Behavioral Mechanisms of Exogenous Cueing

A thesis submitted towards partial fulfilment of

BS MS Dual Degree programme

By

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<u>Certificate</u>

This is to certify that this dissertation entitled "**Behavioral Mechanisms of Exogenous Cueing"** towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune, represents original research carried out by **Vishak Sagar** at Indian Institute of Science, Bangalore under the supervision of **Dr. Sridharan Devarajan**, Assistant Professor, Centre for Neuroscience, IISc Bangalore during the academic year 2016-2017.

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Place: Bangalore

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Date: 29/04/2017

Place: Bangalore

Declaration

I hereby declare that the matter embodied in the report entitled "Behavioral Mechanisms of Exogenous Cueing" are the results of the investigations carried out by me at the Centre for Neuroscience, IISc Bangalore, under the supervision of Dr. Sridharan Devarajan and the same has not been submitted elsewhere for any other degree.

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Contents

Abstract

Attention is a process of selection. Visuospatial attention is the cognitive capacity by which a stimulus at a particular spatial location in the visual field is selected for further neural processing. Here, we sought to understand the effect of exogenous cueing in 4 alternative orientation change detection task. Our study indicates that exogenous cueing reduces sensitivity at all non-cued locations, and decreases criterion at the cued location. This implies that for an observer presented with an exogenous cue the sensory information at the cued location is undisturbed but the sensory information from all the other locations are affected. Also the observer gives more weightage to the cued location in the downstream processing of the information.

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I would like to thank my parents for supporting me through the course of my thesis.

Introduction

Attention is a cognitive process of selection. As animals have limited resources to interact with the environment, prioritizing the resources, both physical and mental, becomes essential. Visual attention enables animals to effectively interact with their surroundings by directing their focus to a particular location in an environment while not favoring others to effectively guide behavioral actions. (Carrasco, 2011; Squire et al., 2013)

The attentional system can modulate the processing of visual stimuli by changing the visually driven neural activity. Neurons tend to engage in competitive interactions for representation of stimulus in a given setting. Neuronal activity at the receptive field of the attended location remains sustained or increases whereas the activity at the unattended location is suppressed. (Carrasco, 2011; Yantis and Jonides, 1996)

Psychophysical experiments involving two alternative forced choice (2-AFC) tasks have shown effects of attention to improve performance of observer at attended location by modulation of contrast gain, response gain, spatial acuity and others. (Barbot et al., 2011; Montagna et al., 2009; Pestilli and Carrasco, 2005; Pestilli et al., 2007)

One can direct one's attention towards a stimulus either overtly or covertly. In overt attention, the observer actively shifts their gaze towards the selected location. It is easier to perceive a stimulus at the center of the visual field than at the periphery. (Berent et al., 2015) However, we can keep our gaze fixed at a point and covertly shift the focus of our attention to a target location. Covert attention, therefore, involves the preferential processing of target sensory information without any change in retinal input. Covert attention allows us to see the environment and guide one’s eye movements to locations containing salient information. (Carrasco, 2011)

Attention can be controlled in one of two ways; ‘top down’ or ‘voluntary’ attention, which is controlled by internal goals. In ‘bottom up’ or ‘reflexive’ attention, it is controlled by external salient stimuli. On a screen endogenous/exogenous cues indicate to the observer as to where to direct their attention. Here, we will be employing a covert, bottom-up attention task.

Attentional shifts caused by centrally placed endogenous cues can be controlled, but shifts due to exogenous cues which suddenly appear at the target are automatic and very difficult to ignore (Marie et al., 2009; Nakayama and Mackeben, 1989; Yantis and Jonides, 1996). Involuntary shifts of attention occur even when the cues are irrelevant (Barbot et al., 2011; Montagna et al., 2009; Müller and Rabbitt, 1989; Pestilli and Carrasco, 2005).

Visuospatial attention enhances perceptual performance either by sensitivity control or bias control mechanisms. Sensitivity control involves enhanced perceptual processing/pre-processing of the attended target stimuli at expense of the unattended distractors. This results in the target stimulus being perceived more clearly than distractors. On the other hand, bias control involves providing greater weightage to the target stimulus in a downstream decision process, i.e. giving more preference to the target stimulus than distractors. As a result, information from distractors is filtered out (Sridharan and Steinmetz, 2014). Observers may have innate preference for a particular choice, (Gold et al., 2008) or biases may be induced by spatial cueing of the location of upcoming stimulus or increasing the frequency of presentation at particular locations (Mulder et al., 2012)

At the end of an experiment we have access to the subjects' performance to the presentation of stimuli. To extract information about the sensitivities and biases we need theoretical frameworks to analyze the psychometric data obtained. Signal detection theory (SDT) is one such well-established framework for understanding behavior in 2-Alternative Forced Choice Tasks (2-AFC).

In 2-AFC (Yes/No) tasks the experimenter tries to measure the subject's perceptual ability to detect a stimulus at a particular location. The observer is presented with a series of trials in which the stimulus is presented at a given location on a random subset of trials and is absent in others. When the observer detects the stimulus, she/he reports it with a “Yes” response; otherwise, she/he reports a “No” response.

SDT models the observer's perceptual decision in 2-AFC tasks as the outcome of an inherently noisy process. In the SDT framework for the 2-AFC task, the observer decides between the two, mutually exclusive events (was the stimulus present or not?) by weighing the relative strength of evidence for each. The decision is based on a latent random variable, the decision variable, whose mean depends on the strength of the stimulus and whose variance arises from the noisiness of the sensory evidence across trials (Sridharan and Steinmetz, 2014).

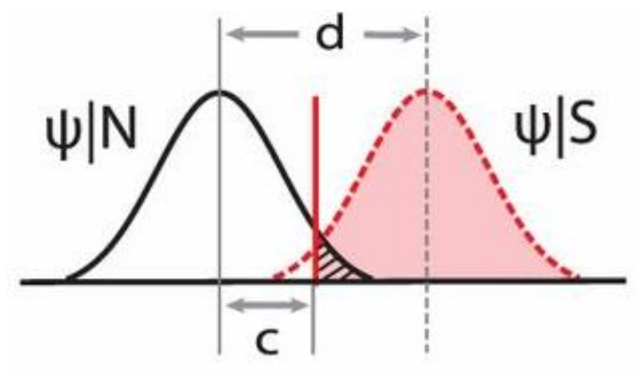

Figure 1. *Signal detection model for a simple typical Yes/No or 2AFC task using a conventional one dimensional signal detection model. Black Gaussian: decision variable distribution when no stimulus was presented, red Gaussian: decision variable distribution when a stimulus was presented. Red shading: Hit rate; hatched region: False-alarm rate; d: perceptual sensitivity for detection; c: choice criterion for a Yes/Valid response (reproduced from Sridharan and Steinmetz, 2014).*

In trials in which the decision variable exceeds a cutoff value, the observer reports having detected the stimulus (“Yes”). The cutoff value or “choice criterion” (**c**) represents the observer's bias for choosing to report detection over no detection. When the observer is highly biased toward the “Yes” choice, she/he adopts a low value for the choice criterion, which manifests as a tendency to report having detected the stimulus even when no stimulus was presented (a high rate of “false alarms”). Conversely, when the observer is highly biased toward the “No” choice, she/he adopts a high criterion, which manifests as a conservative tendency to not report detection even in trials when the stimulus was presented (a high rate of “misses”). Having accounted for bias, the observer's “perceptual sensitivity” (**d’**) to detect the stimulus, an indicator of the strength of the perceived signal, is analytically estimated from the proportion of false alarms and misses based on assumptions about the nature of the decision variable distribution (Sridharan and Steinmetz, 2014). Higher the **d’** more is the separation between signal and noise and easier it is to detect the stimulus.

Table 1 – 2AFC Contingency Table

	Valid response	Invalid response
Stimulus present	HIT	MISS
Stimulus absent	FALSE ALARM	CORRECT REJECTION

$Hit\ rate = \text{Number of Valid Responses / Total number of Trials with valid changes}$
$False\ Alarm = \text{Number of Invalid Responses / Total number of Trials with no changes}$

$d' = \varphi$^−1$(Hit\ Rate) - \varphi$^−1$(False\ Alarm\ Rate)$
$c = -\varphi$^−1$(False\ Alarm\ Rate)$
φ is the inverse of the cumulative distribution function of standard normal distribution.

