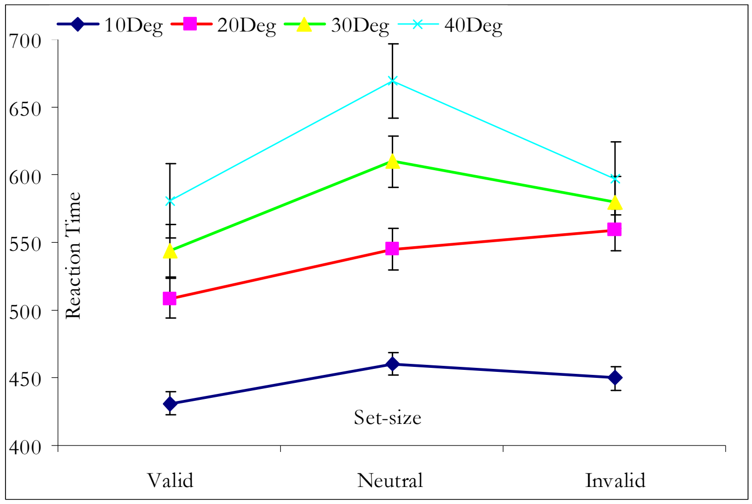

Figure 3-11: Reaction Time Distribution for set-size 2000 at eccentricities

The difference between the mean reaction times for central and peripheral targets in set-size 1000 and 2000 was significant with a t-test.

The reaction times for targets in a set-size 2000 were very low at the center and as the target got more eccentric, the reaction times got higher. Then the targets with neutral, invalid and valid cues were compared for the reaction times. It was found that for the neutral cued targets the pop-out effect was very marked.

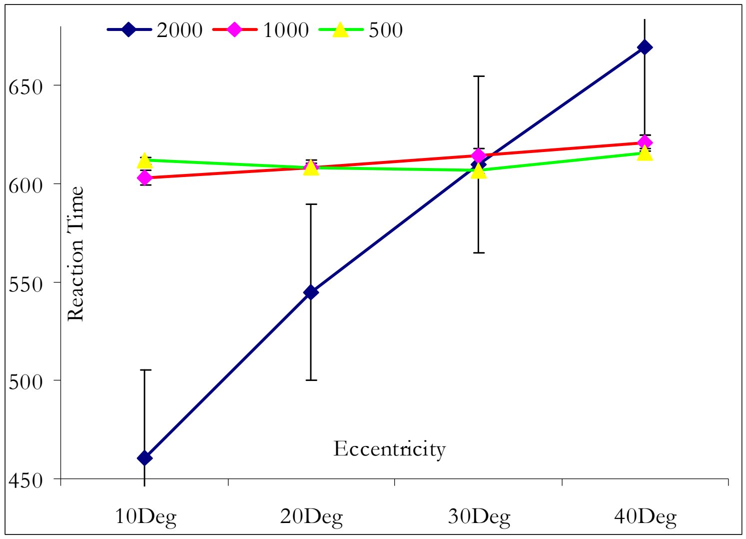

Figure 3-12: Reaction Time of Neutral cued targets in different set-sizes

This resulted as a very small reaction time and errors that rose steeply after 10 degrees eccentricity. (Figure 3-11, Figure 3-12, Figure 3-13, Figure 3-15) The targets in set-size 1000 and 500 did not show much variation in the reaction times and therefore the average reaction time was seen to be reduced for the 2000 set-size.

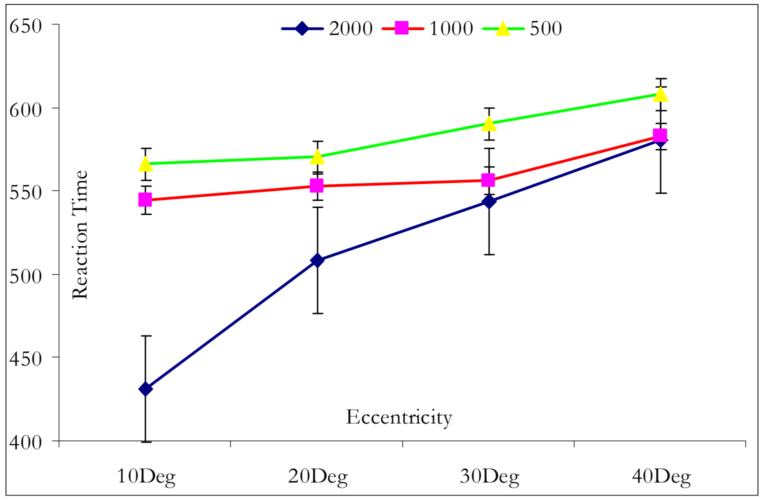

Figure 3-13: Reaction Time when targets presented with valid cues in different set-sizes

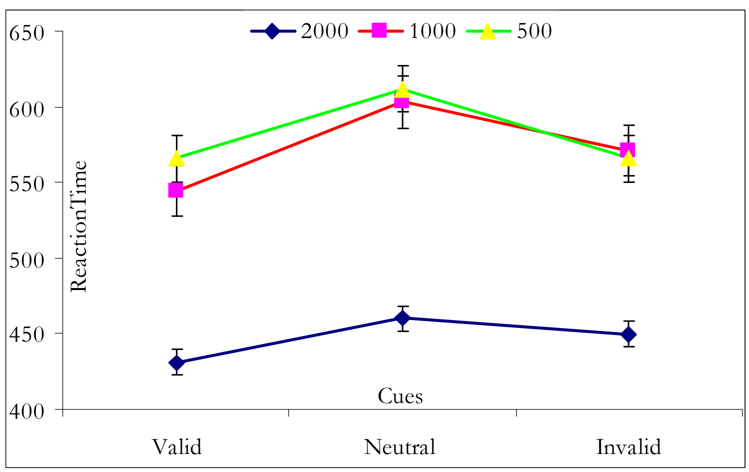

Figure 3-14: Reaction Time for different set-sizes with different cues at 10Deg

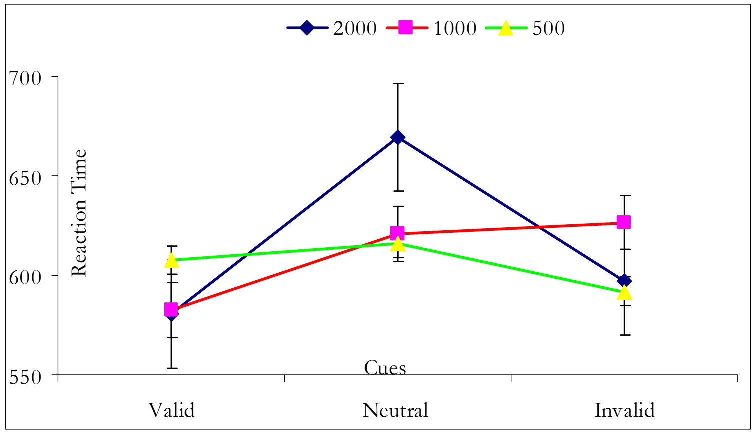

Figure 3-15: Reaction Time for different set-size with different cues at 40Deg

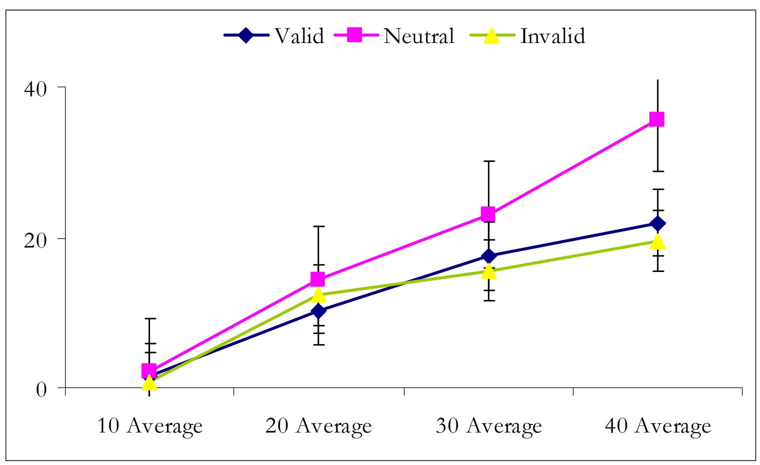

Figure 3-16: Error % with cues in set-size 2000

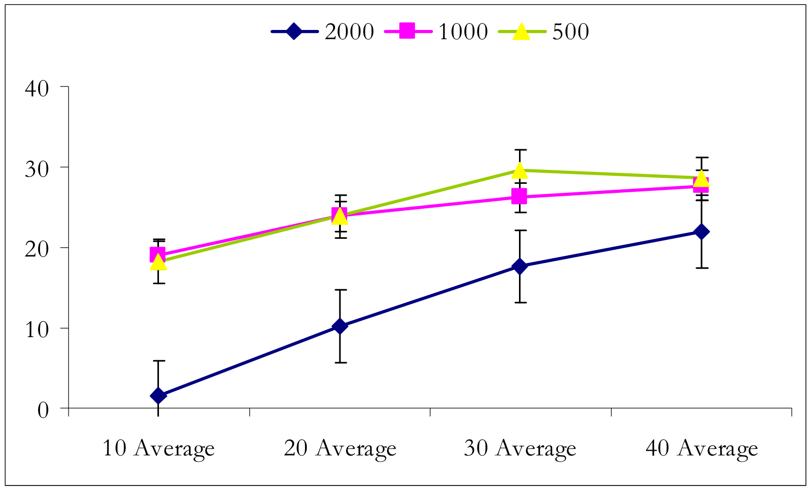

Figure 3-17: Error % with valid cues
in different set-sizes

3.4.4 Cue, Set-size and eccentricity effect

A three-way ANOVA (cue type [valid, neutral & invalid] x set-size [500, 1000, 2000] x eccentricity [0 to <50]) was computed to evaluate the effect of the pre-cuing cues on target eccentricity. Reaction time increased with smaller set-size [$F(2,12)= 86.4, p<0.05$], valid cues [$F(2,12)=28.5$, $p<0.05$], and more central presentation [$F(3,12)= 44.17$, $p<0.05$]. Main effects, set-size and cues had a significant interaction.

The three-way ANOVA for errors also was computed. There were fewer errors with valid cues [$F(2,12)=103.8, p<0.05$], larger set-size [$F(2,12)=350.45$, $p<0.05$], and more central presentation [$F(3,12)=119.5$, $p<0.05$]. As hypothesized, the number of errors decreased with valid cues.

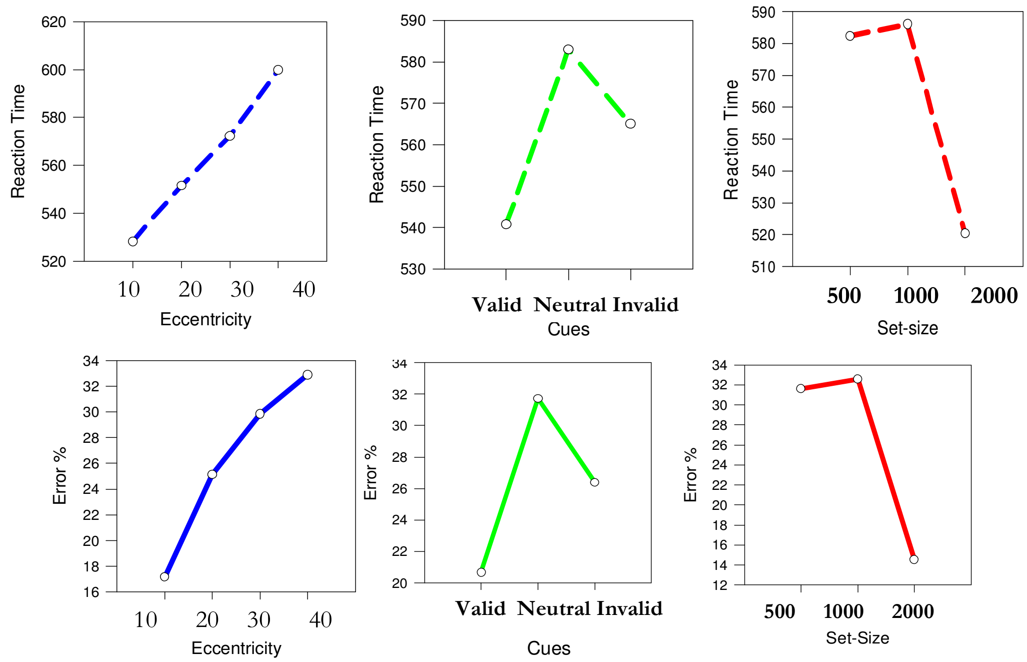

Figure 3-18: Mean reaction time & Error with valid, neutral and invalid cues x set-size x eccentricity

The errors were minimized for the largest set-size in presence of cues, showing the maximum benefit of cues in presence of increased clutter. No significant interaction was found between any of the main effects showing that all effects were independent of each of the main factors.

3.5 Discussion

3.5.1 Effect of eccentricity

Many researchers have studied the eccentricity effect and shown a reduction both in contrast as well as in acuity with a more peripheral presentation of targets (Duncan & Humphreys, 1992, Duncan & Humphreys, 1989, Treisman & Gormican, 1988, Wolfe, Cave & Franzel, 1989, Wolfe, O'Neill & Bennett, 1998). As expected, the reaction times and errors were decreased for cued targets especially with valid cues. Analysis of reaction time and accuracy showed reduced errors and reaction times associated with more central target presentation. With the targets presented more peripherally the reaction times and errors increased in a linear fashion. A significant difference in the mean errors and reaction times was seen at each level of eccentricity showing that with every additional 10degrees of target eccentricity, the responses become slower with increased inaccuracy.

The results in this experiment are in agreement with the results of sustained attention studies on eccentricity with event related potentials (ERPs) by Eimer (Eimer, 2000). Peripheral targets are detected more slowly and inaccurately in the periphery (Eriksen & St James, 1986). It has been shown in earlier research that attentional processing is most efficient at the central field compared to the outer peripheral field (Andriessen & Bouma, 1976, Nazir, 1992). It is also known that attention is inversely proportional to the size of the attended region (Jonides, 1981, Nakayama & Mackeben, 1989). The results in this experiment confirm the previous results, as the reaction time and errors increase with eccentricity. In conjunction tasks, properties of a target (orientation, contrast and salient features) guide attention, thus reducing the effect of eccentricity to some extent. The eccentricity effect results in an unequal allocation of attentional resources to items in the display, the central items being detected faster than the peripheral (Carrasco & Yeshurun, 1998, Yeshurun & Carrasco, 1999, Yeshurun & Levy, 2003).

The physiological properties of the retina have been shown to be associated with markedly reduced acuity, performance and accuracy at eccentric retinal locations (Carrasco, McLean, Katz & Frieder, 1998). The receptor density reduces significantly towards the peripheral retina (Wolfe et al., 1998) and as a result of reduced cortical representation, a decreased resolution of attention leads to reduced sensitivity in the peripheral visual field (Curcio, Sloan, Packer, Hendrickson & Kalina, 1987, Curcio, Sloan, Kalina & Hendrickson, 1990, Wolfe et al., 1998). Peripherally, at an eccentricity of one-third of a degree from the fovea, the grating resolution rapidly falls off to about 6 to 12 times less in a task with crowded displays (Rovamo, Virsu, Laurinen & Hyvarinen, 1982, Virsu, Rovamo, Laurinen & Nasanen, 1982). Therefore, in the presence of multiple distractors the selection drops off steeply with eccentricity.

3.5.2 Effect of Set-size

A 2-way ANOVA for the set-size and cues found no significant difference between the reaction time and errors with the increased set-size of 1000 from 500 within 10degrees eccentricity. However, a significant difference was found when both 500 and 1000 set-sizes were compared to 2000. The errors and reaction times decreased significantly with an increase in the number of random dots to 2000. This decrease emphasized the existence of a strong pop-out effect associated with increased set-size.

The t-test of the mean reaction time for neutral cued central and peripheral targets showed a significant difference in means between set-size 2000 and 1000 but not for 1000 and 500.

When the mean reaction times analyzed for different set-sizes but same cues, the central and peripheral targets showed no significant difference, except for the case of targets shown in set-size 2000 with an invalid cue.

Cues→	Valid	Neutral	Invalid	Valid	Neutral	Invalid	Valid	Neutral	Invalid
Visual Field ↓	**2000 & 1000**	**2000 & 1000**	**2000 & 1000**	**1000 & 500**	**1000 & 500**	**1000 & 500**	**2000 & 500**	**2000 & 500**	**2000 & 500**
Central	0.26	0.24	0.35	0.07	0.48	0.26	0.23	0.25	0.41
Peripheral	0.40	0.56	0.01	0.09	0.13	0.13	0.16	0.47	0.87

Table 3-1: p values for the central and peripheral mean RT for different set-sizes but same cues

The target and distractor heterogeneity and presence of a conjunction target enhances a pop-out effect which eases target detection and discrimination. This experiment showed no change in the reaction time and errors associated with changes in the set-size, in the center and periphery. However, there is in general an increase in reaction time and errors toward the periphery, confirming the eccentricity effect.

The method of search accuracy and time was used. The slopes showed negligible slope differences between the three set-sizes confirming a presence of a parallel processing involved with the target processing.