When a stimulus or target is ‘attended to’, it is expected that either one or both of these components are altered: **d’** may increase and/or **c** may be lowered for the attended signal and increased for unattended distractors. (Cameron et al., 2004; Sridharan and Steinmetz, 2014; Verghese, 2001)

Though 2-AFC tasks are quite popular it is prone to this easy confound that a subject need not pay attention to the cue and only pay attention to one of the spatial locations. Since if the stimulus is not presented at the location it implies that it was presented at the other location. This can be overcome by introducing another cue after which no change happens, a ‘no go’ trial. Making it a 3-AFC task. There is no SDT framework for tasks having more than 2 choices. Also 2-AFC tasks limit the locations at which one wants to study attentional effects to only 2. Thus we will be using a 4-

Alternative Detection/Change Detection (4-ADC) and use the mADC model – multi alternative detection/change detection model to quantify sensitivities and biases.

Table 2 – 4ADC Contingency Table

	Response 1	Response 2	Response 3	Response 4	NoGo Response
Event at 1 Valid	Hit Event 1 Valid	Misidentification Event 2	Misidentification Event 3	Misidentification Event 4	Miss Event 1 Valid
Event at 2 Opposite	Misidentification Event 1	Hit Event 2 Opposite	Misidentification Event 3	Misidentification Event 4	Miss Event 2 Opposite
Event at 3 Ipsilateral	Misidentification Event 1	Misidentification Event 2	Hit Event 3 Ipsilateral	Misidentification Event 4	Miss Event 3 Ipsilateral
Event at 4 Contralateral	Misidentification Event 1	Misidentification Event 2	Misidentification Event 3	Hit Event 4 Contralateral	Miss Event 4 Contralateral
No Event	False Alarm Event 1	False Alarm Event 2	False Alarm Event 3	False Alarm Event 4	Correct Rejection

In a 4-ADC task we are able to study the observer's perceptual ability at 4 locations. The orientation changes can happen at any of these 4 locations and all are equally likely. There are 4 possible cue locations and the cues are random spatially. The cues appear at times which are sampled from an exponential distribution which prevents the observer from becoming temporally familiar with the onset of cues. There are also catch – trials (no change trials) included which prevents observers from randomly guessing.

Materials and Methods

In all 28 experiments were conducted in which 20 healthy adult volunteers participated. Some subjects participated in more than one task. All the participants had normal or corrected to normal vision. The experiment was designed and conducted in compliance with protocols approved by the Institute Human Ethics Committee of Indian Institute of Science. Also a prior written informed consent was taken from the subjects. Upon completion of the experiment, monetary compensation was provided for the participants for their time.

Experiment was performed in a dark room. Subjects were seated approximately 60 cm in front of the monitor screen (Dell 2215H, 22", 1920 X 1080, LCD screen). Screen was aligned perpendicular to the midsagittal plane of the subject, with center of the screen roughly in front of subject's eyes. A chin rest was used to stabilize subject's viewing position. Subjects were instructed to maintain gaze on a fixation cross at the center of screen, throughout the course of experiment. To ensure fixation, eye-movements were monitored using an infrared light based eye-tracker (Gazepoint GP3 eye tracker, 60Hz system).

To examine the effects of visuospatial attention on behavior, a four-alternative detection task was used. This 4-ADC task was developed at cognition lab (original task designed by Sanjna Banerjee and Shrey Grover), Indian Institute of Science, and presented using Psychtoolbox (3.0.11), a MATLAB (R2016a) based psychophysics Utility.

Five variations of the task were tried out. All began with a presentation of a white fixation cross at the centre of the screen to orient the subject towards the onset of trial. Following which four gabors/gratings, placed on the vertices of a square around the central fixation cross, appeared for a variable time which was exponentially distributed (Timing parameters are provided in the schematic below). In the first 3 versions of the task gabors were used and gratings in the rest. The gratings used, were with diameter of

80 pixels, with spatial frequency of 12 cycles per degree. The center of each grating was at a distance of 90 pixels from the fixation cross. In case of gabors, the diameter was 200 pixels enveloped with a gaussian of 10 cycles per degree. The center of each gabor was at a distance of 100 pixels from the fixation cross. The orientation of gabors/gratings was randomly selected to be rotated by a maximum of 90°, either in clockwise or anti-clockwise direction. Surrounding each gabor three black dots of size 12 pixels were placed in task 1 and 2. In task 3, one dot was placed of size 15 pixels around each gabor. In tasks 4 and 5 arcs of width 15 pixels were used. The dots/arcs would change color from black to white briefly and act as an exogenous cue. A blank screen with only the fixation cross was used in task 1. In task 2 onwards the blank screen included the dots/arcs apart from the fixation. Following the blank screen, a new set of gratings would appear of which one of the gabors/gratings may have changed orientation or none of them would have. The fixation cross would be yellow, indicating to the subject to provide response about where the change occurred or if there was no change. Subjects responded by pressing the keys on a response box (Cedrus – RB-840). After response a grey screen was shown to mark end of trial.