3.5.3 Effect of Cues

The effect of a cue is directly proportional to the validity for a symbolic cue (Awh, Matsukura & Serences, 2003). The distractors are found to affect the target identification even in the presence of a 100% valid cue, therefore suggesting that the capacity to overlook irrelevant items is restricted (Duncan & Humphreys, 1989, Egeth, Virzi & Garbart, 1984, Treisman & Gormican, 1988, Wolfe, Horowitz, Kenner, Hyle & Vasan, 2004).

Enhanced performance in presence of valid cues has been shown by previous studies (Eriksen & Hoffmen, 1972a, Eriksen & Hoffmen, 1972b, Ling & Carrasco, 2006). A pre-cue enhances detection performance of the attended stimuli. In presence of cues, attention is directed promptly toward a target location, thereby improving performance. The cues reduced the eccentricity effect but it was not completely eliminated. A similar result is also shown in a study involving transient cues and eccentricity (Carrasco & Yeshurun, 1998, Treisman & Paterson, 1984).

The absence of a significant interaction of cues and increasing eccentricity was evident. Only in the presence of a valid cue was there a significantly different mean reaction time at each level of eccentricity, emphasizing the fact that invalid and neutral did not play a role. This was consistent at all eccentricities.

3.6 Conclusion

Reaction time and errors are dependent on the eccentricity of the target presentation. In presence of cues, attention was focused at the target location and therefore performance improved especially with more cluttered displays.

Summary

The hypotheses of the experiment included evaluating the presence of an eccentricity effect on visual attention, effect of sustained attention with valid and invalid cues and effect of increasing set-size. A total of 25 target combinations were presented with the method of constant stimuli in a random fashion in 1425 trials. The observers were expected to register the direction of the grating that appeared in a particular trial. The responses were analyzed for the reaction times and the errors in target detection.

The overall reaction time was found to increase for all the peripheral targets that confirmed the presence of an eccentricity effect. With every 10 degrees of eccentricity from the center of fixation, there was an increase in reaction times as well as an increase in errors. However, this was uniform for all set-sizes and the mean reaction times in central and peripheral fields with different cues had no significant differences when presented with different set-sizes. This indicated a prominent pop-out effect for the targets in both central and peripheral fields. The data was then analyzed with Palmer's method of search and accuracy, and it was seen that there was a negligible difference in the slopes of the set-sizes, which confirmed the presence of parallel search for target detection. The cues enhanced visual attention, especially in the periphery as evidenced by a significant reduction in reaction times and errors. Therefore, the eccentricity and improved performance with sustained visual attention hypotheses were both proved. Since the target was a conjunction target amidst the heterogeneous distractors, there was a pop-out effect as a result of parallel processing. Therefore, increasing the set-size had no effect on target detection and discrimination. There was no evidence of longer reaction times or increased errors associated with the change in set-size from 500 to 2000.

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4. Visual Attention as a Function of Contrast

4.1 Abstract

The aims of the study were to analyze the changes in target detection due to changes in contrast, sustained attention, increasing set size and target size. The experiment used covert attention and data on reaction times and errors were collected. The visual field involved was central 20deg and peripheral 20- 40deg. Two healthy and young participants (age 29 and 30 years) with normal visual acuity (LogMar) and contrast acuity participated in the experiment. The targets were displayed on a Sony Trinitron monitor, with 100fps and 1028x780pixel resolution. A total of 125 target combinations, with variable visual angle, contrast and spatial frequency, were randomly presented by the method of constant stimuli in 7125 random trials. The reaction times and accuracy were assessed. A significant effect of contrast and valid sustained cues was seen in the reaction times and accuracy. Low contrast targets significantly increased the reaction times and errors for both central and peripheral targets, while valid sustained cues enhanced the responses. The analysis of set-size showed a combination of serial and parallel visual searches involved in this experiment, as the reaction times for a higher set size did not increase but accuracy decreased for target detection.

Keywords: Contrast, sustained attention, attention, eccentricity.

4.2 Introduction:

The effect of attention on the contrast sensitivity has been studied by many researchers in the past. Covert attention enhances visual performance when allocated at a point in the visual field (Robson & Graham, 1981) and pre-cueing of the target with a valid cue pointing towards the location enhances the responses due to the maximum attention resources allocated at that point. The unattended targets in various locations undergo a minimal processing (Posner, 1980, Posner, Snyder & Davidson, 1980). In cases where invalid cues are used, attention is incorrectly guided which results in delayed and inaccurate responses (Eriksen & Hoffmen, 1973, Pashler, 1998, Posner, 1980). Previous studies have shown that it is essential to compare responses obtained with cued trials to neutral-cued trials, to study attentional effects (Bashinski & Bacharach, 1980, Chastain & Cheal, 1997, Eriksen & Hoffmen, 1972a, Eriksen & Hoffmen, 1972b, Theeuwes, Kramer & Atchley, 2001).

The spatial attentional benefits of contrast sensitivity have been studied earlier by many researchers involving a similar visual search with distractors (Dosher, Liu, Blair & Lu, 2004, Dosher & Lu, 2000, Hawkins, Hillyard, Luck, Mouloua, Downing & Woodward, 1990, Lu & Dosher, 1998, Luck, 1994). In limited capacity processing, increased reaction time and errors are seen when there is an increasing numbers of distractors. Marked attentional effects are reported when a target is presented amidst increasing number of distractors in the presence of different cues(Lee, 1999, Lee, Itti, Koch & Braun, 1999). In this experiment we expected to see the same results when presenting targets with increased clutter.

The hypothesis for the study was that with increased target contrast, there should be an increase in accuracy and decrease in reaction time. This should be consistent in both central and peripheral fields. In the presence of sustained cues there should be improved performance at both the central and peripheral fields, especially for targets with low contrast. In addition, there should be a set-size effect evidenced by increased reaction times and lower accuracy when distractors are added to the display.

4.3 Methods

Two participants (29 year-old female and 30 year-old male) with normal general/ocular health participated in the experiment. They had normal vision as measured by LogMar chart and normal contrast acuity measured with a Vistek® chart. At the time of experiment, they were not known to be under any medication, alcohol effect, etc.

The experiment was programmed using Matlab (The MathWorks, Inc.) and displayed on a Cambridge Research System – Visual Stimulus Generator

(CRS Ltd.). The display monitor was a Sony Trinitron monitor with a refresh rate of 100fps and resolution of 1280x780 pixels. The standard background on the monitor was a static, grayscale display with 1000 scattered random dots, which was calibrated each day before the experiment session ($53cd/m^2$ measured using Color Cal). The method of the target display for the experiment was a combination of Yes/No and 2AFC procedures.

The visual attention fields of the eyes being circular, four imaginary concentric circles were set at 10°, 20°, 30° and 40° from the center of foveal fixation. These were used to randomly present targets both in central 0° to 20° from fovea and >20° to <50° in the visual field. The targets in the central zone were shown five times at each of the five random central locations and four times at each of the eight random locations in the peripheral zone. The responses collected were reaction times and errors.

There were 125 possible target combinations with variations in size, contrast and spatial frequency used in the experiment. The targets subtended visual angle of ranging from 1.5-10 arc-minutes. Michelson contrasts of 20%, 40%, 60%, 80%, or 100%. The spatial frequency of the Gabor gratings varied from 1, 5, 10, 20 to 29cycles/degree. Overall, 7125 random trials of Gabor gratings were presented. The reaction time was used only when a target was correctly detected in 3 consecutive trials.

4.4 Results

4.4.1 Change in Contrast

The mean reaction time for central and peripheral targets was 496.34±23.42ms and 530.81± 42.24ms respectively, and the difference was significant using a t-test.

The correct responses for detection in each contrast level against target size showed improved performance with a higher contrast. 63.65% targets were seen in the center compared to a mere 17.17% in the periphery using a t-test for significance.

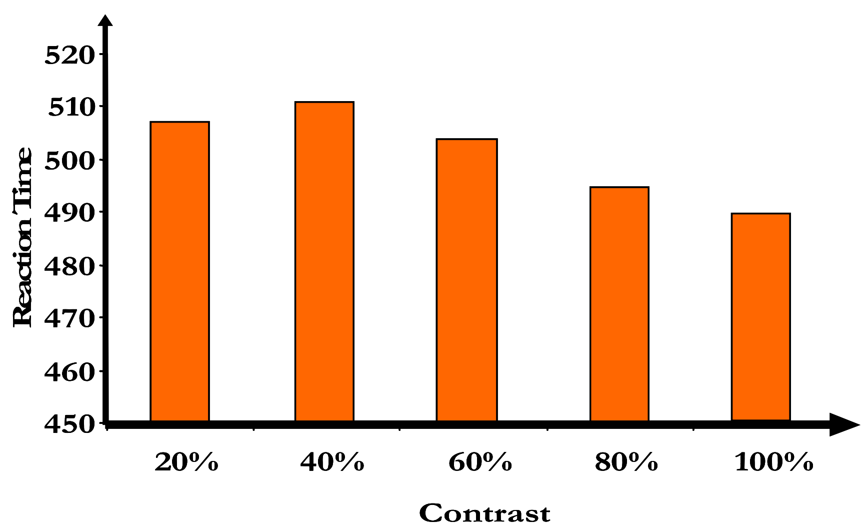

Figure 4-1: Average reaction times for overall targets with different contrasts

The overall mean reaction time for all targets with contrasts ranging from 20 to 100% was 507.70ms±1.24, 511.72ms±5.39, 504.08ms±10.56, 494.84ms±13.34 and 489.55ms±2.66 respectively (Figure 4-1). The mean reaction time decreased with increased contrast of the targets. The t-test showed a significant difference between the mean reaction time for the lowest and the highest contrast target.

The longer reaction time for the low-contrast targets was a consistent finding, both in the central and peripheral fields. Accuracy decreased and reaction time increased as a function of contrast, at different eccentricities for overall as well as for a constant spatial frequency. (Figure4-2, Figure 4-3, Figure 4-4)

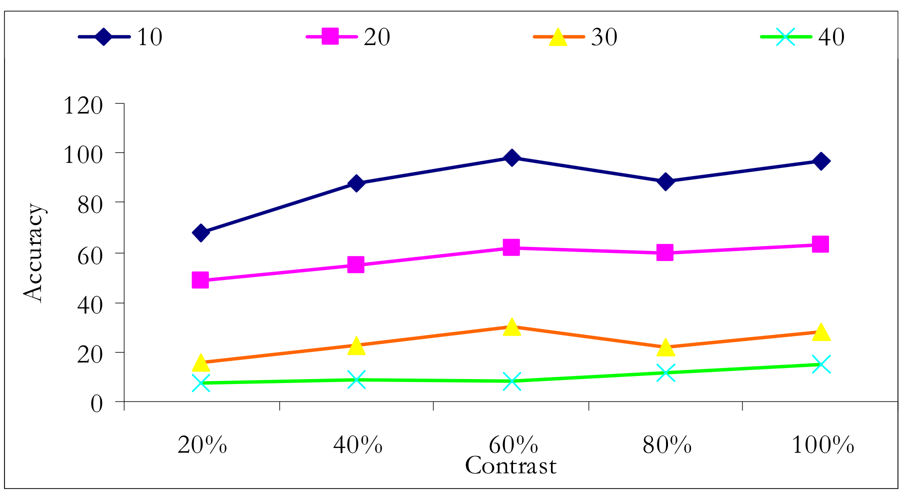

Figure4-2: Overall accuracy for different contrast targets at varying eccentricity

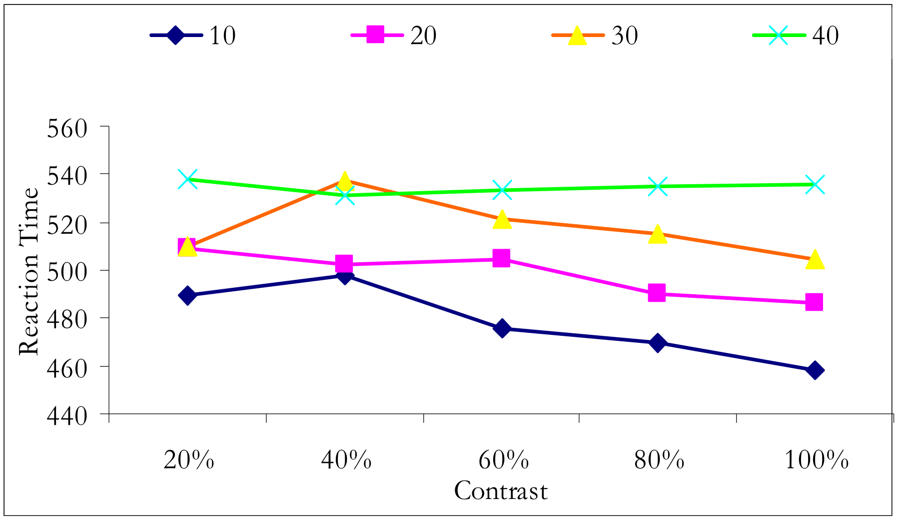

Figure 4-3: Overall Reaction Time for different contrast targets at varying eccentricity

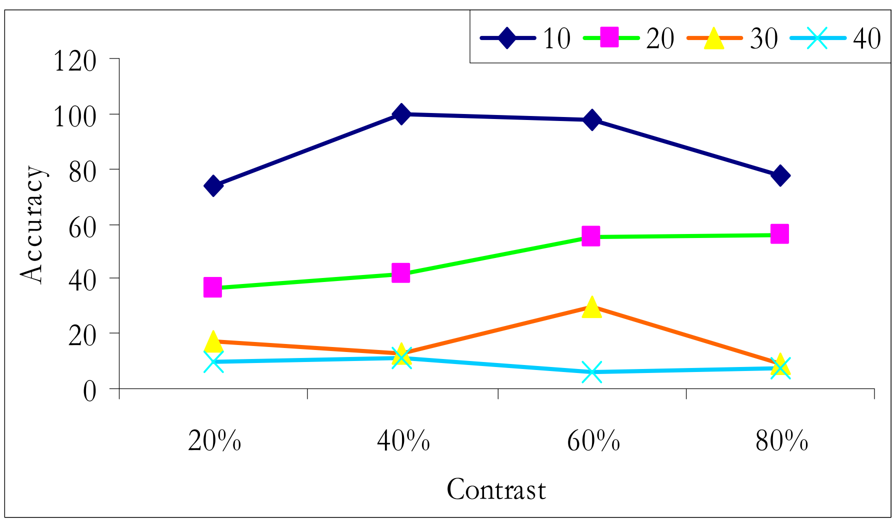

Figure 4-4: Accuracy at changing eccentricities with contrast variations for spatial frequency of CPD 5

The peripheral targets with low contrast showed longer reaction time compared to the targets with a high contrast and more central location (Figure 4-4). Average reaction time for targets with contrast less than ≤60% was 512.92±18.22ms and for ≥80% contrast was 492.87±21.38ms and the difference was significant.

4.4.2 Contrast and Visual Angle (LogMar Visual Acuity)

The overall mean reaction time for the smallest and largest target sizes was 522.16ms and 498.92ms respectively, with a significant difference. The proportion of the correct responses increased with an increase in size and contrast. The reaction time for targets were found reduced for high contrast and larger targets. E.g. Target with spatial-frequency 1CPD & MAR 10. (Figure 4-5)

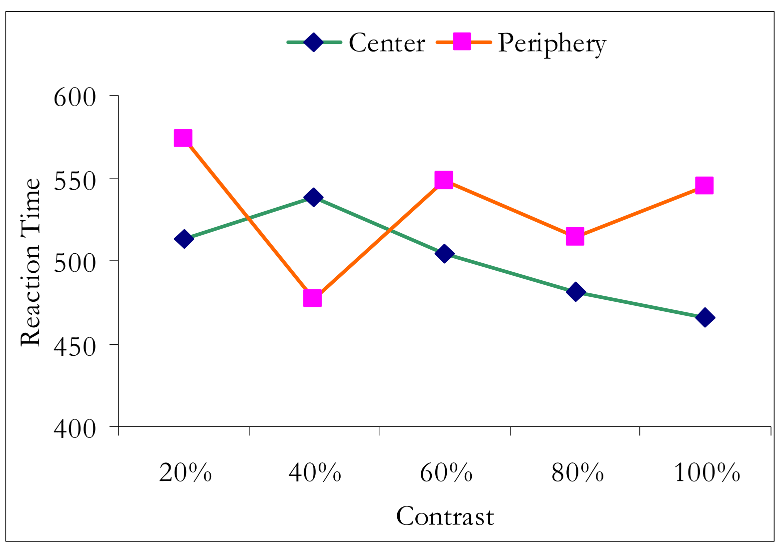

Figure 4-5: Reaction Time for CPD1-
MAR 3

Analysis of the reaction time for the overall targets in the visual field showed a longer reaction time for small targets (Figure 4-6, Figure 4-7); this decreased with increasing contrast levels for a given target size. It showed consistent diminution of reaction times both in the central and peripheral targets.

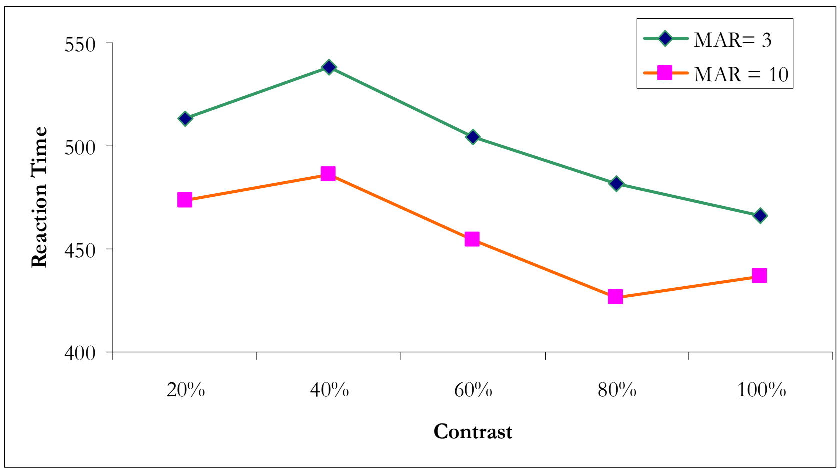

Figure 4-6: Obs 2: Average Reaction Time for target size of CPD3 and MAR 10 with increasing contrast in central field.

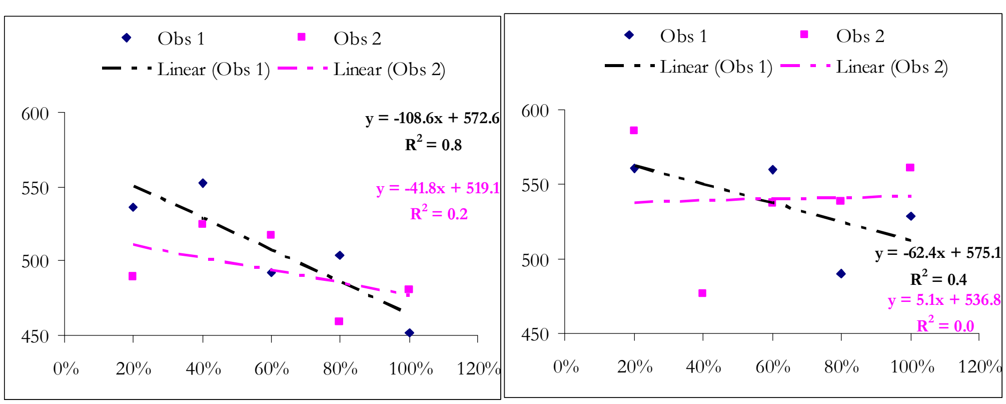

Figure 4-7: Central and Peripheral Reaction Time

Both observers had a similar trend for responses in the central targets but not for the peripheral targets (Figure 4-7). The overall trend of Observer 2 was a consistently decreasing reaction time for the central and peripheral targets. For the Observer 1 the reaction time decreased with increasing contrast for central targets, but there was no specific pattern for the peripheral targets. The responses of both the participants differed for the peripheral field.

An Altman Bland plot (Bland & Altman, 2007) (Figure 4-8) was then used to analyze the differences between responses of Observers 1 and 2. There was a similar trend for differences in the central and peripheral field. The difference between the responses of Observer 1 and 2 was seen to change with increasing contrast for both central and peripheral targets.

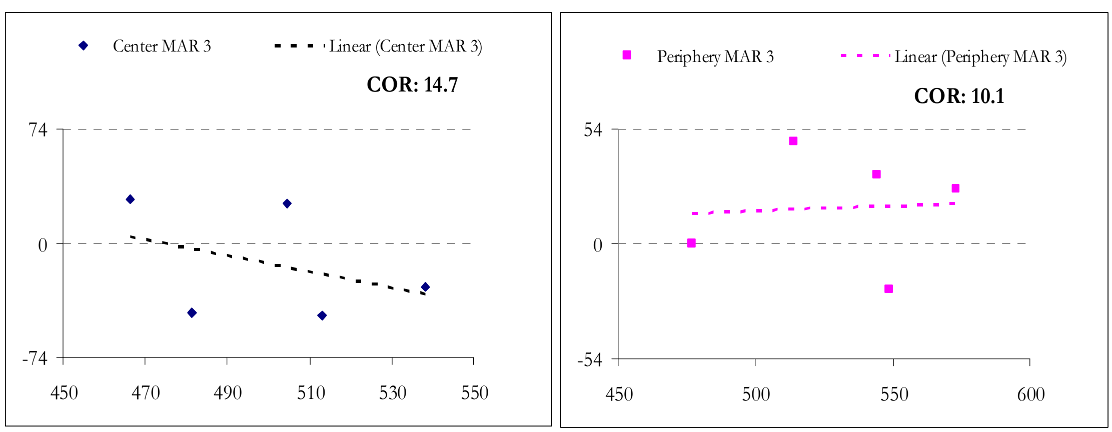

Figure 4-8: Coefficient of repeatability
for CPD 1 MAR 3

The reaction time for the larger target in the center and periphery also showed a similar trend of decreasing reaction time with increasing contrast. There was no significant difference between the mean reaction time for a MAR10 target both in the center and periphery (Figure 4-9).

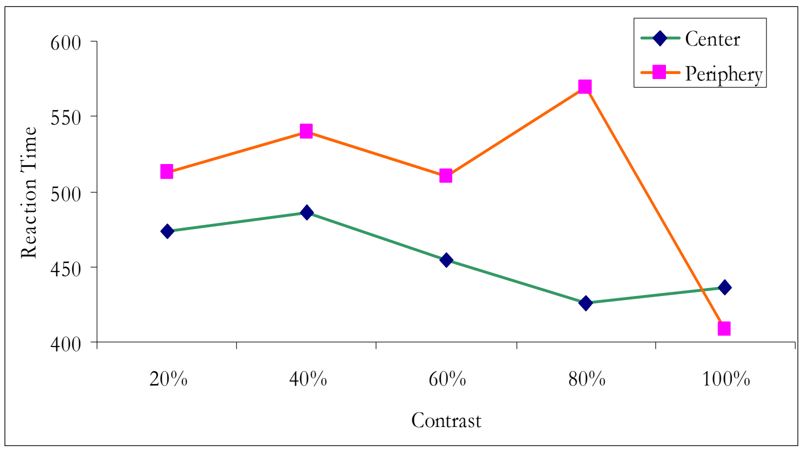

Figure 4-9: Reaction Time for CPD1
and MAR 10 with varying contrast

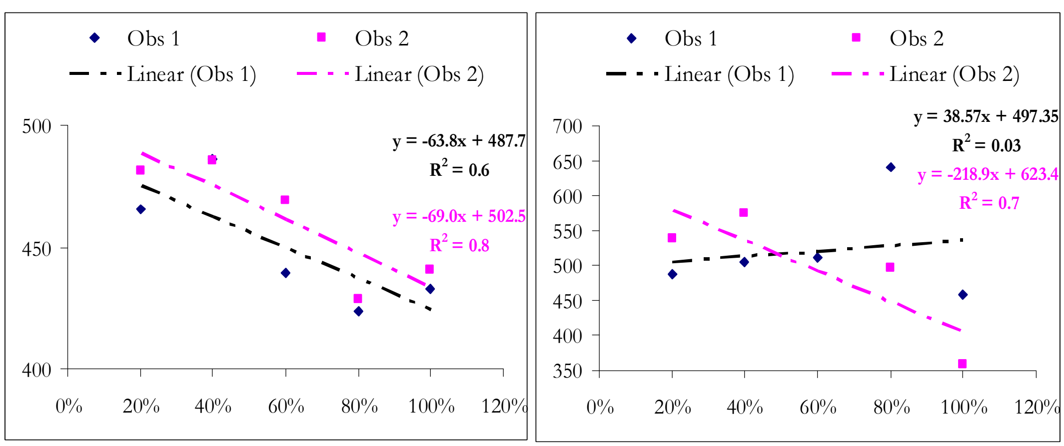

Figure 4-10: MAR 10 Central and
Peripheral Reaction Time

The two observers had a similar trend for responses in the central targets but not for the peripheral targets (Figure 4-10). The overall trend of responses for Observer 2 was a consistently decreasing reaction time for the central and peripheral targets, but for Observer 1 there was no decrease in reaction time seen with increasing contrast for peripheral targets.

For central targets, the Altman Bland plot (Bland & Altman, 2007) (Figure 4-11) for a large target of MAR10, showed consistent difference for the two observers. However, for the peripheral targets the difference between the mean reaction times of Observer 1 and 2 decreased with increasing contrast.

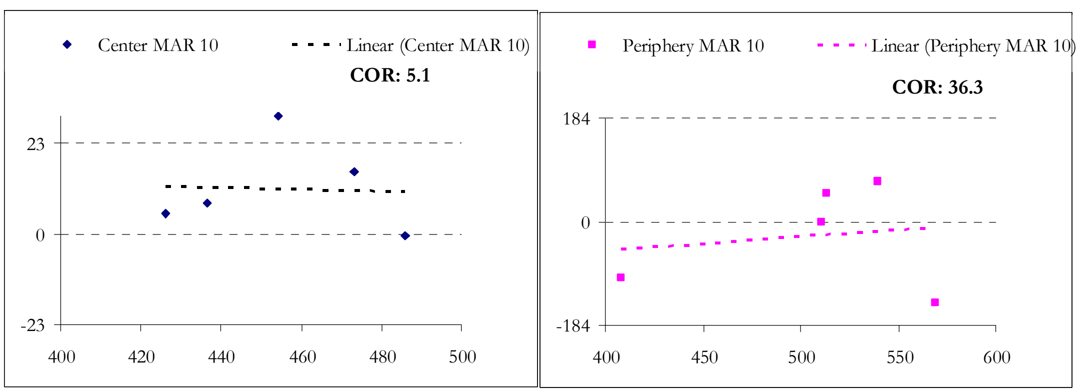

Figure 4-11: Coefficient of repeatability for CPD 1 MAR 10

On the other hand, accuracy increased for the same target size with an increased contrast level for the target size MAR3, but was not affected by target contrast in both the center and periphery. The Altman Bland plot above (Figure 4-11) for the target of MAR10 shows a consistently decreasing difference in mean reaction times with increasing contrast. This difference is small between the two observers and has a high Coefficient of Repeatability (COR) of 5.1. Therefore, the sharp increase in accuracy could be a result of the uneven number of targets tested at various contrast levels.

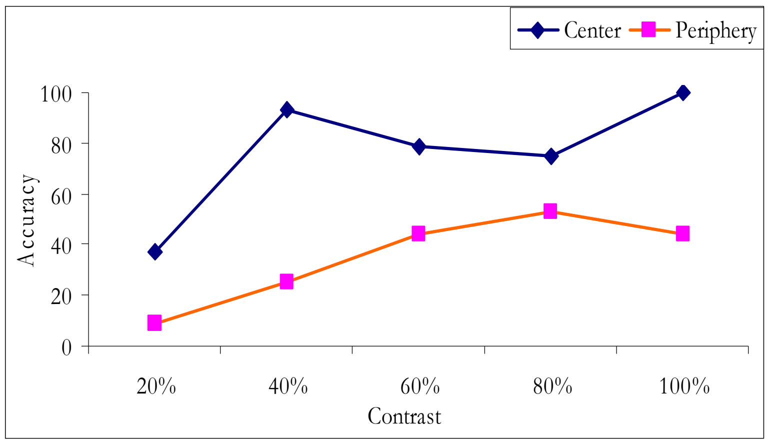

Figure 4-12: Accuracy for CPD1 -MAR 3 with varying contrast in the central and peripheral field

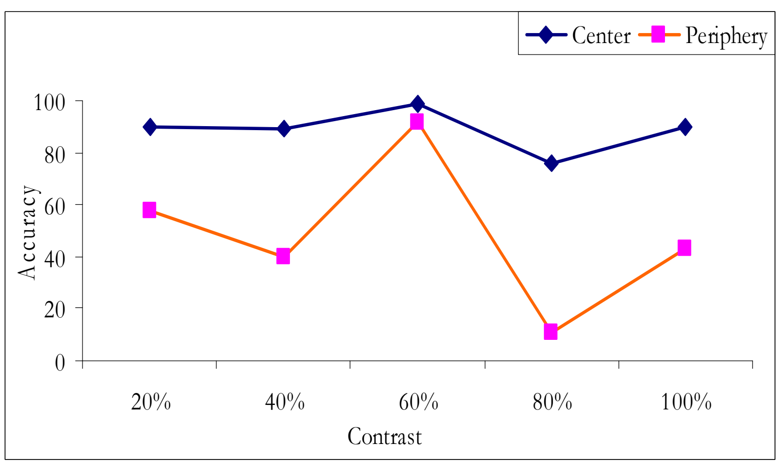

Figure 4-13: Accuracy for target size of CPD1 - MAR 10 with increasing contrast in central field.

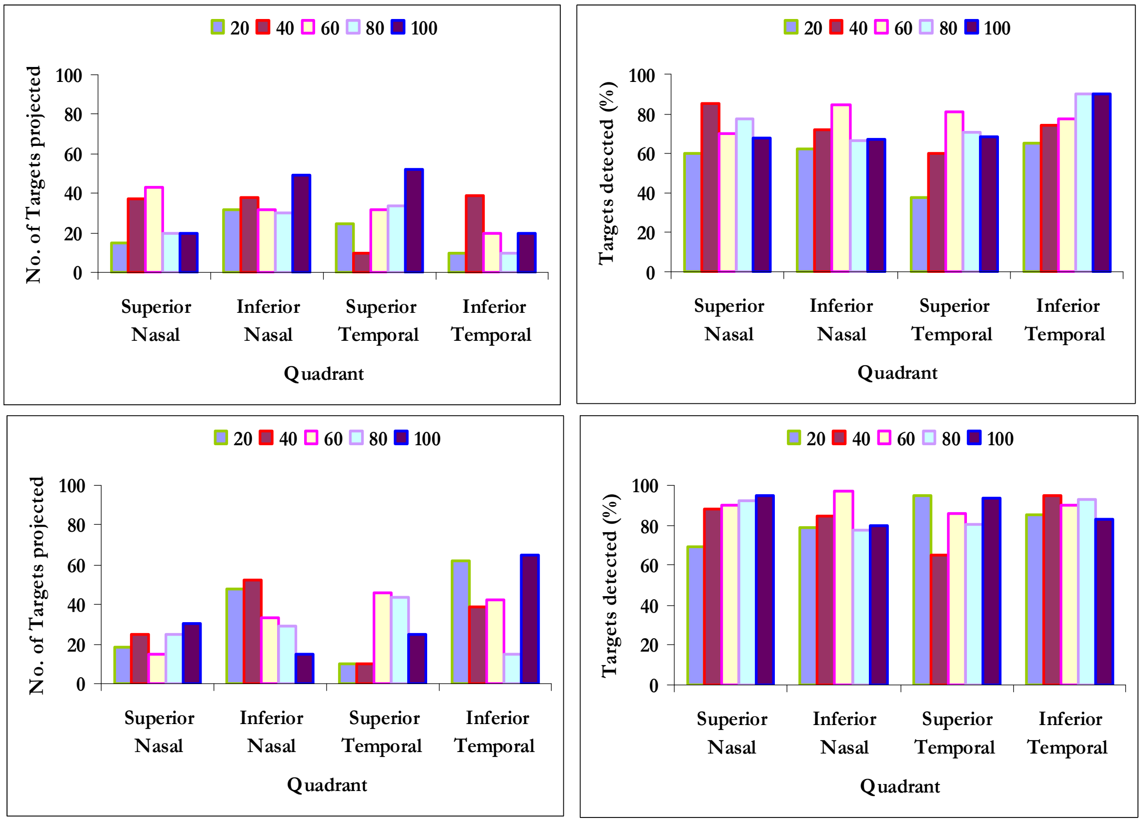

Figure 4-14: Obs 2: No. of targets projected and detected for MAR 3 (Top) and MAR 10 (Bottom) in the center

The targets projected and detected in the central and peripheral fields for MAR 3 and 10 were plotted. The visibility of targets in nasal and superior quadrants of visual field is small when compared to the other quadrants. Since many targets were displayed for a contrast of 40% and 60% and the detection also was high due to the location of the display, there were slightly peaked accuracy rates at the 40% and 60% contrast for the MAR3.