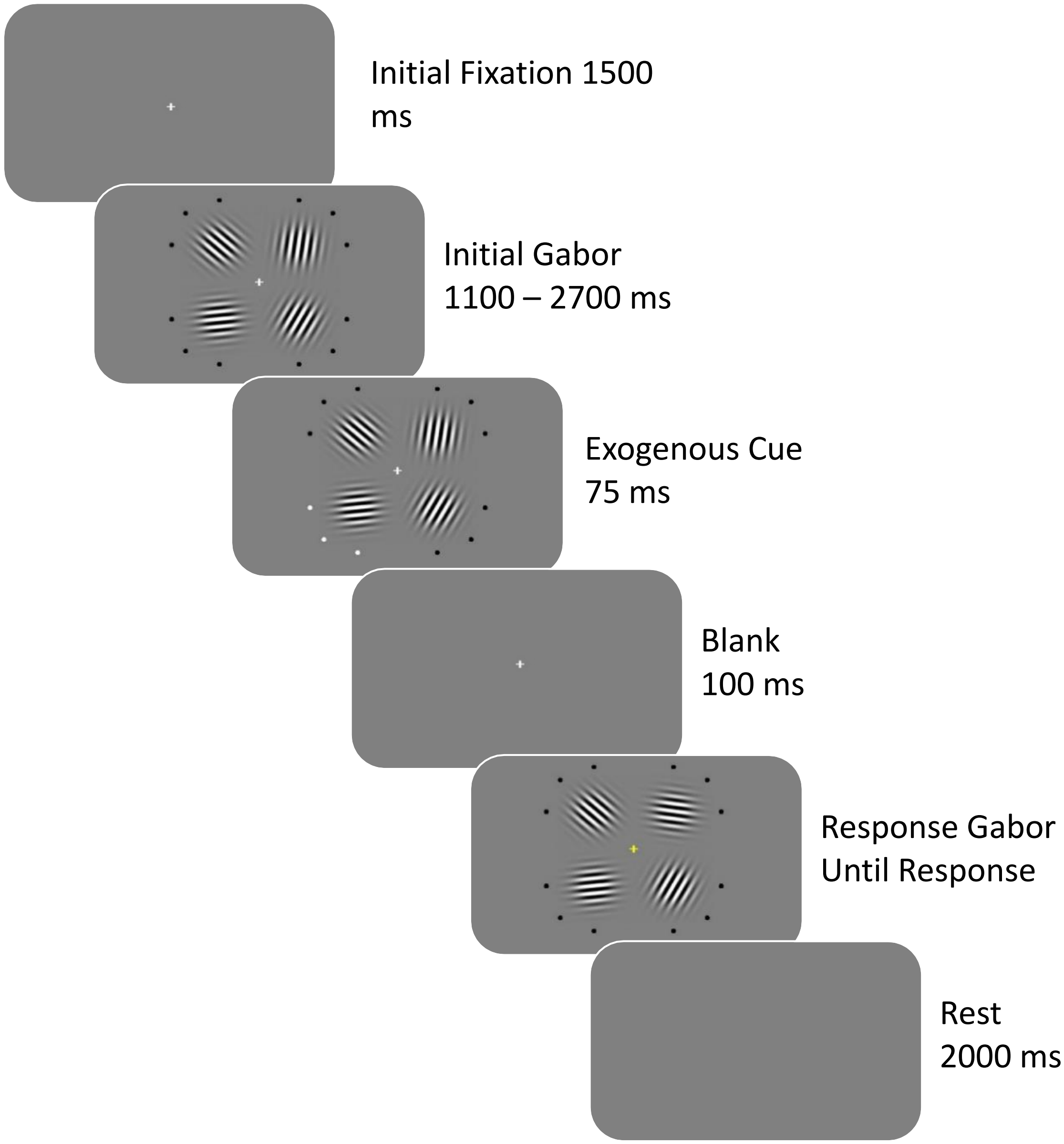

Fig 2a – Task Design 1

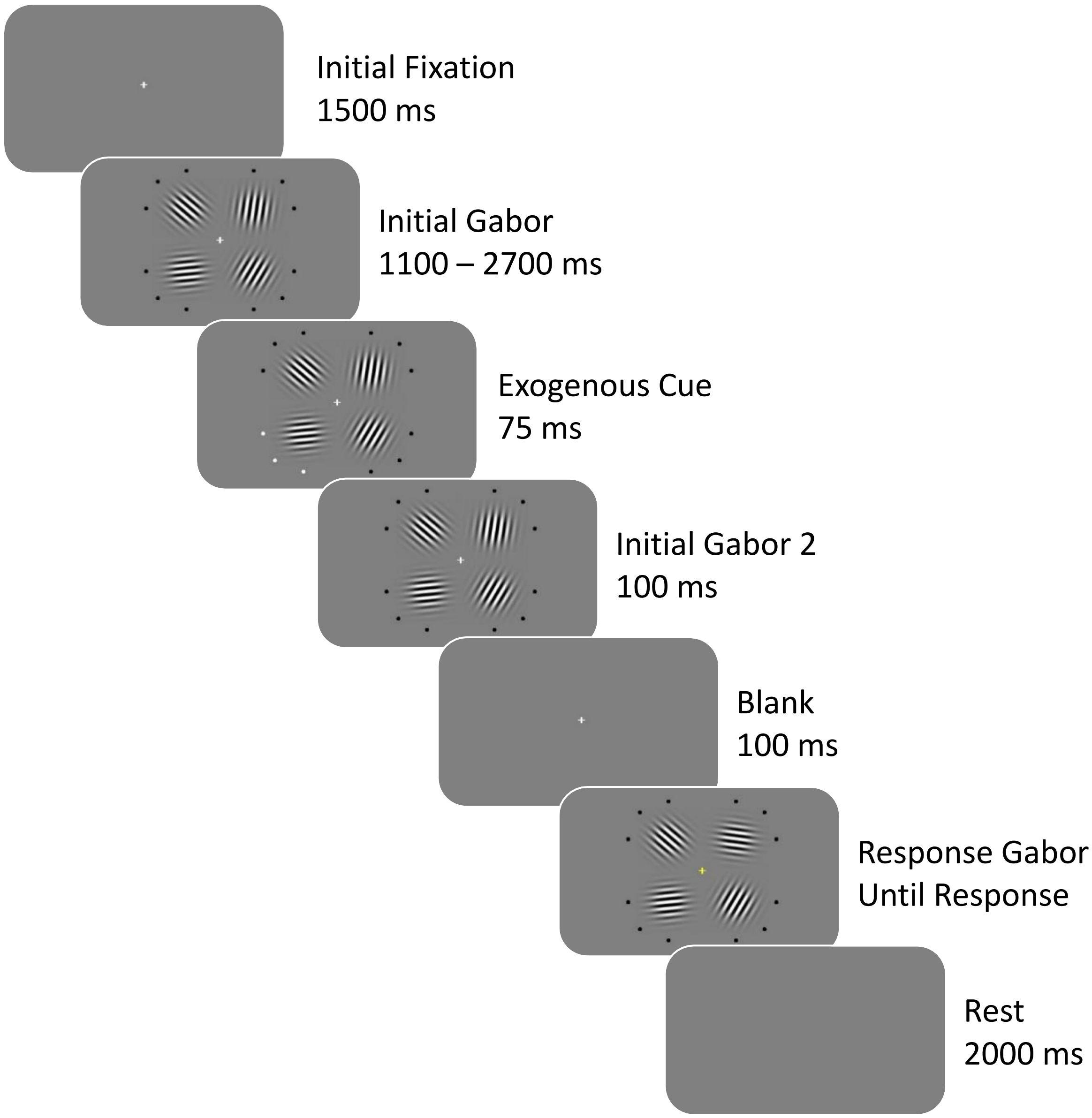

Fig 2b – Task Design 2

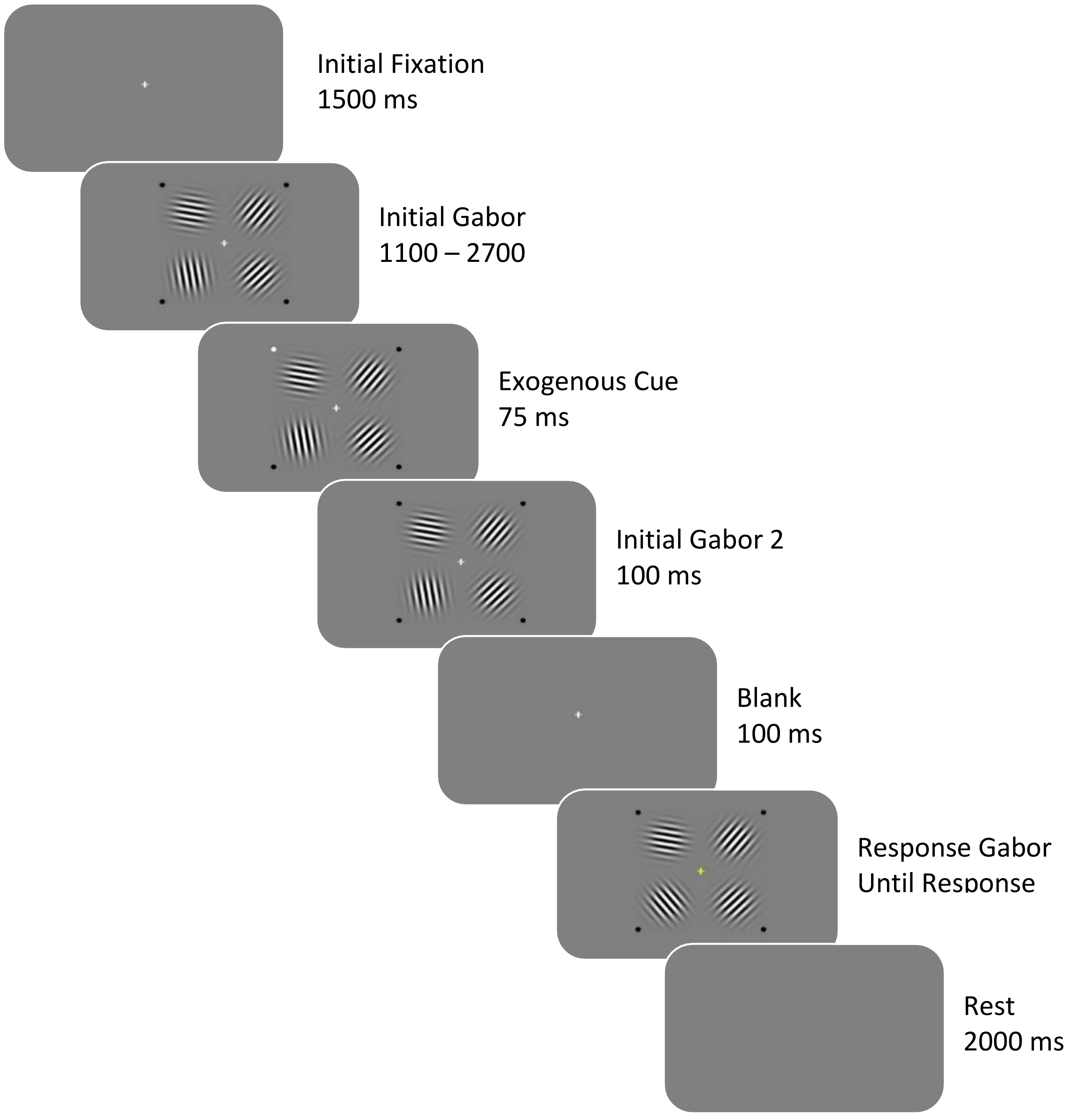