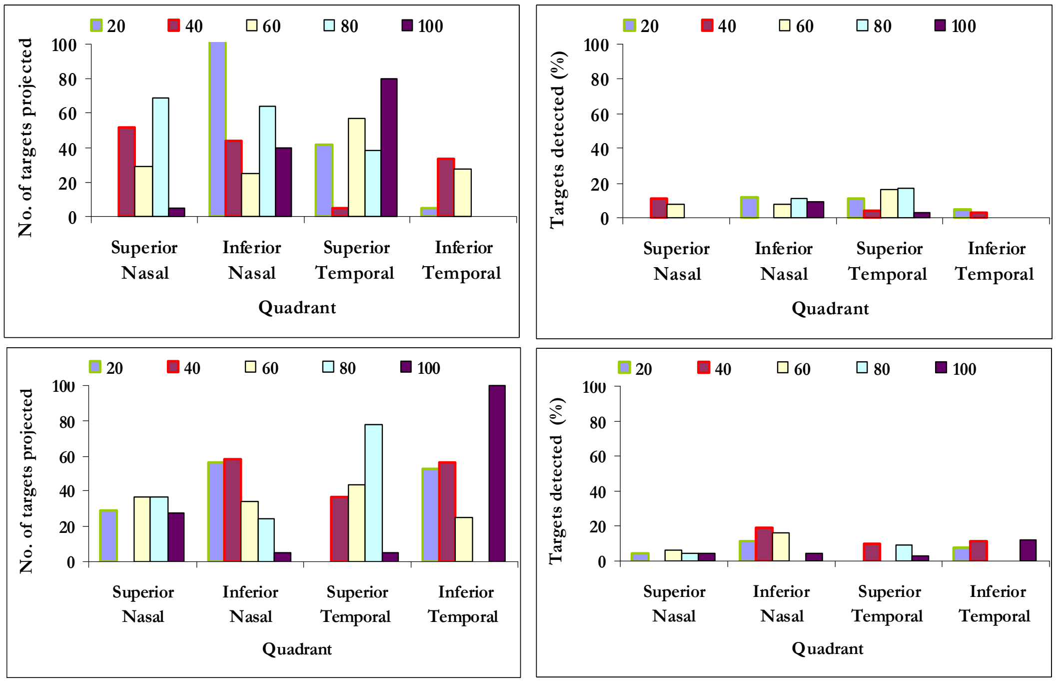

Figure 4-15: Obs2: No. of targets projected and detected for MAR3 (Top) and MAR 10 (Bottom) in the periphery

For MAR3, there were more targets at 40% contrast in the inferior nasal field and therefore the detection was lower. Fewer targets were displayed at contrast 80% and 100%, and therefore the detection rate showed a decrease beyond the 60% contrast for MAR 10.

The numbers of all targets tested at each quadrant were plotted. It was found that maximum numbers of targets were presented at the 60% contrast. A plot of all the four quadrants for the targets with different contrasts showed highest accuracy for the contrast at 60% for both observers.

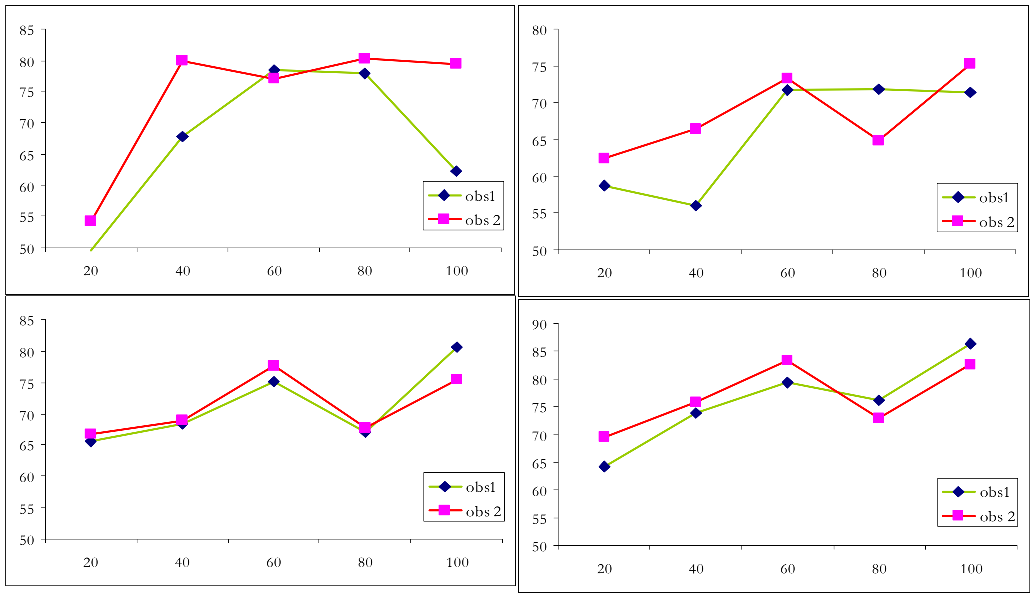

Figure 4-16: Quadrant wise responses for both the observers for central targets.

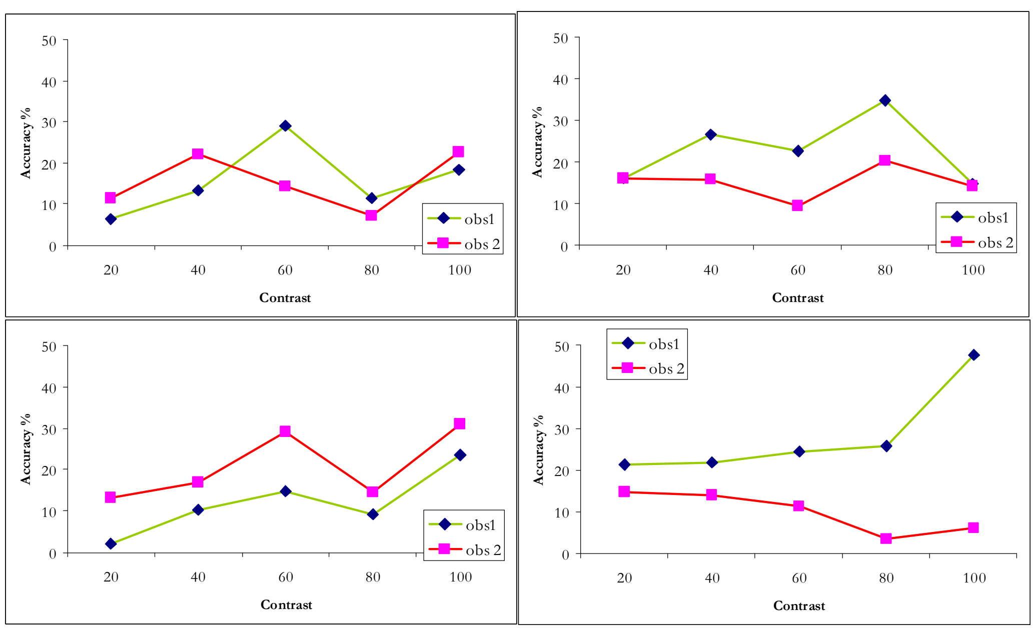

Figure 4-17: Quadrant wise responses for both the observers for peripheral targets

The responses in the periphery were distributed in a very different manner between the two observers, especially for the quadrant 1 and 4. The responses seem to follow a trend for all the quadrants except for the 4th quadrant, where the trend of Observer 2 was completely opposite to that of Oserver1 and showed a reduced accuracy at higher contrast levels.

A t-test was performed to determine if the difference in the mean reaction time between the reaction times of both the observers was significant. It was not significant ($p>0.05$) therefore showed that the mean reaction time remained the same for both the observers for all the different levels of contrasts used in the targets. Hence, the data from the two observers was consistent with regard to the mean reaction times obtained for each contrast level.

The reaction time and accuracy for the responses in both central and peripheral field were found to follow identical trends for both the participants. The slopes for the reaction times were identical, both in the center and periphery, for the two observers and the reaction time was seen to decrease with increase in target contrast.

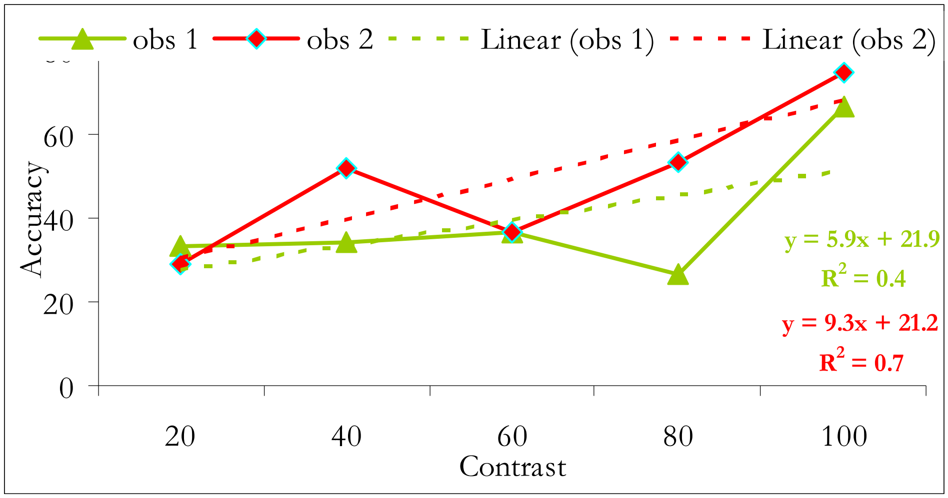

Figure 4-18: Trend of accuracy CPD1
MAR3 in the central field

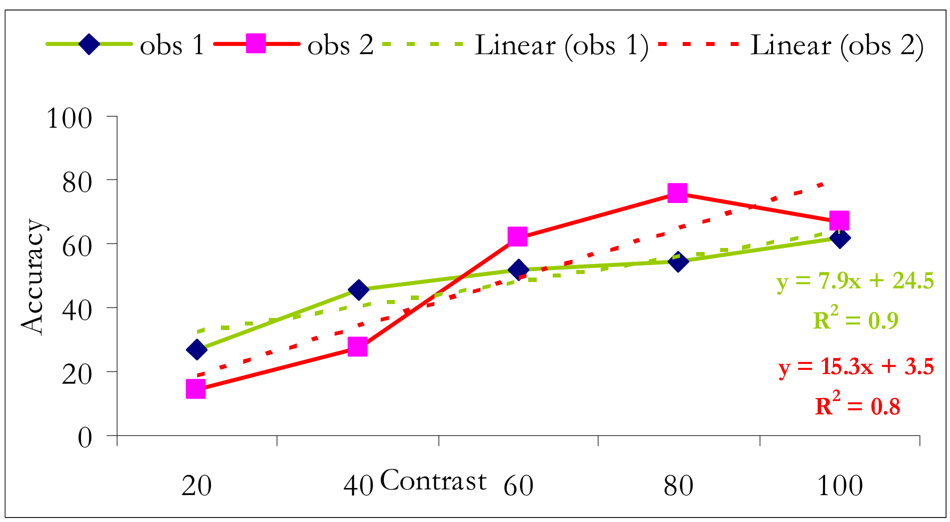

Figure 4-19: Trend of accuracy CPD1
MAR3 in the peripheral field

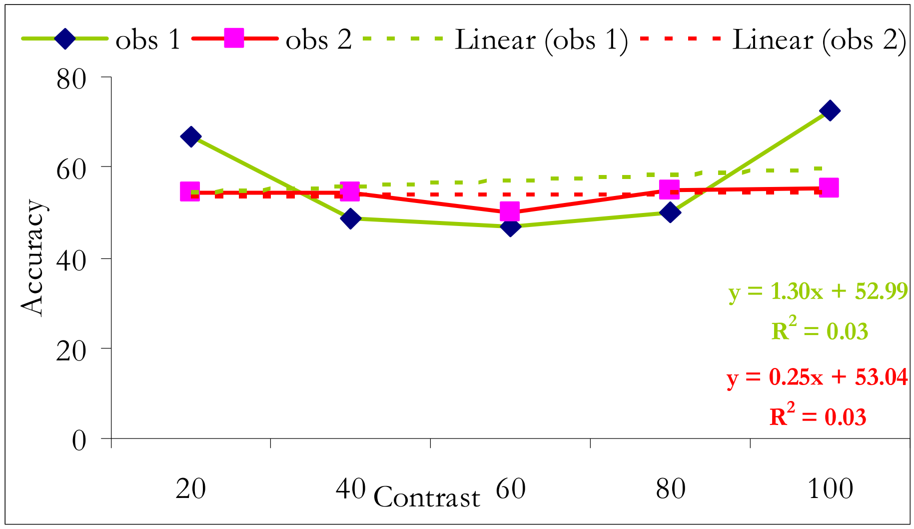

Figure 4-20: Trend of accuracy CPD1
MAR10 in the central field

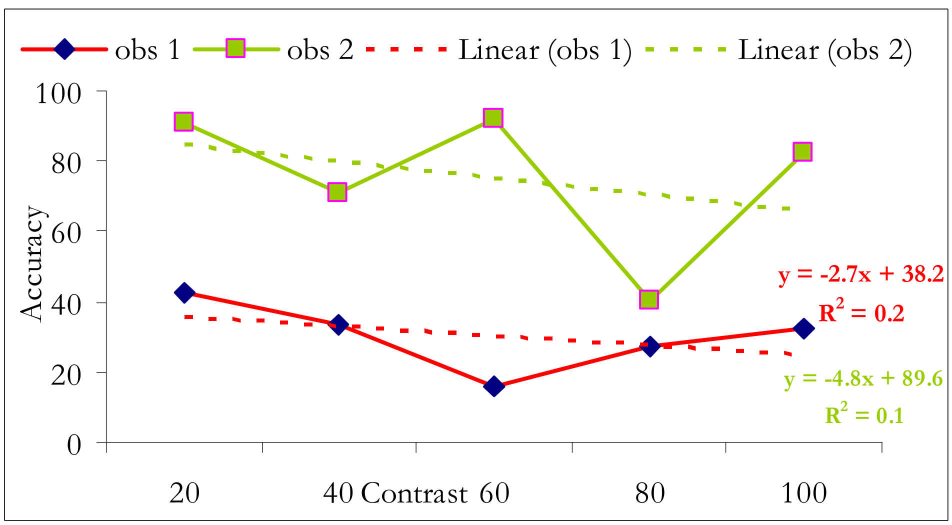

Figure 4-21: Trend of accuracy CPD1
MAR10 in the peripheral field

The accuracy for both observers was found to increase with increase in target contrast, for both central and peripheral fields. The observers had a similar pattern for target detection but not for discrimination of the orientation of the Gabor. From the above it is evident that the reaction time and accuracy followed the same pattern of responses in both observers 1 and 2, leading to lower reaction times with the increase in target contrast. This trend of low reaction time with high contrast was consistent in the central and peripheral fields. The correctly identified targets increased both at the central and peripheral field, for a target with a small MAR.

For a larger target size of MAR10, the accuracy was consistent for central targets and was found to decrease for the peripheral targets indicating no effect of increased contrast on target detection. But, towards the peripheral field the differences in accuracy of both the observers increased. The accuracy of responses by observer2 was quite higher compared to observer1, but accuracy seemed to decrease with higher contrast for the peripheral targets for both the observers.

4.4.3 Spatial gratings and Contrast

The reaction time for spatial gratings increased with increased contrast of the target. The proportion of correct-responses increased and the reaction time decreased with higher contrast levels. The average reaction time for targets with 20% contrast was 510.59±22.85ms and it reduced to 493.82±20.5ms for a target with 100% contrast.

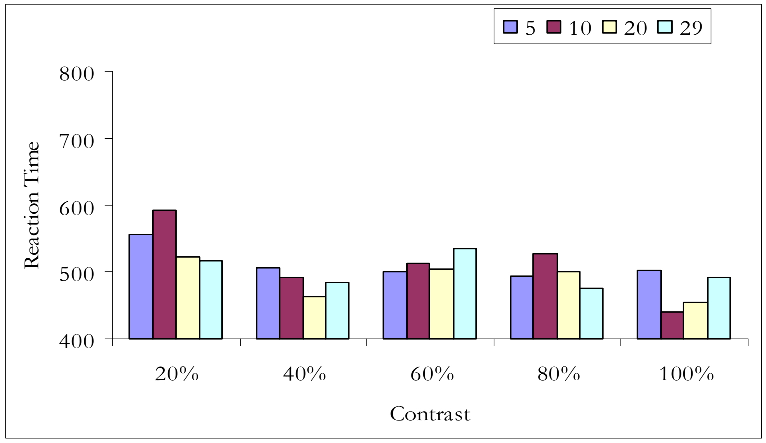

Figure 4-22: Reaction time for different spatial frequency as a function of contrast in the central field (Target size: MAR 3)

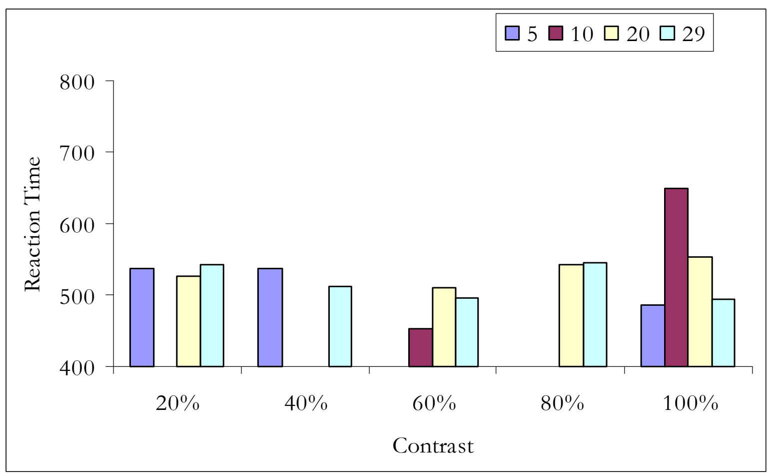

Figure 4-23: Reaction time for different spatial frequency as a function of contrast in the peripheral field (Target size MAR3)

The reaction times beyond 20 degrees were longer and near about the same for all contrasts. Most of the small targets were not visible in the peripheral visual field.

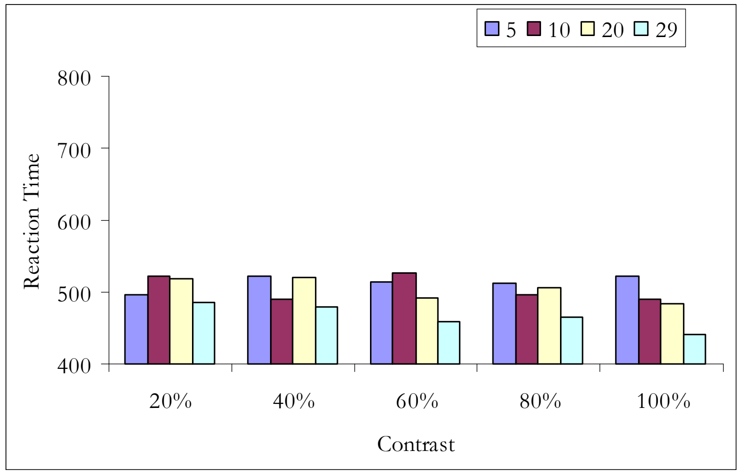

Figure 4-24: Reaction time for different spatial frequency as a function of contrast in the central field (Target size MAR 10)

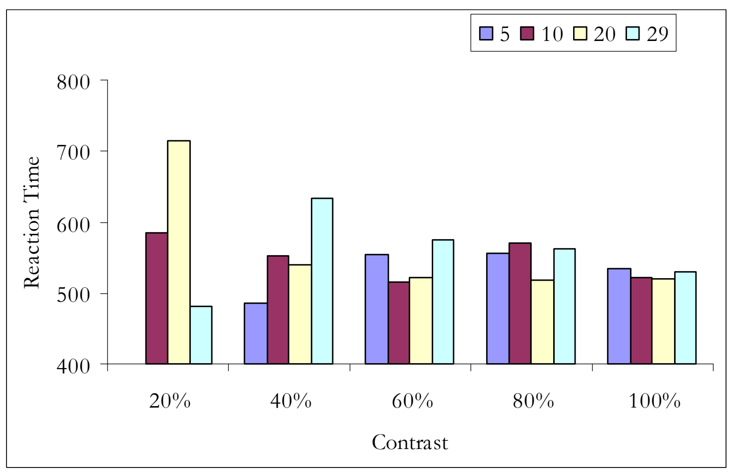

Figure 4-25: Reaction time for different spatial frequency as a function of contrast in the peripheral field (Target size MAR 10)

The target with a larger MAR of 10 was then analyzed. The reaction time was found to be longer for the peripheral targets. The reaction times decreased for all the spatial frequencies presented in both the center and periphery with increasing contrast.

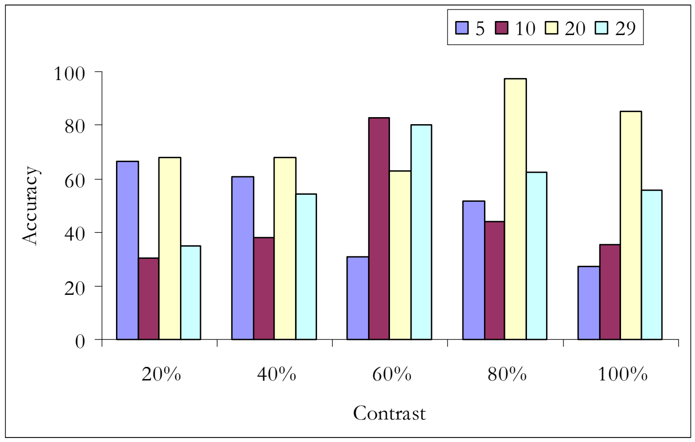

Figure 4-26: Accuracy of central targets with changing contrast (Target Size MAR 3)

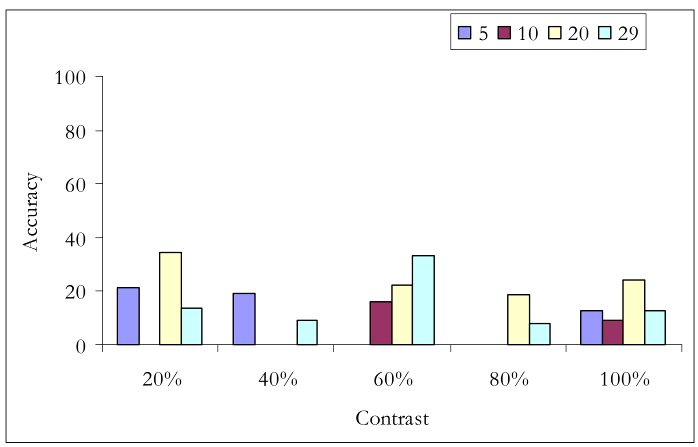

Figure 4-27: Accuracy of peripheral targets with changing contrast (Target Size MAR 3)

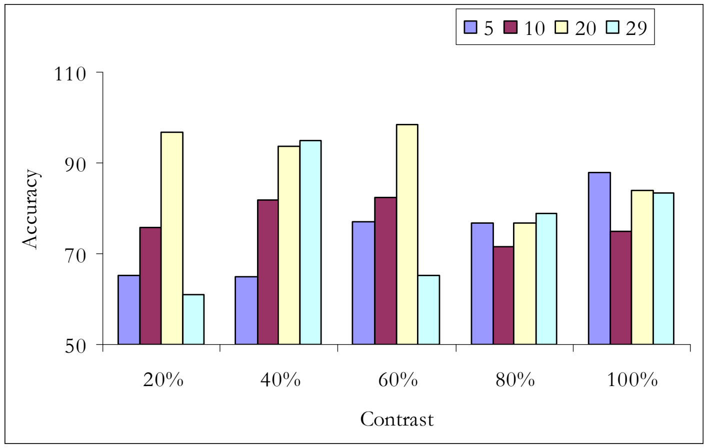

Figure 4-28: Accuracy of central
targets with changing contrast
(Target Size MAR 10)

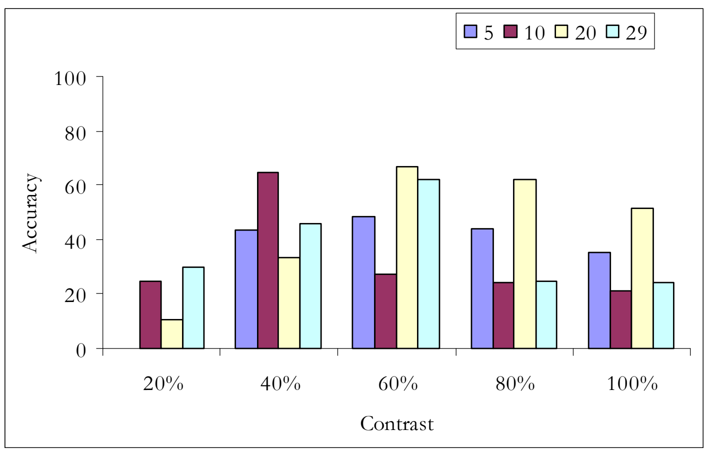

Figure 4-29: Accuracy of peripheral
targets with changing contrast
(Target Size MAR 10)

The accuracy beyond 20 degrees declined gradually (Figure 4-28Figure 4-29). A paired t-test for the differences in mean reaction time and accuracy for all the eccentricities was found to be statistically significant. Reaction time was directly proportional to the increase in spatial frequency and accuracy of responses for was inversely related to the increasing spatial-frequency. The difference between the average reaction time and responses for the highest and lowest spatial frequency grating was also statistically significant.

4.4.4 Contrast and Cues

The responses were analyzed on the basis of sustained cue they were presented with. The mean reaction time for the targets with different contrast were analyzed as a function of the cue involved and compared with the neutral cue. Accuracy was analyzed in the central and peripheral fields with other factors held constant under neutral, invalid and valid cued conditions (Figure 4-30Figure 4-31).

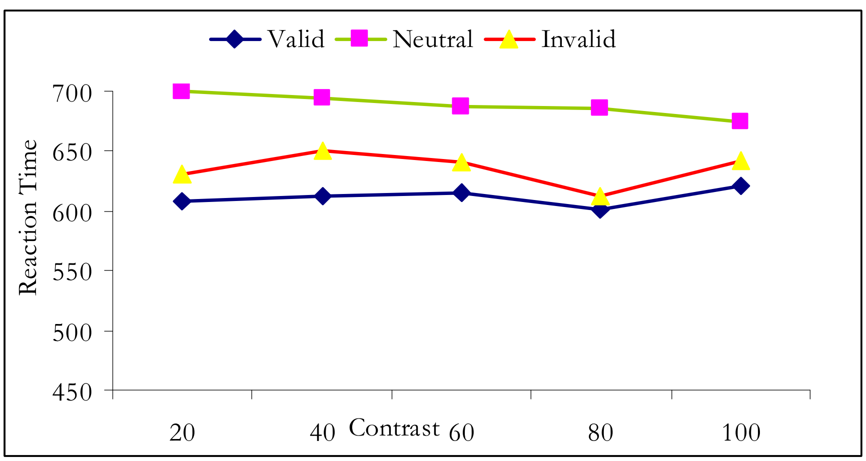

Figure 4-30: Reaction time for peripheral targets with different contrast and cues

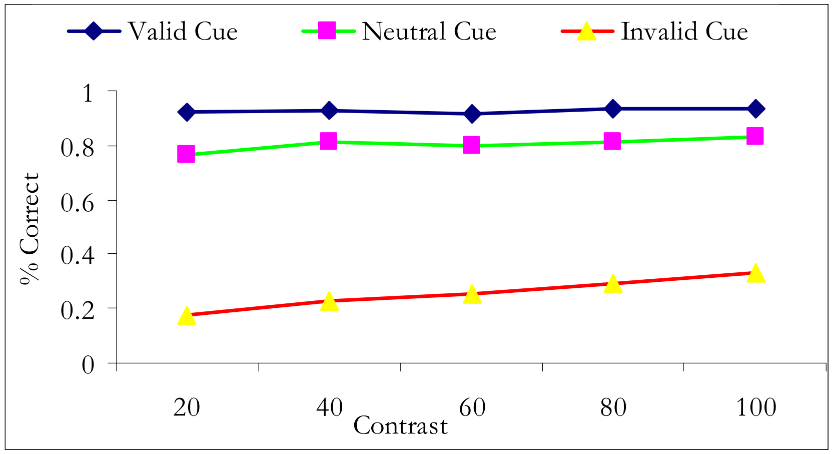

Figure 4-31: Accuracy for peripheral targets with different cues and contrast

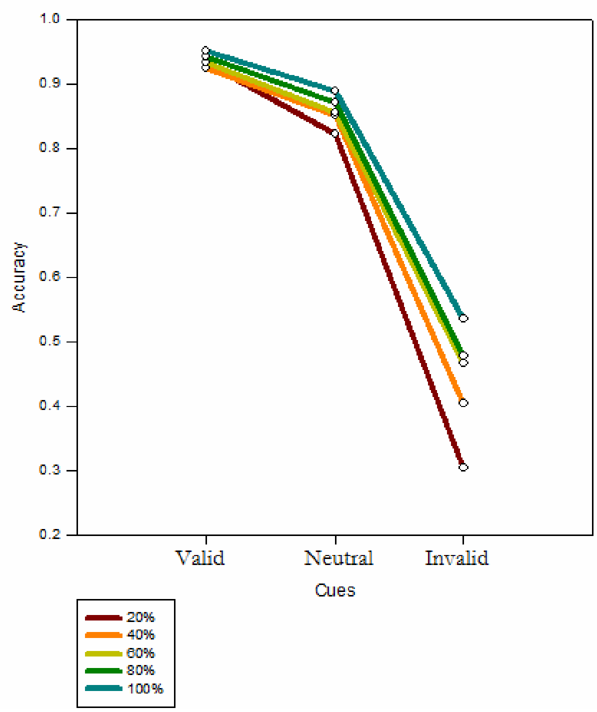

Figure 4-32: Accuracy Cues and Contrast

A 2-way ANOVA **for** the effects of contrast and cues for both central and peripheral targets showed a higher detection level with the valid cues F (2,15)=28.82, $p<0.05$ at center and F (2,15)=0.378, $p>0.05$. The main effects were not significantly associated with each other.

The valid cued **targets** showed a steady increase in accuracy with valid cues (Figure 4-31, Figure 4-32). An increased reaction time was associated with neutral or an invalid cue as F (4,15)=8.88, $p<0.05$ but not for a low contrast target F (4,15)=0.19, $p>0.05$.

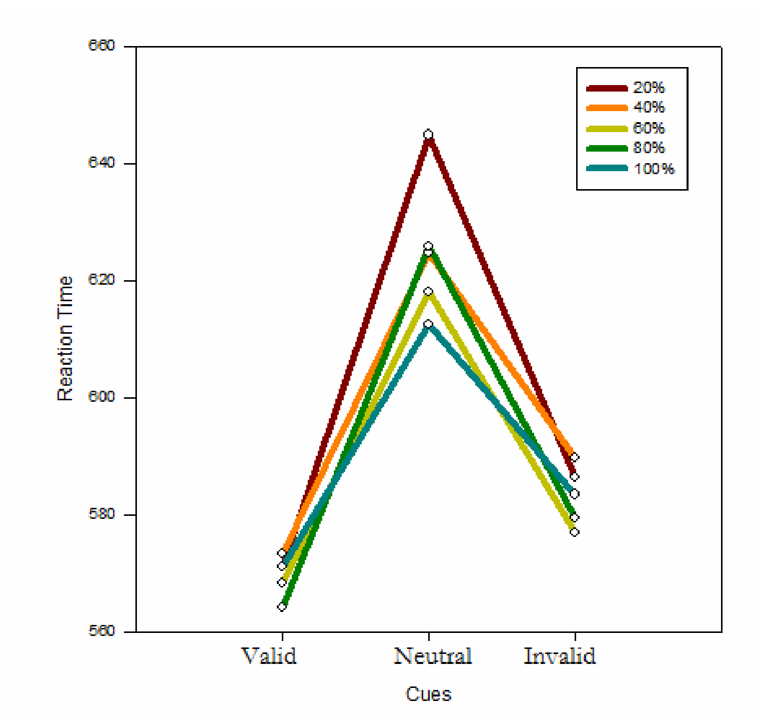

Figure 4-33: Reaction times with different Contrast and Cues

A 3 way ANOVA for location (center x periphery), cues and contrast was done and it was seen that the location and cues did affect the reaction times but the contrast did not have significant effect on the same (Figure 4-33). The accuracy significantly increased with change in location, cue validity and contrast of a target. The main effects, namely, cues and location had a significant interaction for both accuracy and reaction times.