Fig 2c – Task Design 3

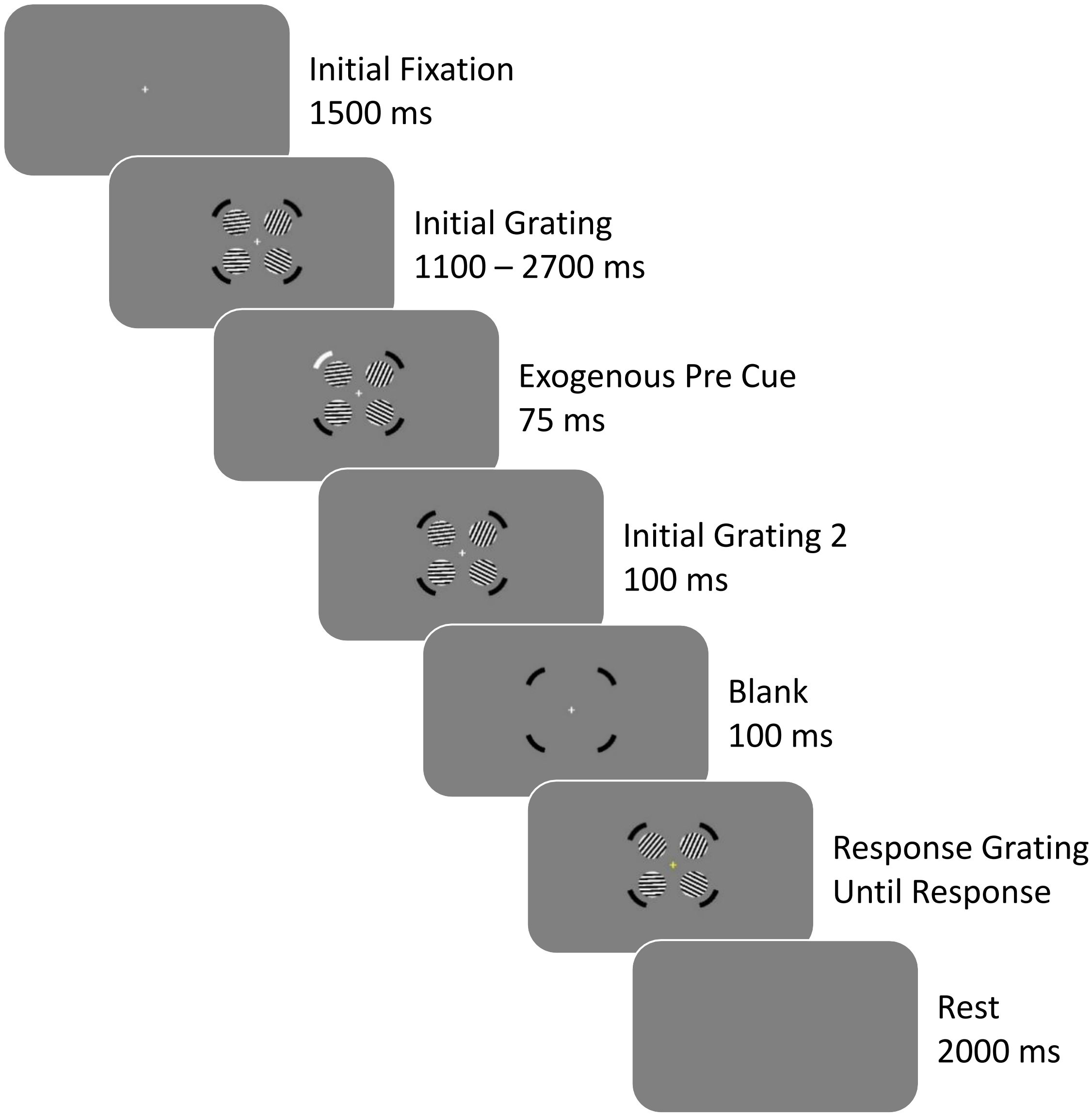

Fig 2d – Task Design 4

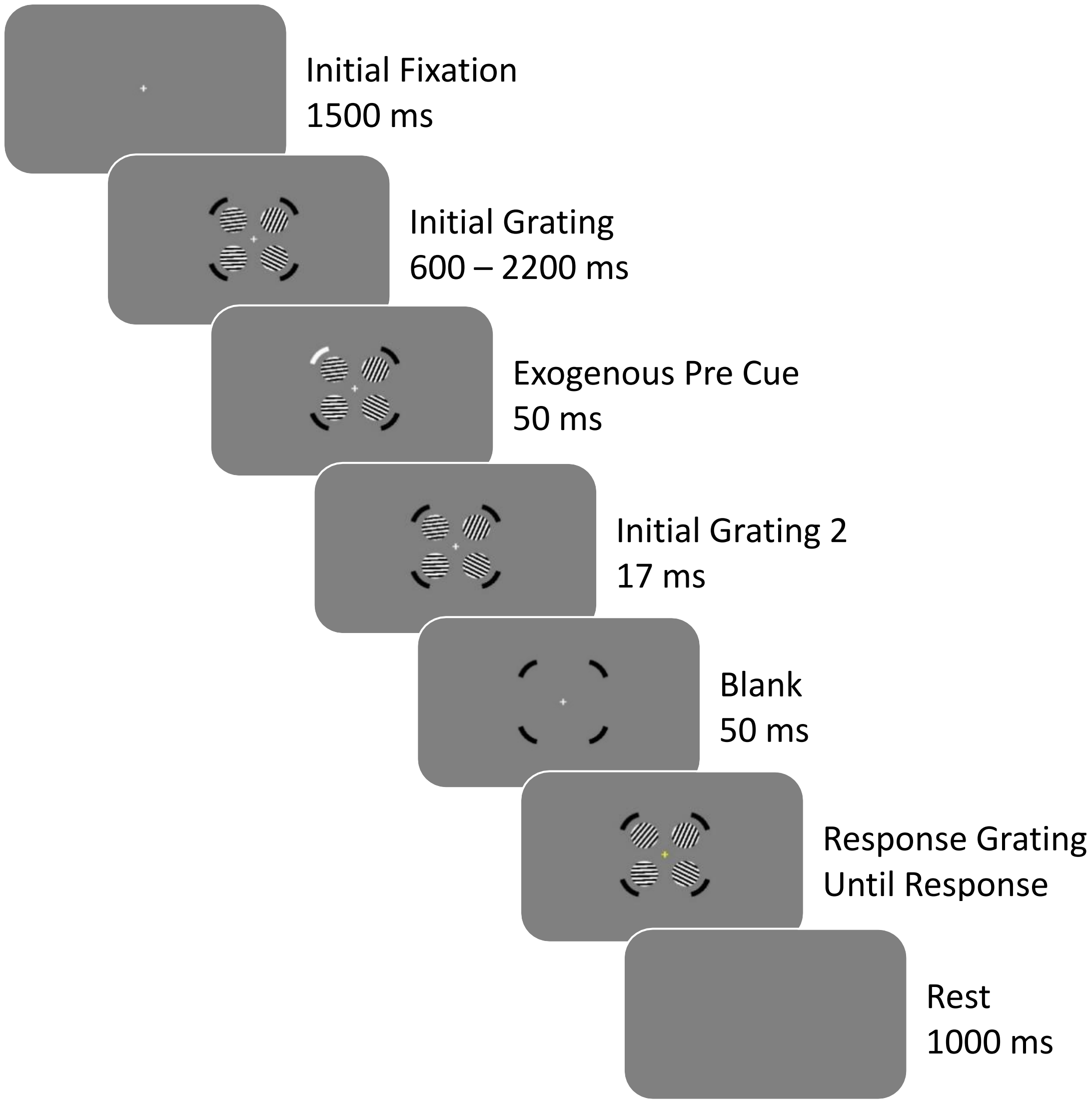

Fig 2e – Task Design 5 – Type 1 (Precue)