4.4.5 Contrast, Cues and Set-size

The effect of the change in contrast and cues in various set-sizes was analyzed. The central targets showed a consistent increase in the accuracy with increasing contrast but for the peripheral targets the responses did not seem to depend on the contrast levels. (Figure 4-34Figure 4-35)

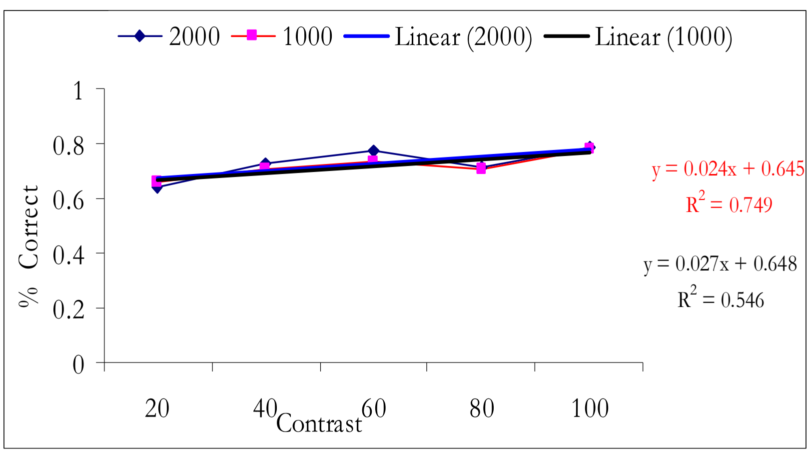

Figure 4-34: Accuracy in the center with different contrast targets with varying set-sizes using neutral cues

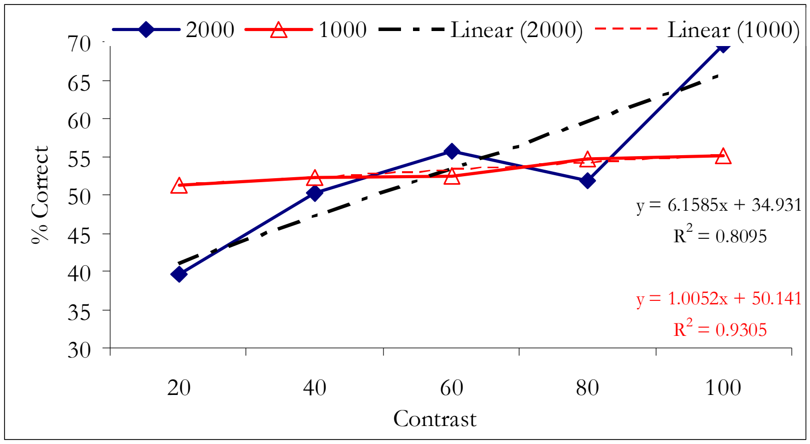

Figure 4-35: Accuracy in the periphery
with different contrast targets with
varying set-sizes using neutral cues

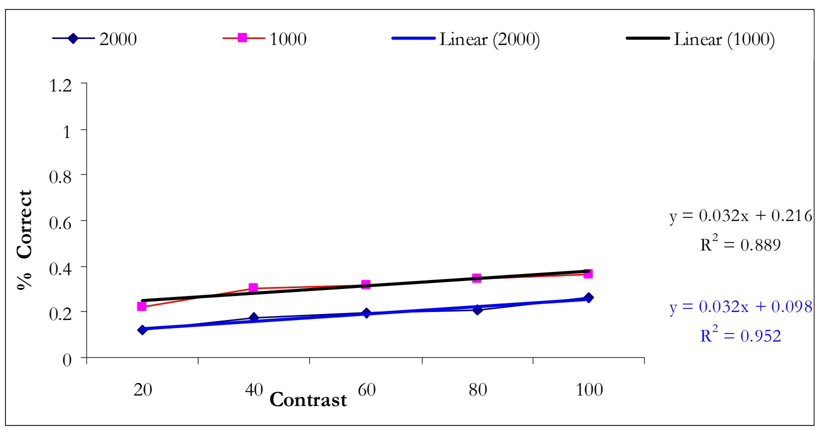

Figure 4-36: Accuracy in the periphery
with different contrast targets with
varying set-sizes using valid cues

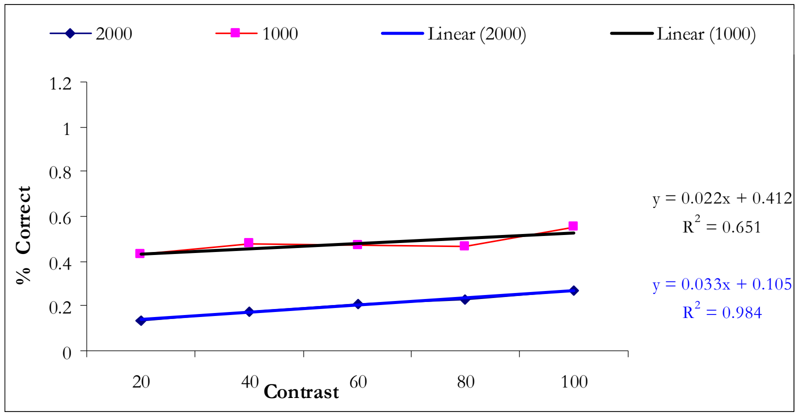

Figure 4-37: Accuracy in the periphery with different contrast targets with varying set-sizes using invalid cues

A regression analysis of accurate responses in periphery as a function of contrast with different set sizes and cues showed that responses vary as a function of contrast in a similar fashion for both valid and invalid cues across both set-sizes.

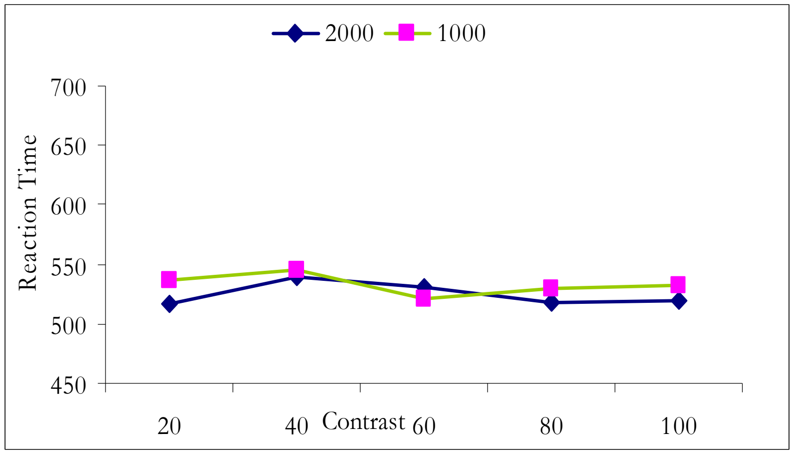

Figure 4-38: Reaction time in the periphery with different contrast targets with varying set-sizes using neutral cues

The reaction times were decreased for increased contrast for a smaller set-size both at center and periphery (Figure 4-38).

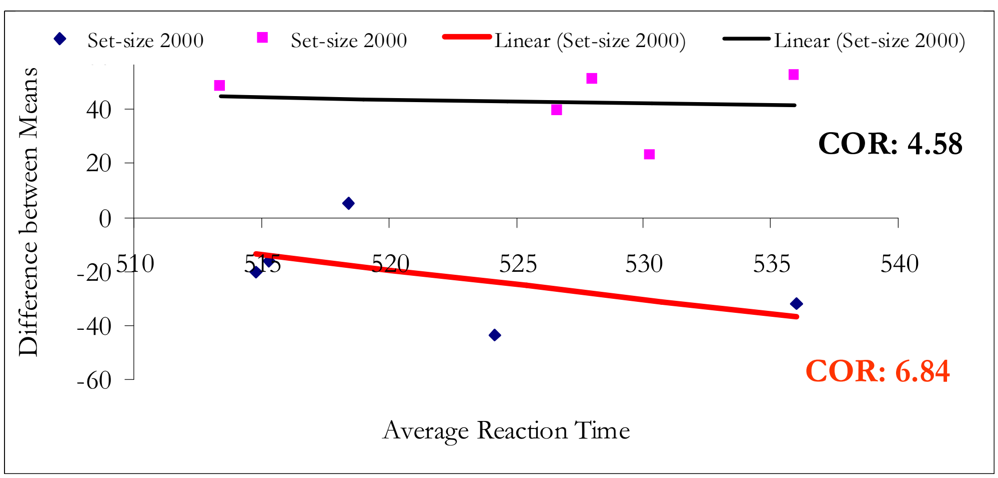

Figure 4-39: Trend seen in the Average responses and the difference between the means for set-size 2000 and 1000

The plots for the two observers were then analyzed for the variation in the means of their responses. The trends in the 1000 and 2000 dot density were similar (Figure 4-36, Figure 4-37, Figure 4-39).

The reaction times were also plotted for both observers separately to see if the trend they showed was the same. The trend in the responses for both observers shows an increase in the difference between means with increasing contrast for set-size 2000, whereas for the set-size 1000 the responses had a consistent overall difference.

4.5 Discussion

Significant effects on perceptual and neural responses have been reported with contrast changes (Morgan, Ward & Castet, 1998, Palmer, Nasman & Wilson, 1994). Discrimination of a target with a high contrast target, compared to the background, is reported to be more precise and rapid to produce a superior neural response (Chichilnisky & Wandell, 1995). On analyzing all the targets, presented in the overall visual field, the reaction time was to be reduced with increasing levels of contrast. As expected more targets with higher contrast levels were easily visible compared to low contrast targets.

4.5.1 Contrast and Eccentricity

This effect of contrast was uniform over all the eccentricities. At a peripheral location the with the changes in the physiological properties of the visual system(Albrecht & Hamilton, 1982), there is a marked reduction of performance and accuracy. Earlier studies done with transient cues to study eccentricity effects show higher reaction time and errors with the target located more eccentrically. The trend was found to be similar for the targets used in this experiment. The increasing contrast showed a decrease in the reaction time for all the targets at all eccentricities. Only at extreme peripheral locations the reaction time got longer and there was no effect of contrast. The accuracy was seen to increase with the increasing contrast at all levels of eccentricity.

It could be therefore concluded that the experiment was in agreement with the zoom lens model by Eriksen, (Eriksen & St James, 1986), wherein the central targets gain immediate attention compared to the peripheral ones, which is reflected by short reaction time and accuracy in the center. A similar assessment was previously reached by Eimer (2000), using event related potentials (ERPs). The results from this experiment are in agreement with results of Eimer's study that found attentional processing most efficient in the central ring of attention and least at the outer(Eimer, 2000).

4.5.2 Contrast and Target Size

Visual acuity decreases with increasing retinal eccentricity and so does the sine-wave contrast sensitivity (Riggs & Ratliff, 1951, Westheimer, 1965). Previous studies dealing with contrast matching as a function of eccentricity have reported similar results(Daitch & Green, 1969, Hilz & Cavonius, 1974, Virsu, Rovamo, Laurinen & Nasanen, 1982) and these effects are considered to be dependent on the physiological structure of the retina(Green, 1970).

The increase in the contrast for a given target size resulted in a decreased reaction time. The effect was consistent both in the central and the peripheral visual field. Owing to the effect of eccentricity on contrast and the target size the errors and reaction times were higher for periphery and less for the center. Detection of a small target is difficult irrespective of its location of presentation. The trend of response was therefore found identical for both the central and peripheral fields. With the increase in contrast and the visibility of the target, the differences in mean reaction times got longer. On the other hand, for targets with MAR10 the trend was opposite, as the mean reaction time differences between the two observers became smaller with the higher contrast in both center and periphery. The response variability seems to be inversely proportional to the size. With the increase in size and visibility of a target, the ease of responding to it leads to a variable reaction time depending on the observer's reactions. On the contrary, a large target of MAR 10 is clearly and easily visible even under low contrast conditions and this leads to faster and accurate responses. This ease increases with increased target contrast, thereby leading to a lower difference between the mean reaction times for both the observers.

Detection was found to increase with increasing contrast for a small target but for a larger target the accuracy seemed to be consistent at the same level for all contrast levels. The contrast of a target mattered if the target was very small otherwise the accuracy was seen to be within 80-100% for the targets in the central field. The responses in the peripheral field were not very consistent within the two observers and therefore it could not be concluded how detection is done in the periphery. For Observer 2 the responses seemed to peak with increasing contrast levels but for Observer 1 it was found to be an opposite trend. Moreover, the presentation of the targets towards the fields of lower retinal sensitivity also resulted in a reduction in target detection.

4.5.3 Contrast and Spatial frequency

For a target of a constant size, the maximum contrast sensitivity at any spatial frequency is at the fovea, decreases rapidly with increasing eccentricity (Virsu & Rovamo, 1979). The resolution of gratings reduces by 6 to 12 times in crowded displays (Kelly, 1984). The periphery is more sensitive to low spatial frequencies and with more peripheral presentation of the grating, the contrast sensitivity shifts toward lower spatial frequencies (Kelly, 1984, Virsu & Rovamo, 1979). But, beyond 20degrees of eccentricity strong aliasing effects of the retina enhance the detection of a higher spatial frequency results into a higher grating acuity (Kelly, 1984, Virsu & Rovamo, 1979). This can be understood as a reason why maximum targets with spatial frequency 1, 20 and 29cycles/degree, in this experiment, were detected at the peripheral zone.

4.5.4 Contrast and Cues

A reduction in contrast and acuity in peripheral targets has been reported in previous studies (Anderson, Mullen & Hess, 1991). Pre-cueing a target enhances the responses by reducing reaction time and errors (Posner, 1978, Posner, 1980). The results for this experiment are in agreement with previous findings with sustained and transient cues (Cameron, Tai & Carrasco, 2002, Carrasco, Williams & Yeshurun, 2002).

The invalid and valid cues were mixed in a proportion of 3:1, i.e. one out of 4 cues presented in invalid cue trials was a valid cue. This was done in order to make the observer attend the cues voluntarily. Invalid cues for sustained attention can be completely neglected at will, which can affect the result data. The reaction time with the valid cues were less compared to the neutral and invalid cues, at all contrast levels, both in the center and periphery. A valid cue directs attention directly and to enhance response accuracy and validity. The accuracy increased with valid cues for each level of contrast and so did the reaction times. The reaction time was smaller for both invalid and valid cued targets but not for the neutral-cued targets. The location and the cues had a significant interaction thereby indicating that for any location a valid cue will have an effect and it will enhance the responses.

4.5.5 Contrast, Cues and set-size

Added distractors to a limited processing model of attention have been shown to delay processing thus affecting performance (Cheal & Lyon, 1991, Jonides, 1981, Muller & Rabbitt, 1989, Nakayama & Mackeben, 1989, Yantis & Hillstrom, 1994). Opposite results were seen with the variable contrast targets that were presented among distractors. The target being a conjunction target was dissimilar with the heterogeneous distractors. They had a pop-out effect and as a result involved parallel processing of the targets. Therefore, with the increase of set-size, no increase in reaction time was found.

Though the reaction time was less, there was lower accuracy for targets presented in a larger set-size. It maybe thought of as a result of the reduced time to discriminate between the orientations of the gratings, though it was enough to detect it. The targets with low contrast, small size or high spatial frequency are difficult to identify between the distractors. Being conjunction targets and different from the distractors it was easily detected from the background due to the pop-out effect. The trend of responses for both the observers was consistent.

So, there maybe a component of serial processing involved in the detection process. There is evidence of existence of parallel models that behave like serial models, and vice versa, thereby making it difficult to completely characterize a model as either serial or parallel (Naitoh & Townsend, 1970). Hence, it could be understood as a system involving both serial and parallel processing simultaneously.

4.6 Conclusion

Target contrast plays an important role in the visual attention. A large size target and low spatial frequency do not show much effect of contrast alterations. These targets being easily detectable due to their parameters showed a consistent reaction time and accuracy unlike the smaller targets and high spatial frequency for which the effects of increasing contrast were prominent. The reaction time for these targets increased and accuracy decreased with decreasing contrast, smaller visual angle and higher spatial frequency, especially with presentation at larger eccentricities. The target contrast had a prominent effect at all eccentricities except at 40 degrees and accuracy seemed to significantly increase at all eccentricities. The results were consistent throughout the central and the peripheral visual fields. Cue validity was also found effective in enhancing responses in both, the central and peripheral fields. Visual search in presence of valid cues increased drastically both in terms of accuracy and reaction time. The final analysis involved an analysis of the set-size effect. The increased clutter resulted into a pop-out effect of the target due to its salient features compared to the distractors. Therefore, there was an ease of target detection, but the discrimination was not found efficient enough as there was a reduced accuracy for the larger set-size compared to the smaller one. This suggested the presence of a combination of parallel and serial processing involved in detection and discrimination of targets with varied contrast.

Summary

The hypotheses of the experiment included evaluating the effect of contrast on visual attention, studying the effect of sustained attention with valid and invalid cues and effect of increasing set-size on detection of targets with varied contrast. A total of 125 target combinations were randomly presented with the method of constant stimuli in 7125 trials. The observers were expected to register the direction of the grating that appeared in a particular trial when seen. The responses were analyzed for the reaction times and the errors in target detection.

The overall reaction time was found to decrease with increasing contrast. At eccentricities up to 30deg the reaction times were found to reduce, but at 40deg eccentricity the reaction time were no longer affected by the target contrast. The accuracy increased with increasing target contrast at all eccentricities tested. A small target size was found to increase the reaction times and accuracy, but with increased contrast the responses were enhanced with decreased reaction time and increased accuracy. The conjunction targets resulted into a pop-out effect and the reaction time for the targets were found to be independent of a set-size effect. Though the reaction time showed a benefit, the accuracy was low with the higher set-sizes which can be attributed to insufficient time to discriminate the grating pattern orientation. Therefore, the presence of the effect of contrast and sustained visual attention could be confirmed. The target being a conjunction target amidst the heterogeneous distractors resulted in a pop-out effect and thereby underwent parallel processing. So, the increasing set-size did not delay target detection. However, there was a drop in accuracy which indicated the presence of simultaneous serial processing.

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5. Signal Detection Theory Applied To Visual Attention Experiments

5.1 Abstract

The purpose of this chapter was to apply the methods of signal detection theory to the data obtained from the 2 of the participants who performed visual search experiments. The targets were displayed on a Sony Trinitron monitor. There were 25 different target combinations that were displayed randomly over 1425 trials and the method of constant stimuli was used. The target parameters that were varied included the visual angle and spatial frequency. The targets were presented over a 40degrees visual field from the fovea on all sides.

The observer's responses were based on a yes/no procedure wherein correctly identifying a horizontal grating orientation of 180degrees was counted as a yes. The bias, detectability and the criterion for the observers showed a lower hit and false alarm rate, increasing detectability with increasing MAR and a more conservative strategy for the targets presented in the peripheral field. The ROC curve predicted a better performance skill for the peripheral target detection when compared to the central field as evidenced by the low false alarm rate along with a lower hit rate (hence, a more conservative response strategy). From the psychometric curves, a shift in threshold was evident in the peripheral field when compared to the central field, owing to the change in criterion with target location. The search accuracy method (Palmer, 1994) showed negligible slopes

for various set sizes. We conclude that a parallel processing is involved in the visual search in this experiment.

Keywords: Signal detection, sustained attention, attention, visual attention.

5.2 Introduction:

In a visual search target detection is dependent on the presence of both signal and noise. Signal detection methods can be used to parse out the observer's sensitivity and the decision criterion for a particular task. A sensitivity measure is dependent on the stimulus strength as it measures the ability of the sensory system to process the target stimulus. Decision criterion is the observer's independent, individual and internal categorization of noise and signal. Both stimulus strength and criterion affect the decision criterion of an individual.

In a typical visual search experiment the observer has to detect a target presented between the distractors. In such detection experiments, internal and external noise affects an observer's performance. External noise comprises of all noise sources such as brightness, sound, etc. and internal noise is the intrinsic characteristic of an observer's sensory system. It is due to the intrinsic noise of the observer that the same target can have a different response with each presentation of the stimulus. The purpose of this chapter was to evaluate the effectiveness of the observer's performance in these visual search tasks based on analysis under signal detection theory.

5.3 Methods

Data from two participants was included in the analysis. Both participants had a visual acuity of 6/6 (LogMar chart) with normal ocular and general health.

Gabor targets with different sizes and spatial frequency were presented between distracters in 1425 random trials. The target size was designed as Snellen equivalents subtending a minimum angle of resolution (MAR) of 1.5, 3, 4, 6 or 10 min-arc at a viewing distance of 25cm. The spatial gratings were oriented at either 90deg (vertical) or 180deg (horizontal). The spatial frequency of the gratings was randomly varied at 1, 5, 10, 20 or 29cycles/degrees. The neutral cued experiments were repeated in different set-sizes of 500, 1000 and 2000.

The tests were done both in the center and the periphery to compare the results. There were 5 locations tested in the central 20deg and at 8 locations in the peripheral 20- 40deg visual field. Each point was tested for 4 times in the periphery at each location.

The targets were randomly presented by the method of constant stimuli. The observer had to identify the Gabor with horizontal (180) grating, i.e. the signal when presented and respond in a Yes/No procedure. The data was then segregated on the basis of responses obtained for the targets with same parameters. The correct and the wrong responses for targets registered were evaluated. The targets were presented with and without cues. The cued targets were either valid or invalid cues. This data was also analyzed.

5.4 Results

5.4.1 Detectability

Detectability measures an observer's sensitivity for different targets. This index helps to find whether there is a change in signal detection sensitivity or if the observer prefers a "yes" response. The detectability was measured by calculating the difference between the z-scores of false-alarm rate and the hit-rate.

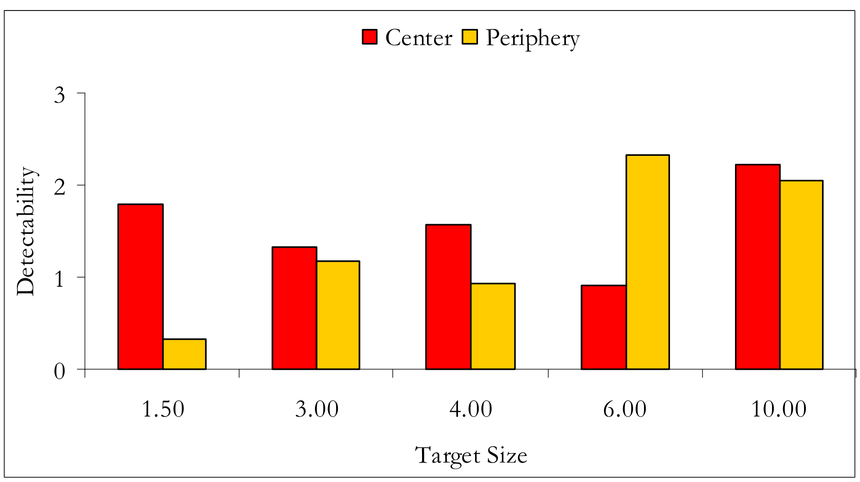

Figure 5-1: Detectability for observer1
for targets with spatial frequency
5cycles/degrees

The detectability increased with the target size increments as expected. Figure 5-1 shows that the target was detectable at all times to the observer, since detectability (d') at all levels are above 0. The detectability for the central and peripheral targets was then compared. The detectability in the periphery gradually increased with target size unlike the central targets that were closely spread within a small range of detectability.

5.4.2 Hit rate and false alarm rate

The hit rate and false alarm for the targets was calculated. The hit rate was found to be higher for the targets with a larger size and higher spatial frequency. The peripheral hit-rates and false-alarms were low when compared to central targets. Figure 5-2

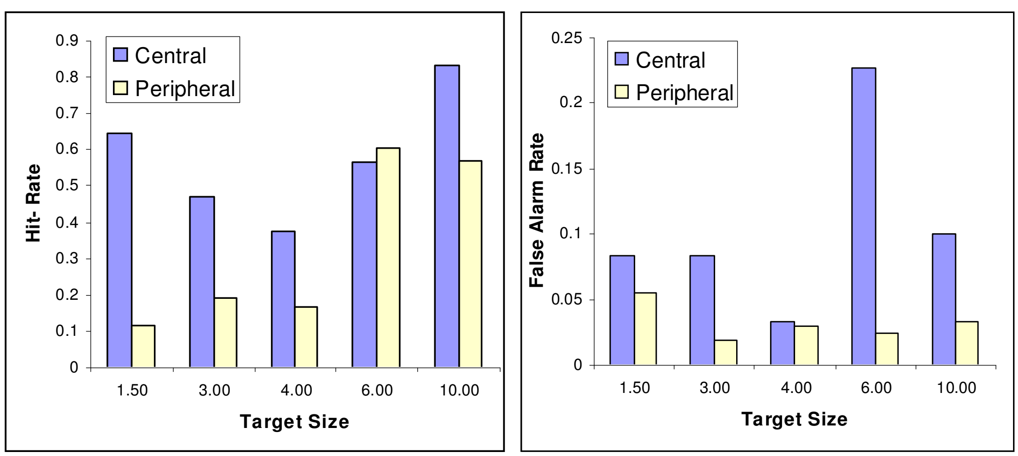

Figure 5-2: Observer1 Hit-rate and False alarm rate

5.4.3 Response Index Bias

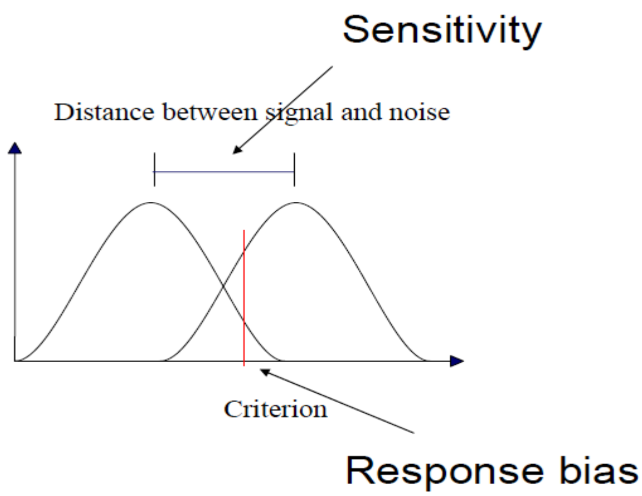

Figure 5-3: Response Bias and Criterion

A high false-alarm rate is usually associated with a high hit-rate. Therefore, an observer chooses a criterion based on the stimuli. When the strength of the stimulus is higher than the criterion, response is registered as "detected" else "not detected". The response bias index is an indicator of the degree to which a "yes" or a "no" dominates the observer's responses. (Figure 5-3) It was measured as the half of the sum of z scores of the hit-rate and the false-alarm rate. The response bias for observer's index was always positive implying a more conservative approach of the observers. This gradually declined with the increasing target size.

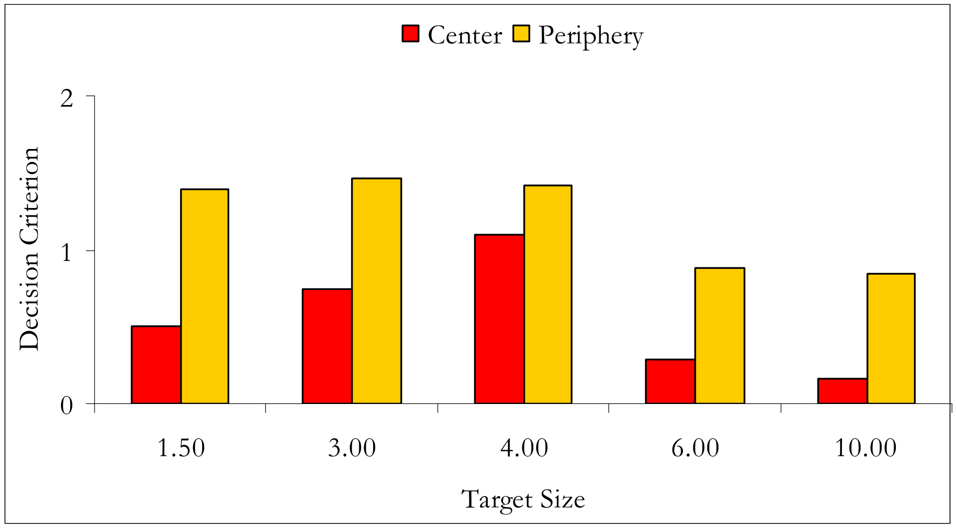

Figure 5-4: Decision criterion for Observer1 for targets with spatial frequency 5cycles/degrees

Decision criterion analyzed for the same set of targets for both center and periphery showed a difference as the criterion for the central targets was always lower compared to periphery.

5.4.4 Receiver Operating Characteristic (ROC) curve

A ROC curve was plotted using data from responses to targets with a spatial frequency of 5 cycles per degree, using the hit-rates and the false alarm rates for observer 1. The area (A) is an index of estimated performance skill on the basis of the false-alarm rate and the hit-rate. For tables refer to Appendices A & B.

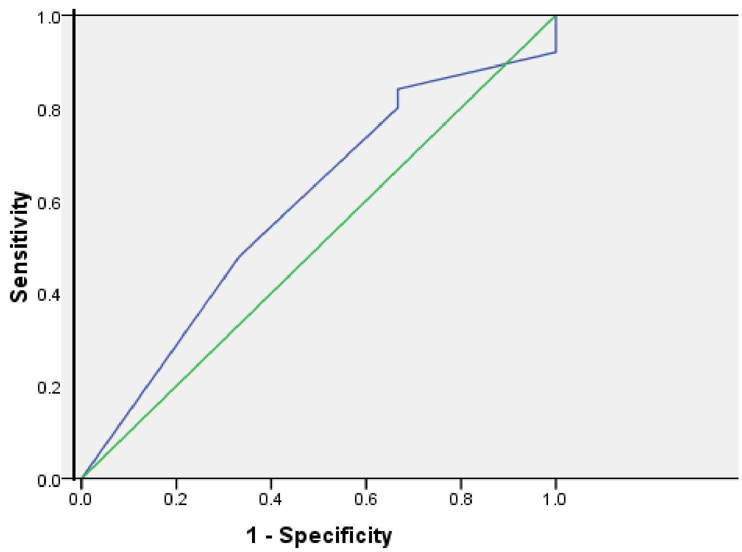

Figure 5-5: ROC curve for Observer1 at periphery (right) for targets with spatial grating 5cycles/degrees

The ROC curve for the central targets showed performance skills (A<0.5), whereas performance changed positively (A=0.587) for the peripheral targets.

5.4.5 Psychometric Function

An intra-observer comparison of thresholds for 20cycles/degrees showed the thresholds at 50% correct responses to be 2.5min-arc and 4.3min-arc for center and periphery respectively (**Error! Reference source not found.**).

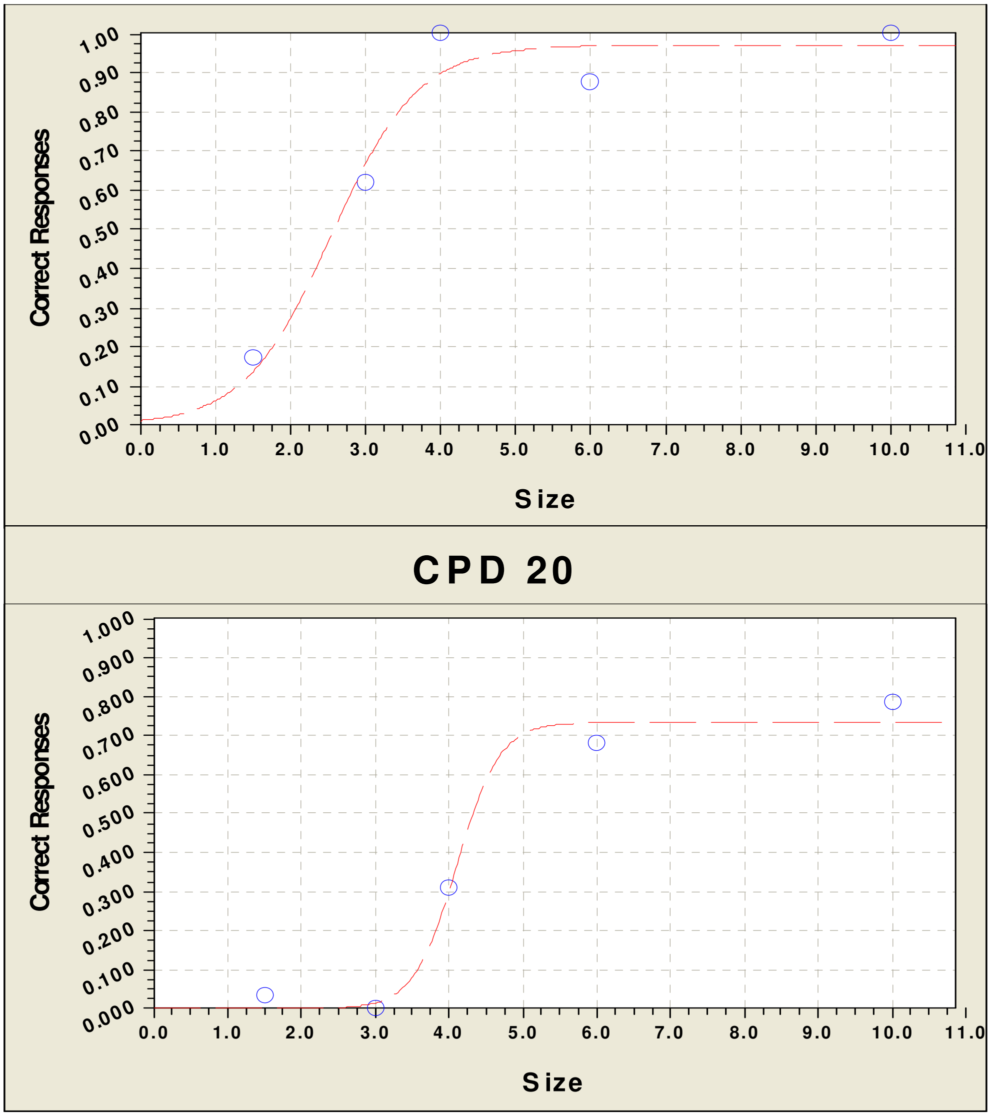

Figure 5-6: Psychometric functions for targets with 20cycles/degrees: central (top) and peripheral (down) visual fields

5.4.6 Method of search accuracy and time

The method of search accuracy and time(Palmer, 1994) was used to study the effect of set-size and cues on the targets. The visual angle increment threshold versus the set-size was plotted on a log-log scale and the slopes were obtained for set-sizes 500, 1000, 2000 and 500, 2000 neutral-cued targets.

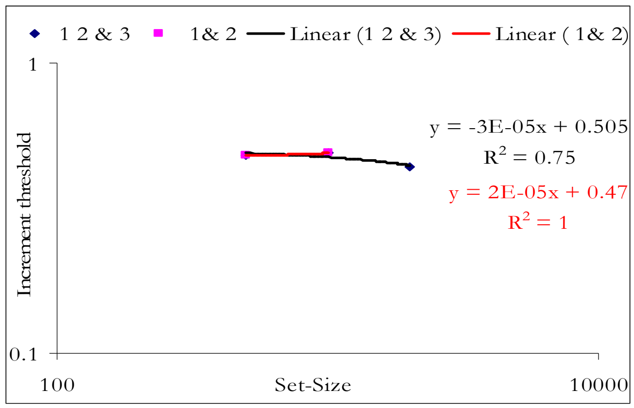

Figure 5-7: Slope for different set-sizes

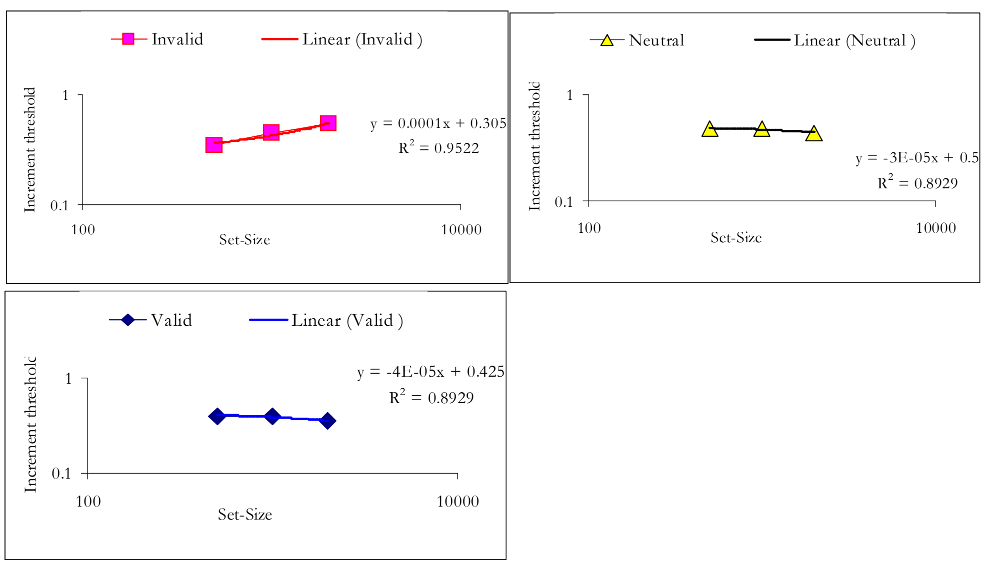

Figure 5-8: Slopes for cued and uncued targets in different set sizes

The slopes obtained for different set-sizes in valid and invalid cued conditions showed a presence of parallel processing involved in the process of visual search in this experiment in both cued and uncued conditions.