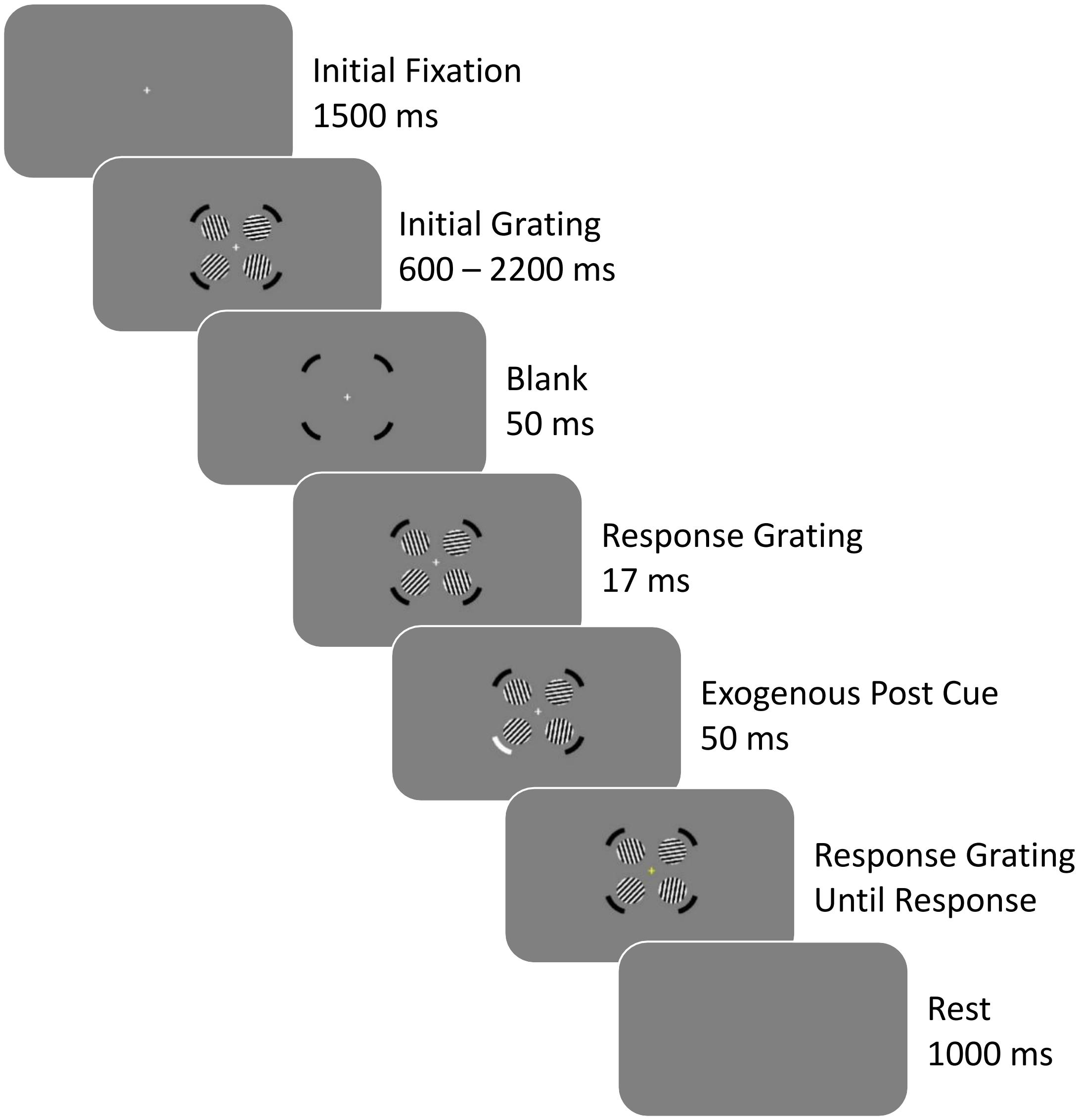

Fig 2f – Task Design 5 – Type 2 (Postcue)

Subjects were given a training block in which they were provided feedback about their response indicating correct or incorrect. In the main task there was no feedback. Subject started each block at will, by giving a key press. Trials were randomly selected to be cued (change occurs in the cued direction), opposite (change occurs opposite to the cued direction), ipsilateral (change occurs ipsilateral to the cued location), contralateral (change occurs contralateral to the cued location) with equal probability. Ratio of change to no change trials per block was kept as 3:1 in tasks 1,2,3 and some in task 4 and 4:1 in the rest of task 4 and all of task 5. Before starting the experiment, the subjects were instructed that the cue would be non-informative about the location of change. The change angles varied from 2-90°. The angles tested for each task is provided in the table below.

Table 3 – Task Parameters

	Task 1	Task 2	Task 3	Task 4	Task 5
Angles Tested (degrees)	2, 25, 90	2,10,30	2,10,30	2,10,15,25,45,90	2,12,25,45
Trials per block	64	64	64	64,100	160
No. of Blocks	4	4	4	4,3	2
Change to No change	3:1	3:1	3:1	3:1 (angles 2,10,25), 4:1 (angles 2,10,15,25,45,90)	4:1
No. of Subjects	2	2	2	14	8

From the recorded eye tracking data, the co-ordinates of the medians as estimated by the eye-tracking software in the X and Y directions were extracted per trial. Using 60cm as subject's separation from screen, the deviation of gaze from the center was estimated in visual degrees, using standard MATLAB function. While subject performed experiment, this deviation of gaze along X and Y direction with time, was plotted and observed for each trial during training blocks, and after each block during the rest of experiment. Subject was given constant feedback about fixation of gaze through online tracking of eye movement. In case, subject's gaze was found to be deviating more than 2° from the fixation after correcting for offset, immediate feedback was given to maintain fixation at the cross and such trials have been excluded from further analysis.

To compute sensory information: sensitivity values, criterion values, and psychophysical function from behavioral performance, m-ADC model was fit to the experimental data. For average data of all subjects in a group for task 4 and 5 jackknife error in sensitivities and criterion were calculated, across the subjects in the group.

Results and Discussion

Task 1

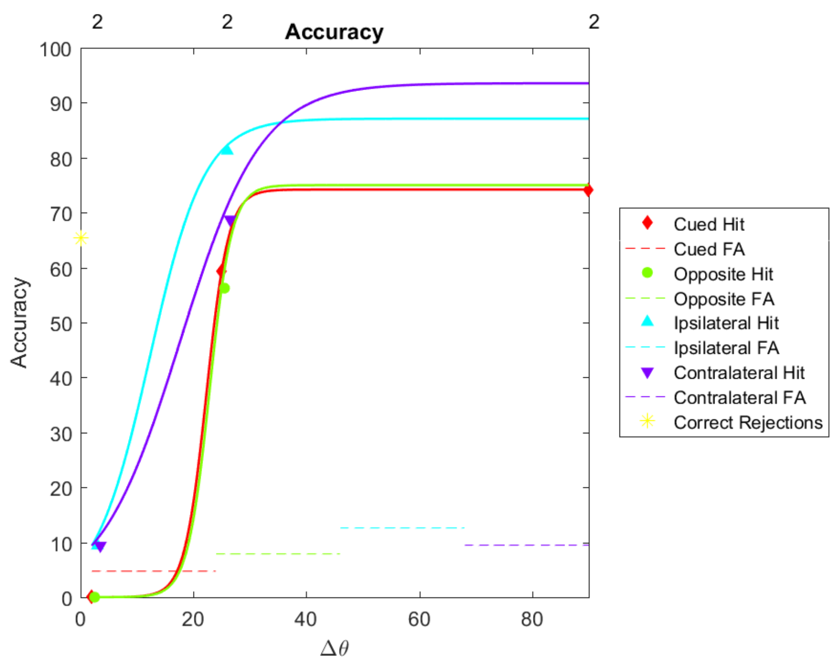

Fig 3a – Psychometric Curve – Task 1

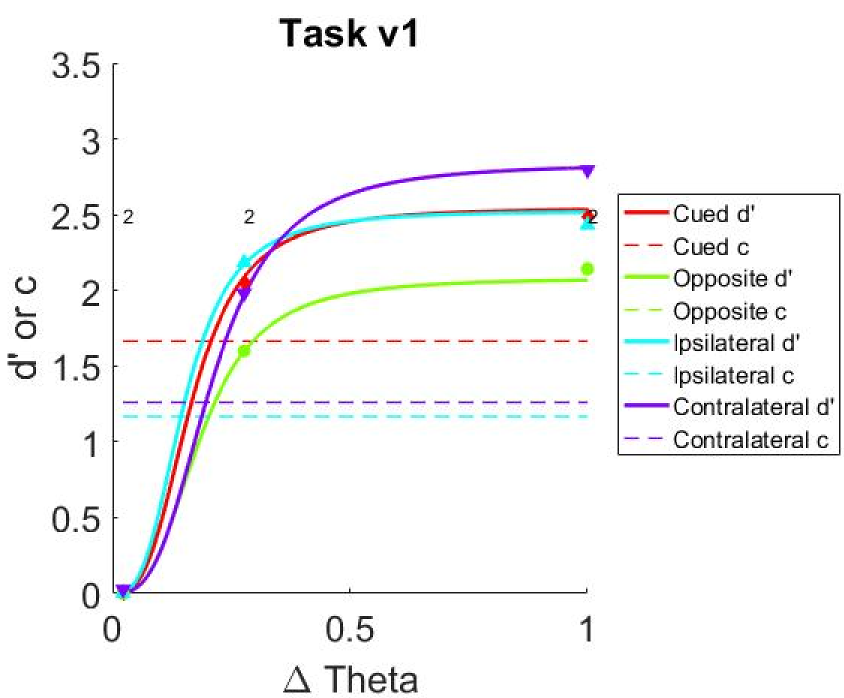

Fig 3b – Psychophysical Curve – Task 1

In task 1 the cued accuracy is least and the false alarm level is also low. At the angles tested there is no significant difference between performance at 25° and 90°. Also the criterion for the cued side is higher than the other locations. This implies that the exogenous cue was drawing attention to the other locations than the cued side. The cue was acting as a distractor and the subjects were not able to perform well on the cued side.

By convention a cue draws attention towards it, not away from it. On close inspection of the stimuli, it was observed that the blank screen (containing only fixation) presented after the exogenous cue before the response grating created an illusion that the other three locations were being cued after the initial cue. To correct for this, place holders for exogenous cues were placed at the cue locations during the blank presentation. The performance of the subjects was saturating at lower angles itself so the angles tested were reduced to increase difficulty of task.