5.5 Discussion

5.5.1 Detectability

Detectability is a sensory measure of sensitivity for different targets. This index measures whether the signal detection sensitivity changes results in the response variation or an observer's willingness towards a "Yes" under certain conditions when compared to others.

The detectability was based on the visibility of the grating orientation with varying target size within the distractors. A positive detectability value for all observers indicated signal and noise curves to be significantly apart. The salient and supra-threshold conjunction targets "popped-out" in the heterogeneous background resulting in a higher detectability. All targets in the central 20 degrees had high detectability irrespective of the target size but targets displayed peripherally were found to be dependent on the MAR subtended as evidenced by the fact that the detectability increased with increase in the minimum angle of resolution. Therefore, there the hit rate was higher in the center compared to the peripherally presented targets.

Sutter et. al. (2000) have shown an ease of detecting a salient target due to the higher intrinsic variability. These investigators used tilted lines. The internal decision is based on the stimulus that evokes a greater response when observers look for a target within distractors. It is dependent on target and distractor differences, as shown by Verghese (Verghese, 2001) in her review that with increasing target and distractor dissimilarities the target response generated is always expected to be bigger than the distractor. This experiment involving salient target gives similar results thereby confirming that saliency does result in a higher detectability leading to immediate attention orientation.

5.5.2 Hit rate and False alarm rate

The overall hit rate was high with a low false alarm rate in the periphery whereas the central targets result in higher false alarm rates. A high hit-rate is usually associated with a higher false alarm rate. As seen in the false alarms were consistently low for all the targets. The supra-threshold conjunction targets were visible due to a pop-out effect in the center, due to which there was a high detectability and hence a high hit rate in the center. The search task is easy when the target is salient compared to the distracters. The Gabor target being a conjunction target with salient features can definitely be thought of "popping-out" from the background with only grayscale random dots and no gratings. This resulted in widely spread signal noise curves, due to the less noisy probability density functions, therefore leading to a higher detectability. The strategy in the center was therefore a more "liberal" approach due to the high detectability for all the targets. However, due to the more liberal approach the number of false alarm was also correspondingly high.

Compared to the center, the periphery had a lower hit rate from which one can infer that the observers were more conservative in registering the responses to targets presented peripherally compared to the central visual field. The conservative approach therefore resulted in fewer responses, i.e. a low hit rate and a low false alarm rate.

5.5.3 Response bias

A tendency to give more hits results into a higher likelihood of false alarms. Therefore, the ideal strategy that can be adopted by an observer, to avoid false alarms or false negatives, is to pick a criterion location along the internal response axis, i.e. "no bias" for registering a response. For every given trial, it can be understood that the observer sets up a criterion. If the strength of the stimulus is greater than the criterion then the response is registered as "detected" or else it is "not detected". Therefore, how the response bias guides an observer to respond can be evaluated by the degree a "yes" or a "no" dominates the observer's responses.

Owing to the high detectability of a larger salient target, the response bias was low for a bigger target. The response bias being set at a lower criterion, the appearance of a smaller target resulted in smaller response curve for the target compared to the response curve of the distractors, thereby increasing the chances of wrong response and missing a small target. A conservative criterion observed in the responses for peripherally presented targets resulted in low false alarm rates, though there were relatively a higher number of hits.

5.5.4 Receiver Operating Characteristic curve (ROC)

The ROC curve evaluates the sensitivity as an interaction of false alarms and hit-rate with change of a "criterion". It is known that the responses are affected by expectations of an observer.

Display elements	**Noise**	Gabor with 90 Degree Orientation
	Signal	Gabor with 180 Degree Orientation
Categories (Criteria)	**Barely Visible**	Target Size MAR 1.5
	Better Visibility	Target Size MAR 3.0
	Good Visibility	Target Size MAR 4
	Mostly Visible	Target Size MAR 6
	All Visible	Target Size MAR 10

Table 5-1: Signal, Noise and Detection Criterion for ROC curve

An observer is conservative in registering a "yes" response when a target stimulus is shown infrequently and results in a high number of correct rejections and misses whereas , incase the target stimulus is frequently displayed the responses yield a higher amount of hits and false alarms.

The Gabor gratings with orientation at 180 degrees represented the Signal to be identified and the gratings oriented at 90 degrees represented the noise. The "criterion" for plotting this ROC curve was the target size under each spatial frequency. There were 5 different target sizes based on (MAR) under each spatial frequency and the ROC curve obtained was based on the correct and wrong responses registered by observers. E.g. Responses for MAR: 1.5, 3, 4,6,10 under spatial frequency of 1 cycle per degree.

The detectability being equally high for all centrally presented targets resulted in a high the hit-rate leading to a shift of response bias to a more liberal approach. It is known that a high false alarm rate is associated with a liberal approach. When plotted it is seen that the false-alarm rates were high for the targets presented in the central field due to an equally high retinal sensitivity for all target sizes presented at the central retina. Therefore, the response curve of the target was larger than the distractor curve for each target displayed in the central 20 degree radius.

As evident from the results (Figure 5-1), the detectability increased proportionately with increase of target size (MAR). The lower probability of stimulus detection reduces the expectancy and therefore results in a high hit-rate with a low false alarm rate, as seen in the case of peripherally displayed targets. The response bias indicated a conservative approach. This resulted in a low hit and false-alarm rates for the targets shown in the peripheral field. Therefore, the response curve got dominant with a larger target that subtended a higher MAR. Consequently, the area under the ROC curve was larger for peripherally presented targets (A=0.6) compared to centrally presented targets (A<0.2). The change in performance with the level of bias that was present along with the variable sensitivity predicted a better performance in peripheral field as compared to central field.

5.5.5 Psychometric Curve

According to the classical threshold theory a psychometric curve helps to estimate the mean and variability of the distribution of momentary thresholds for the stimulus presented. A psychometric function plots the transition of a stimulus from not-seen to seen as a sigmoid shaped curve (Ehrenstein & Ehrenstein, 1999). The linear interpolation method (Figure 5-9) to estimate threshold uses the highest and lowest stimulus with the stimulus above and below the detection threshold (e.g. 50%) proportion of reported targets (Ehrenstein & Ehrenstein, 1999).

$$Threshold = a + (b - a) \times \left(50 - a \big/ b - 50\right)$$

Figure 5-9: Linear interpolation Equation

In the above equation (Figure 5-9), T represents the threshold, a and b are the intensity levels of the stimuli that bracket 50% detection ("a" < "b"), and pa and pb the detection percentages respectively.

Therefore, in the case when all the targets used are supra-threshold and decision criterion is at 50% proportion of targets seen, the estimation of the threshold for the observer will not be possible as the proportion of targets seen will always be plotted above the detection criterion of 50%. The targets used in the experiment were a combination of sub- and supra-threshold targets for an appropriate estimation of threshold using psychometric function plots. But, the proportion of targets from the display set that were visible at the center was more than in the periphery, which was indicated by high calculated values for detectability.

The psychometric plots plotted as a function of size, for both observers 1&2 showed a difference in the level of sensitivity for the peripherally presented targets compared to the central ones as the curve for the peripheral targets showed a right shift, indicating a change in the criterion for peripheral targets.

The method of constant stimuli can be affected by changing the proportion of trials of the signal presentation. With an increase in the proportion of signal, the proportion of "yes" responses increase for all intensities of the signal due to lowering of observer's criterion(Eckstein, Thomas, Palmer & Shimozaki, 2000) thereby causing a shift of the psychometric curve and lowering of the threshold.

5.5.6 Method of Search Accuracy and Time

This model is based on signal detection theory by Green and Swets and was first applied by Tanner(Green & Swets, 1966). Palmer (Palmer, 1994) introduced the method of search accuracy and time to find the effect of set-size on target detection which is independent of assumptions about any alteration in the quality of the representation of each individual element as a function of target / distractor similarity or increasing number of distractors (Tanner, 1961, Tanner & Swets, 1954). This method of search accuracy and time has been successfully applied in predicting the set-size effect on performance in various search tasks (Eckstein et al., 2000) and including tasks involving the detection of contrast-defined targets on a variety of backgrounds (Palmer, 1994). In the context of SDT, the internal discriminability between the target and the distractor is dependent on the alterations in the physical difference between the target and the distractors along the relevant feature dimensions (Burgess & Ghandeharian, 1984, Eckstein & Whiting, 1996, Swensson & Judy, 1981).

Studies of attention as a function of enhanced noise under cued and uncued conditions have been previously done by Dosher and colleagues to emphasize signal enhancement (Dosher, Han & Lu, 2004, Dosher & Lu, 2000a, Dosher & Lu, 2000b, Lu & Dosher, 1998, Lu & Dosher, 2000, Lu & Dosher, 2004, Lu, Lesmes & Dosher, 2002). The results of this experiment involving three different set-sizes resulted in slopes with negligible differences that confirmed no effect of set-size on accuracy. This was consistent for both cued and uncued conditions.

The targets being different from the distractors in 2 different feature dimensions follow a max-linear rule in a disjunction search and the distractors follow the max-min rule. According to the "Max Rule", the detection of a target is a decision based selection of the largest response across the units(Palmer, 1994). This explains that since the target in a disjunctive visual search has a larger response in both the dimensions, the target will be chosen over the distractor anyhow (Eckstein et al., 2000). Therefore, the overall detectability performance is higher for all targets in the experiment. It is also shown by Eckstein et. al. (2000) in his study with conjunction targets that it adheres to the predictions of the signal detection theory and that the stimulus do not undergo a serial limited processing.

5.6 Conclusion

The performance of the observers was in line with the predictions of the signal detection theory. A large number of targets were registered correctly in the central field compared to the peripheral field due to a high detectability of the targets and a "liberal" response bias. The ROC predicted a better performance in the peripheral field compared to the central field. The detectability, response bias/criterion, psychometric curve and the search accuracy measures showed a predicted effect on the overall performance.

Summary

This section aimed to study the relevance of SDT with the data obtained in a visual search and attention experiment. The data was based on detection of a 180 and 90 degree grating orientation. The targets were combinations of 5 different spatial frequencies and sizes. Various tests of signal detection were applied to the data and analyzed. The detectability was found consistently high for central targets and were independent of the MAR of the target, whereas the peripheral targets had a dependency on the MAR as the detectability increased with the target MAR in the periphery. Owing to the high detectability of targets in the central field the response bias was low that resulted in a higher hit-rate and false-alarm rate. The peripheral targets showed a more conservative approach and therefore there was a less false-alarm rate associated with the hit-rate in the periphery. The psychometric plots were made for both the observers, which showed same threshold for both the observers for the centrally presented target with spatial frequency 1 cycle per degree. There was a change in thresholds for the peripheral >20 to <50 degree field due to the change in observer's response bias. Owing to the high detectability, and high hit and false alarm rate for the targets presented in the central fields, the area under ROC predicted a failed test for the central targets. The search accuracy plot indicated the presence of a parallel processing involved with the visual search. Overall the data was found to be consistent with the predictions of the signal detection theory.

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6. Conclusion

Visual attention is essential in day to day life in order to locate and identify objects in the visual field. This has to be done accurately in spite of the infinite number of distractors in the environment. The distractors in the environment may differ or be identical to the target. The more the dissimilarity between the target and distractor, the easier it is to identify the target.

The targets presented as Gabor gratings in the present experiment were conjunction targets with different physical characteristics and the distractors were small grey-scale dots. The large dissimilarity of the targets and distractors led to a pop-out of the targets thereby facilitating a parallel processing of the targets presented. Sutter et. al. (2000) showed that with a salient target the ease of fast and accurate detection increases. Verghese, (Verghese, 2001) in her review showed that with increasing dissimilarities between the target and distractor, the target response generated is always expected to be bigger than the distractor. The experiments described in this thesis involving salient targets gives similar results thereby confirming that saliency does result in a higher detectability leading to immediate attention orientation. Other SDT evaluations like detectability, response bias/criterion, psychometric curves and search accuracy measures showed a predicted effect on the overall performance.

The reaction time and accuracy have been studied by researchers under both transient and sustained cues. These studies have analyzed the effects of contrast, eccentricity, spatial frequency, target size, etc (Cameron, Tai & Carrasco, 2002, Carrasco, Evert, Chang & Katz, 1995, Carrasco, McLean, Katz & Frieder, 1998, Carrasco, Penpeci-Talgar & Eckstein, 2000, Carrasco, Williams & Yeshurun, 2002, Carrasco & Yeshurun, 1998, Yeshurun & Carrasco, 1999, Yeshurun & Levy, 2003) involving covert attention. The cues involved in most of these studies were transient in nature with the cue appearing at the target location. The field of vision involved was less than 40 degrees of eccentricity. The present experiments studied attention with conjunction targets, i.e. targets with a combination of different physical characteristics and features, in a field more than 40 degrees radius.

The reaction time and errors were found to be dependent on the eccentricity of the target presentation as shown in previous studies using transient cues (Cameron et al., 2002, Carrasco & Frieder, 1997, Carrasco et al., 1998, Carrasco & Yeshurun, 1998). The cues enhanced the responses at all eccentricities and improved performance. Sustained attention cues like transient cues reduced the eccentricity effect but did not completely reduce the eccentricity effect. Enhanced signal with cues is also shown experimentally by Dosher and Lu (2000a,b) . The reaction time increase with presentation of targets with different contrast is associated with a smaller visual angle, and higher spatial frequency at greater eccentricity. It is consistent both in the central and peripheral visual fields. Conjunction targets presented with contrast alterations were found to enhance the signal with increasing contrast by reducing the reaction time and errors in detection of targets, at all eccentricities.

In this thesis I studied how reaction time and accuracy changes with changes in target characteristics. The study was performed up to an eccentricity of 40 degrees radius. To the best of my knowledge this study is the first of its kind as it includes Gabor targets with combination of 5 different sizes, 5 different spatial frequencies and 5 different contrast levels in a visual field of a radius of 40 degrees.

The study predicted enhanced attention, in terms of reaction time and accuracy of detection, with increased contrast and target size in the visual field. If a target is designed to attract observer's attention, it should be a high-contrast, large and salient to "pop-out" from the background to effectively draw attention irrespective of the amount of distractors in view.

Applications and Future work

The findings from this thesis can be utilized in designing banners, traffic signals and road signs to more effectively draw attention of the pedestrians and drivers towards the same. This work can be extended by including presenting of colored conjunction targets within distractors in a dynamic environment to predict covert attentional skills both during driving and walking around. Additionally the background can be modified to a more real life scene to predict performance in a much realist situation. The results can be then used to come up with a model of attention for the visual field up to 40 degrees radius of eccentricity. The model can be tested in virtual reality conditions, such as driving.

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Appendices

Appendix A

Center

Area Under the Curve

Test Result Variable(s):size

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.290	.107	.168	.080	.500

The test result variable(s): size has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Coordinates of the Curve

Test Result Variable(s):size

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
.5000	1.000	1.000
2.2500	.659	1.000
3.5000	.500	.750
5.0000	.341	.750
8.0000	.159	.250
11.0000	.000	.000

The test result variable(s): size has at least one tie between the positive actual state group and the negative actual state group.

a. The smallest cutoff value is the minimum observed test value minus 1, and the largest cutoff value is the maximum observed test value plus 1. All the other cutoff values are the averages of two consecutive ordered observed test values.

Case Processing Summary

c1[a]	Valid N (listwise)	
	Unweighted	Weighted
Positive[b]	5	44.00
Negative	3	4.00

Larger values of the test result variable(s) indicate stronger evidence for a positive actual state.

a. The test result variable(s): size has at least one tie between the positive actual state group and the negative actual state group.

b. The positive actual state is 1.00.

Appendix B

Periphery

Area Under the Curve

Test Result Variable(s):size

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.587	.175	.629	.243	.931

The test result variable(s): size has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Coordinates of the Curve

Test Result Variable(s):size

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
.5000	1.000	1.000
2.2500	.920	1.000
3.5000	.840	.667
5.0000	.800	.667
8.0000	.480	.333
11.0000	.000	.000

The test result variable(s): size has at least one tie between the positive actual state group and the negative actual state group.

a. The smallest cutoff value is the minimum observed test value minus 1, and the largest cutoff value is the maximum observed test value plus 1. All the other cutoff values are the averages of two consecutive ordered observed test values.

Case Processing Summary

c1	Valid N (listwise)	
	Unweighted	Weighted
Positive[a]	5	25.00
Negative	3	3.00

Larger values of the test result variable(s) indicate stronger evidence for a positive actual state.

a. The positive actual state is 1.00.