Task 2

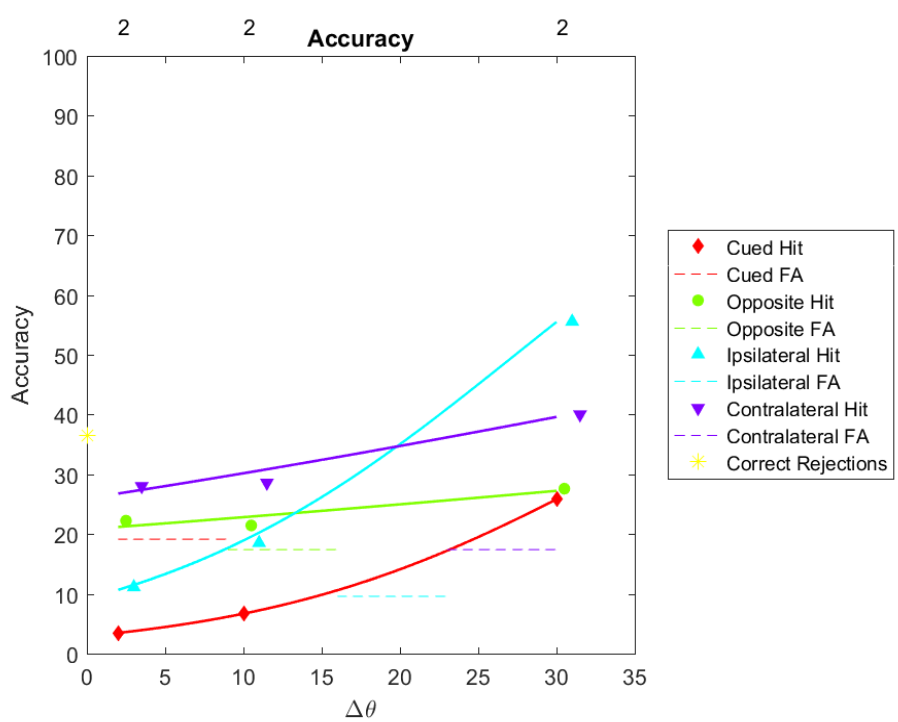

Fig 4a – Psychometric Curve – Task 2

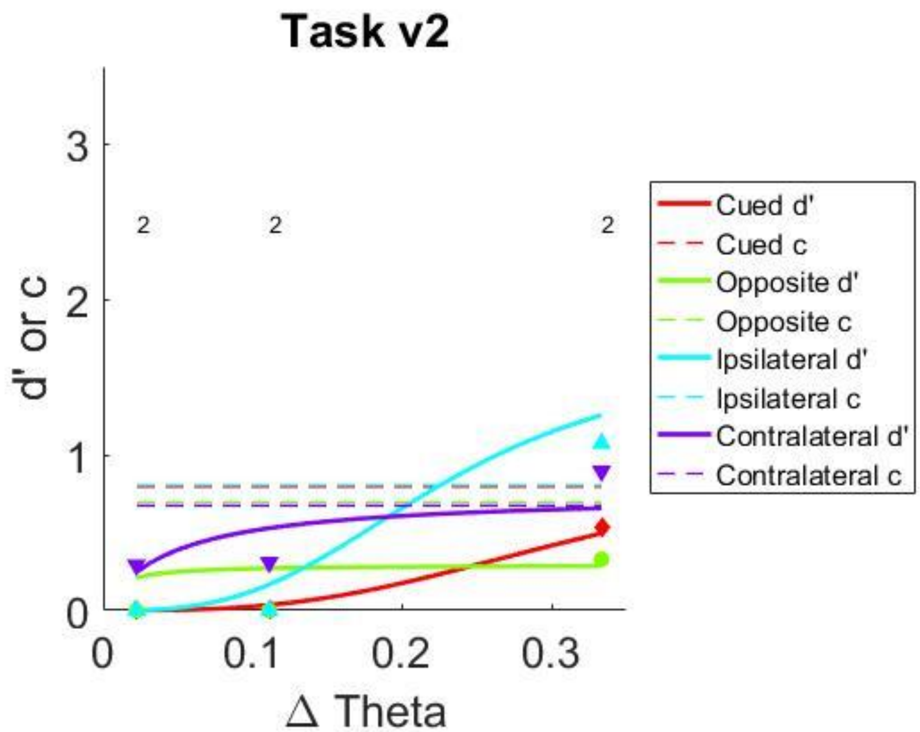

Fig 4b – Psychophysical Curve – Task 2

Although the problem of the cued side having higher criteria than the other locations seized. The performance of the subjects in task 2 reduced significantly compared to task 1. Subjects complained that the exogenous cue distracted them too much to focus on the task. To correct for this the exogenous cues which were 3 dots each of size 12 pixels surrounding each grating as shown in fig 2a were reduced to 1 dot of size 12 pixels.

Task 3

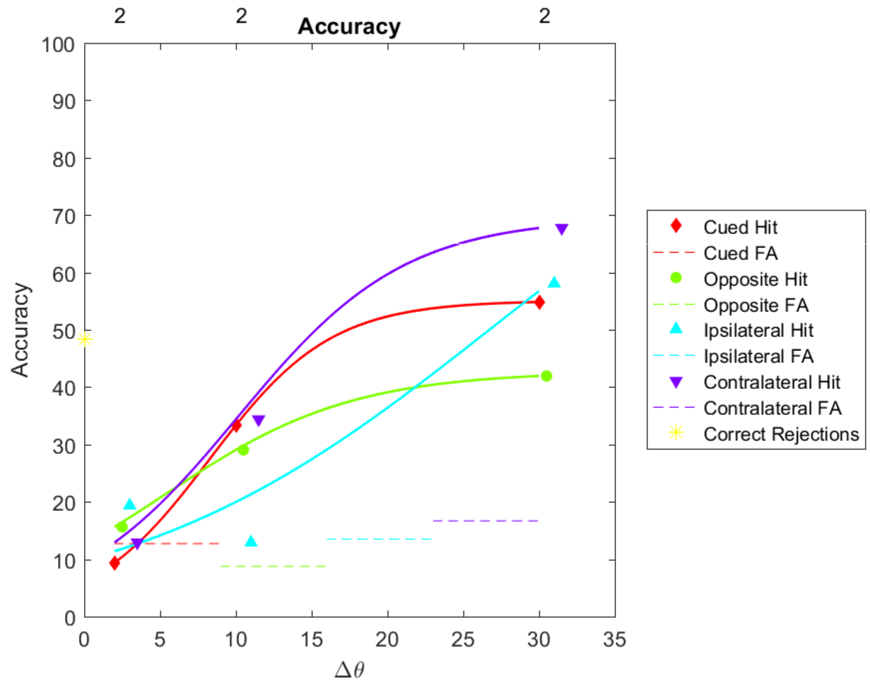

Fig 5a – Psychometric Curve – Task 3

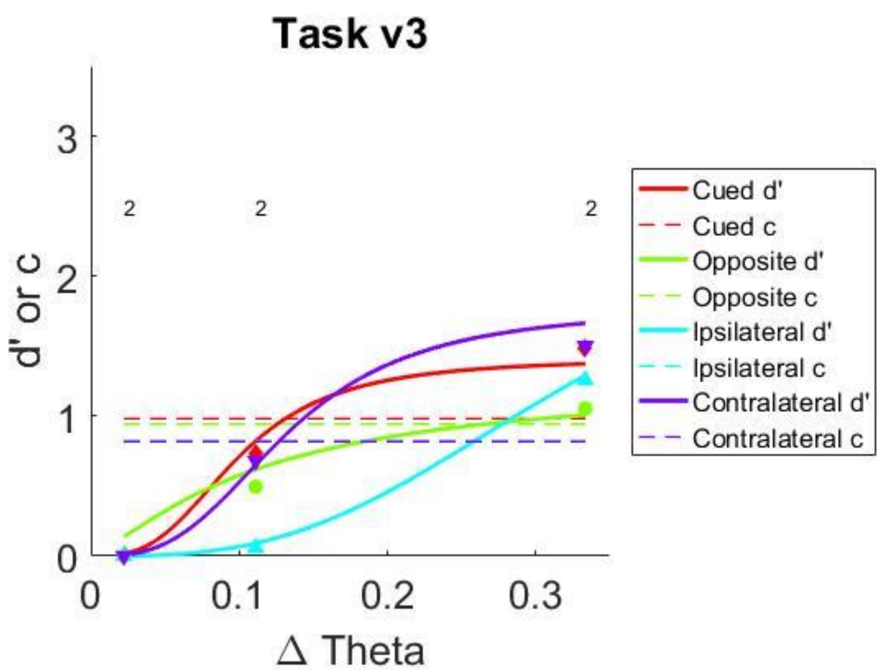

Fig 5b – Psychophysical Curve – Task 3

The performance of the subjects in task 3 improved but 1 dot was not a salient exogenous cue. After a few trials the subjects were easily able to ignore the cue. No differences between the sensitivities / criterion of the cued and uncued locations was noticeable. We decided to bring the stimuli closer to the fixation cross and change them from gabors to gratings for easier identification thus to improve performance. The cues were changed to arcs from dots to increase their salience.

Task 4

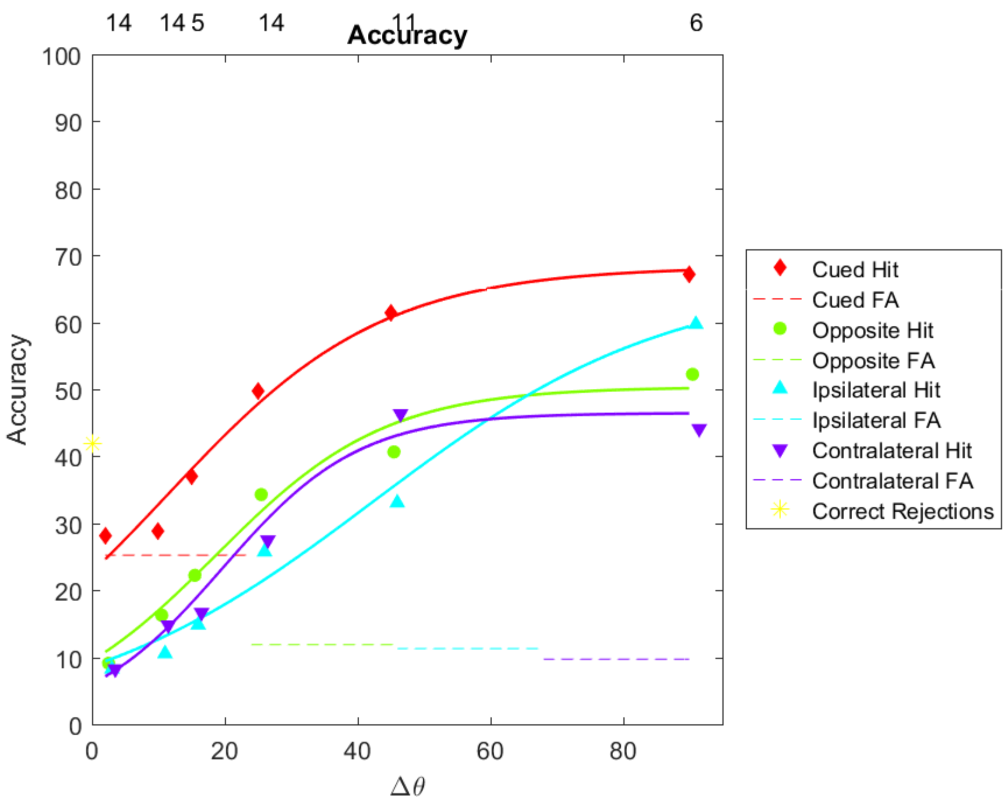

Fig 6a – Psychometric Curve – Task 4

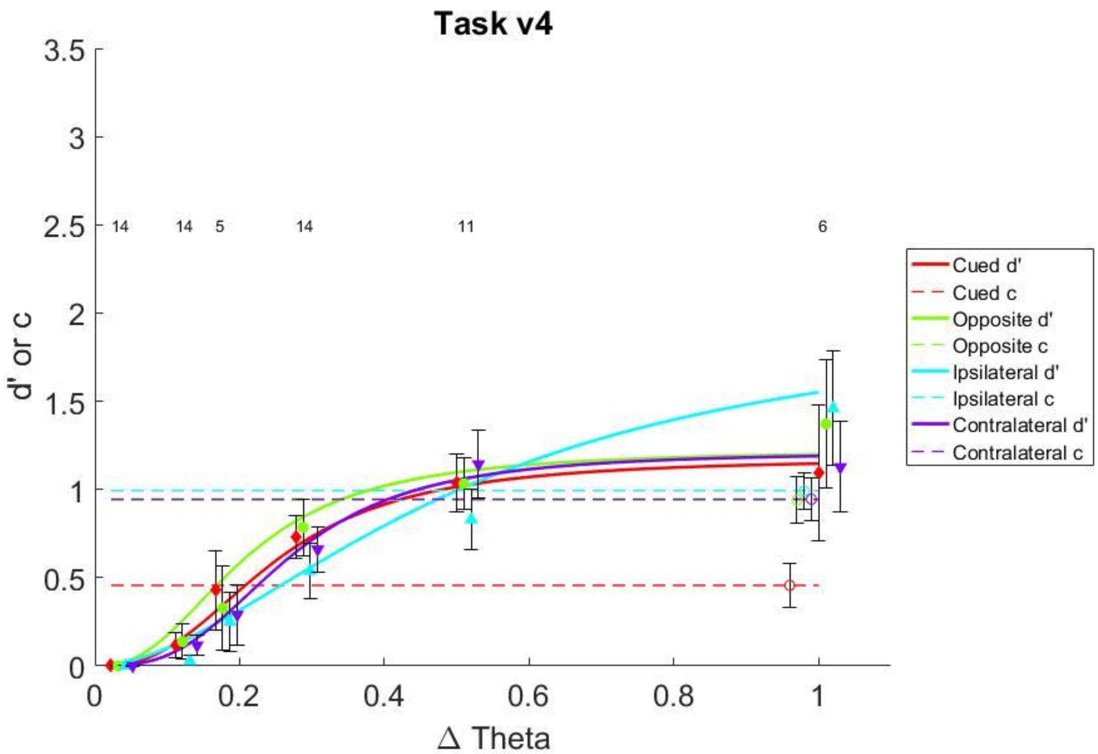

Fig 6b – Psychophysical Curve – Task 4

In task 4 we observe higher performance on the cued side compared to the other locations. Subjects also have a high false alarm rate on the cued side compared to the other locations. In the psychophysical plot we can see that only the cued criterion (c) is significantly different and lower than the other criteria values. The sensitivities (d') for the different locations, for each angle overlap. The number of subjects tested at each angle are mentioned at the top of each angle in the plots.

There were 2 issues with this experiment.

1) Is the effect observed, because of change in perceptual information at the stimulus location or due to attention?
2) From the onset of cue, it was 275 ms before the response gratings were shown. By this time exogenous effects would have reduced considerably (Herrmann et al., 2011; Tassinari et al., 1994) so is the conclusion valid?

In task 5 to address these issues, we interleaved trials in which, the exogenous cue came up before the change in orientation (precue) in half the trials and the other half where the cue came after the change in orientation (postcue). The timings of the exogenous cue and blank were reduced. Refer fig 1e and 1f. If the effects of the exogenous cue were purely perceptual the performance in both the precue and postcue tasks should be the same. Also the performance of the precue task should be similar to task 4.

Task 5

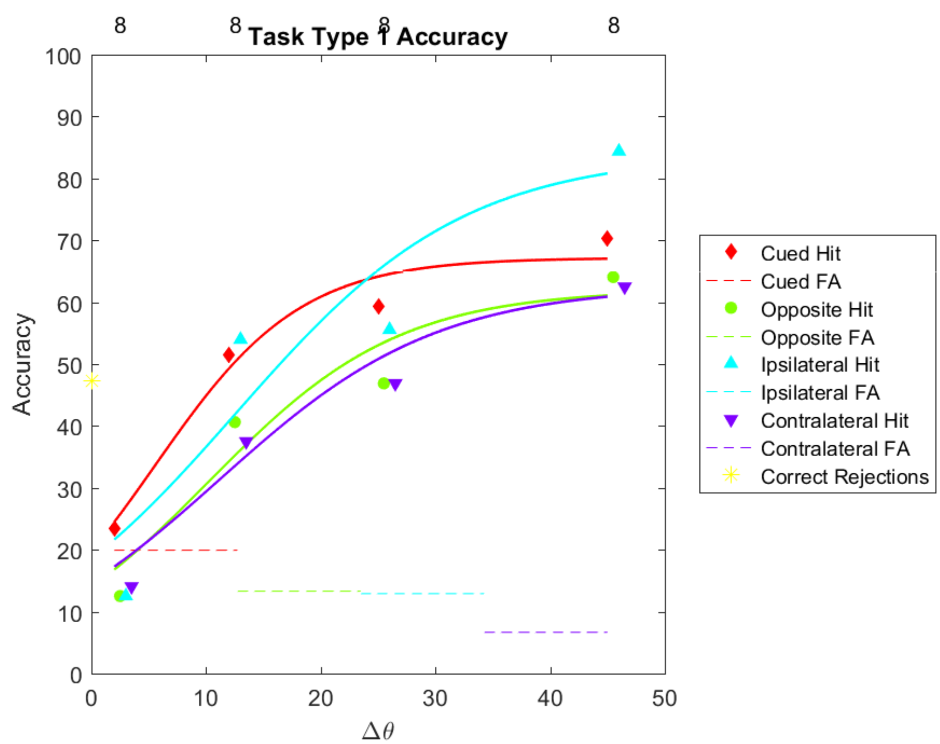

Fig 7a – Psychometric Curve – Task 5 – Type 1 (Precue)

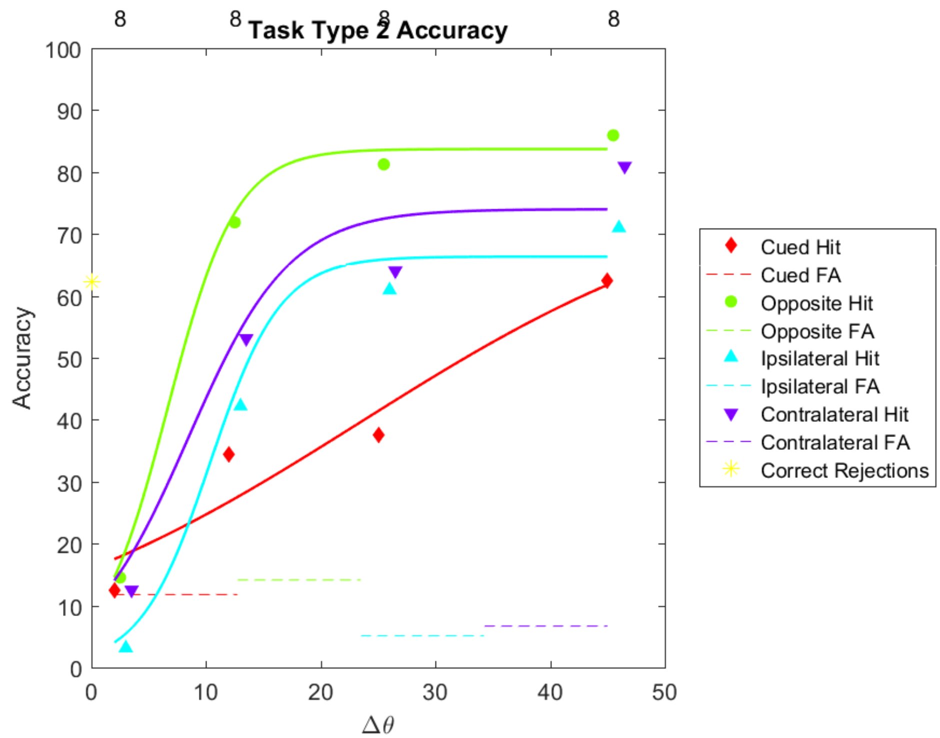

Fig 7b – Psychometric Curve – Task 5 – Type 2 (Postcue)

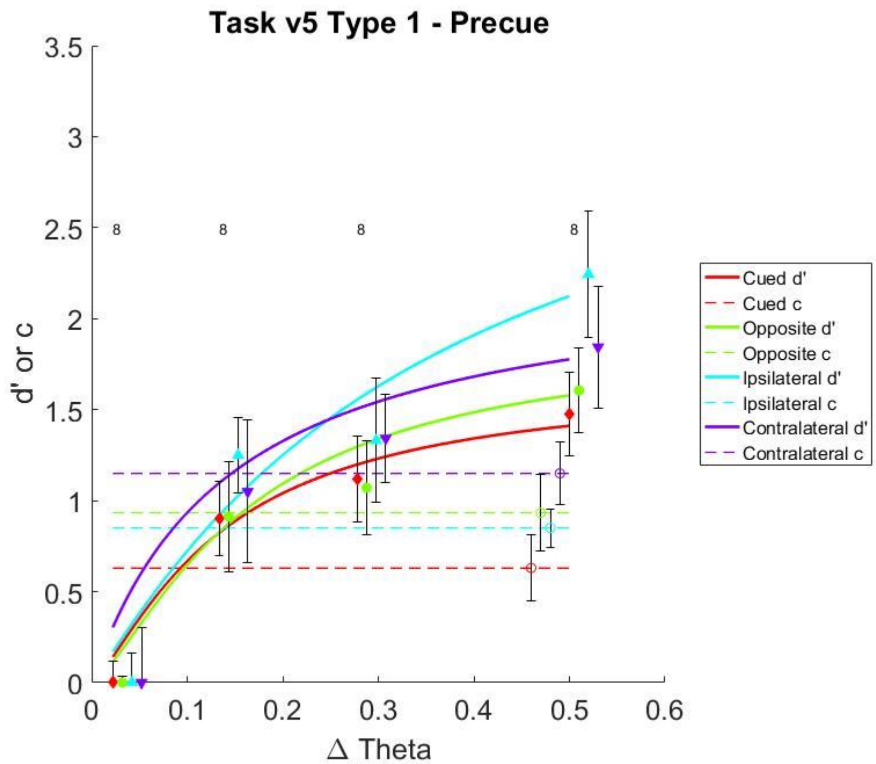

Fig 7c – Psychophysical Curve – Task 5 – Type 1 (Precue)

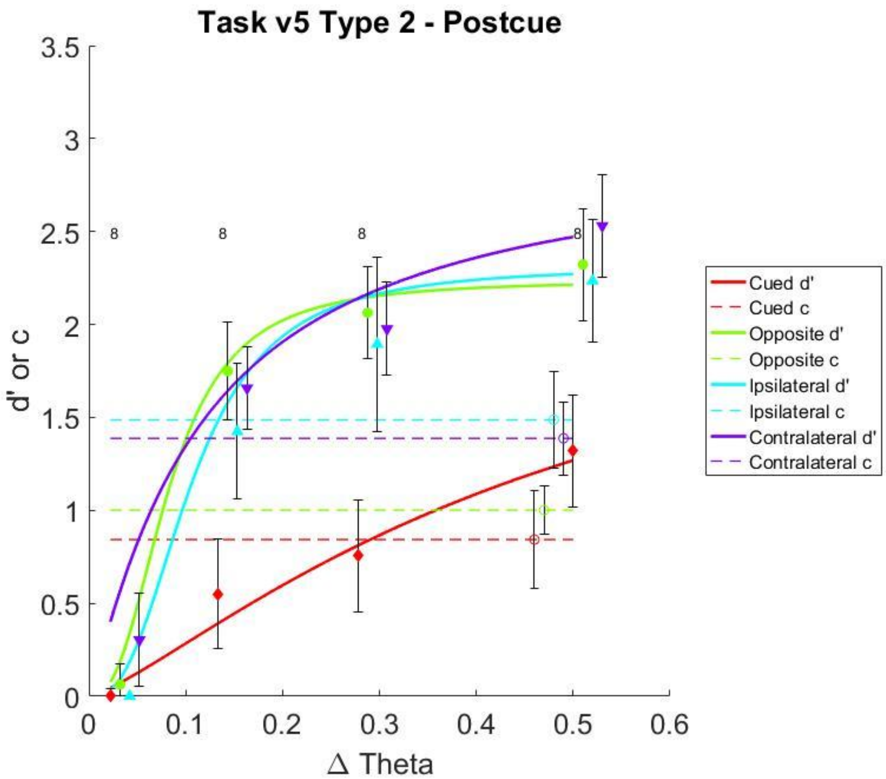

Fig 7d – Psychophysical Curve – Task 5 – Type 2 (Postcue)

The performance on the cued side is higher in the precue condition than the post cue condition. There is a higher false alarm rate for the cued side in the precue condition but there are no significant differences in false alarm rates of the different locations in the postcue condition. In the precue condition we observe that the sensitivities for the different locations are not significantly different and the criterion at the cued location is least. In postcue condition the sensitivities for the cued side are similar to those at pre cue. But there is a significant increase in sensitivities for all the non-cued locations.

Conclusion

We have designed a task after various iterations to observe the effect of exogenous cueing. The cue being temporally and spatially random does not hold any information to aid the observer to perform better in the task. But we are able to observe that there is an increase in performance by cueing at the cued location. The subject tends to take more guesses about change happening at the cued location than others. The subject lowers his/her criterion and biases themselves towards the cued location. It can also be seen that the subjects are able to perform much better at the uncued locations in the post cue task. Comparing the precue and postcue conditions we can see that an exogenous precue reduces the performance at the other locations. The same can be seen through the sensitivities, in precue the sensitivities are similar while there is an increase in sensitivity for uncued locations.

Exogenous cueing increases performance at the cued location by decreasing the quality of sensory information from the other locations and also increases weightage to the downstream processing of the information at the cued location.

This experiment can be integrated with Electro Encephalo Graphy (EEG) to study brain oscillations using Steady State Visually Evoked Potential (SSVEP) which is involved in attentional processes. We can use Transcranial Magnetic Stimulation (TMS) and Transcranial Alternate Current Stimulation (TACS) to suppress or entrain Frontal Eye Field (FEF) / Posterior Parietal Cortex (PPC) to decouple their role in affecting sensitivity and bias while doing exogenous cueing tasks.

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