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Project work on

Selection in visual working memory due to exogenous visuospatial attention

Submitted by

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Jan. - Apr. 2020

under the guidance of

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DEPARTMENT OF BIOTECHNOLOGY

PROGRAM B Tech

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CERTIFICATE BY EXTERNAL GUIDE

This is to certify that the Project Report entitled

Selection in visual working memory due to exogenous visuospatial attention

is a bonafide work carried out by

Mirudhula Mukundan (01FB16EBT026)

for the completion of her 8th semester course work in B.Tech. Biotechnology, at PES University. The project was carried out at the Cognition Lab, Centre for Neuroscience, Indian Institute of Science, during the period Jan. 2020 – Apr. 2020, under my guidance.

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CERTIFICATE

This is to certify that the Project Report entitled

Selection in visual working memory due to exogenous visuospatial attention

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Mirudhula Mukundan (01FB16EBT026)

in partial fulfillment for the completion of 8th semester course work in the Program of Study B.Tech.-Biotechnology under rules and regulations of PES University, Bengaluru during the period Jan. 2020 – Apr. 2020. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report. The project report has been approved as it satisfies the 8th semester academic requirements in respect of project work.

Signature with date & Seal *Internal Guide*	*Signature with date & Seal* *Chairperson*	*Signature with date & Seal* *Dean of Faculty*

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FACULTY OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF BIOTECHNOLOGY

PROGRAM B Tech

DECLARATION

I, **Mirudhula Mukundan,** hereby declare that the Project Work entitled, **Selection in visual working memory due to exogenous visuospatial attention,** is an original work done by me under the guidance of **Dr. Sridharan Devarajan**, Assistant Professor, Centre for Neuroscience, IISc, and is being submitted in partial fulfillment of the requirements for completion of 8th Semester course work in the Program of Study B.Tech in Biotechnology.

PLACE: Bangalore
DATE: 17th June 2020

NAME, SRN AND SIGNATURE OF THE STUDENT/S

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Abbreviations

1) WM - Working Memory
2) ERP - Event-related Potential
3) SSVEP - Steady State Visually Evoked Potential
4) AMI - Attended Memory Item
5) UMI - Unattended Memory Item
6) V1 - Visual Cortex 1
7) IP - Intraparietal Areas
8) FEF - Frontal Eye Fields
9) SDT - Signal Detection Theory
10) HR - Hit Rate
11) FAR - False Alarm Rate
12) cc - Choice Criterion

ABSTRACT:

Attention is that entity that helps manoeuvre our focus to task-relevant items, inducing a selective storage of that item in our working memory. This is important since the working memory is known to have limited capacity. Therefore, the selective storage not only resolves this issue, but this also induces efficient processing of information. Our attention can be guided in the external visual space as well in the internal representations of information stored in the working memory. The effect of orienting attention to internal representations has been well studied, and researchers were able to draw conclusions about the modulating effects of retrospective cues that were presented during the information maintenance period of a working memory task. However, the cues given in previous researches were more endogenous in nature, and had some validity to the objective of the task. So the effect of exogenous cues, especially uninformative retro cues, on the orienting of attention in working memory remains largely unexplored. With this in mind, in this project, we examined the role of exogenous visuospatial attention on selection in working memory. We found that the subjects, performing the working memory task, were able to recall the item that was cued, better than the other items on the screen. The results indicate a modulating effect on the behaviour in the presence of an exogenous, uninformative retro cue, and this drives us to expand the objective of the project in the future, to report neurophysiological evidence as well.

OBJECTIVES:

(1) To study the effects of exogenous visuospatial attention on selection in working memory using exogenous, uninformative retro cues, in a remote and uncontrolled environment.
(2) To study the effects of exogenous visuospatial attention on selection in working memory using exogenous, uninformative retro cues, performed in a controlled environment inside the laboratory.

1. INTRODUCTION:

In recent years, there has been a growing interest in the study of various cognitive processes of the human brain. Amongst these processes, studies on attention, or, more specifically, visual attention has been viewed as a conundrum to be solved. This recent trend might also be due to the rapidly developing neuroimaging techniques like FMRI, DMRI, EEG, MEG, etc.

1.1. Attention:

Attention may be understood as that cognitive process that governs the ability to selectively focus on a particular instance or entity to process information for optimum decision-making, be it in the form of a mental shift in focus or by selectively processing information in the external space around us. There are many theories about the working of attention. One of the more famous ones is the *biased-competition model*. Specific to spatial visual attention, when an observer attends to a particular location in an external visual space, neurons with receptive fields at that location become more active or remain active, while others might possibly be suppressed. This is the biased-competition model [11, 5]. Touching on the various types of visual attention, when the focus of attention is in line with gaze, it is known as *overt attention* (Fig. 1a), and when attention is deployed without any movement of eyes, it is known as *covert attention* (Fig. 1b). Most of the experiments that are conducted to decipher human behaviour are associated with covert attention. This is mainly because of two reasons - (1) Eye movement causes huge artifacts (i.e. signals not associated with the brain), while performing EEG experiments, due to which processing of brain signals become difficult, (2) It could create a spatial bias while doing cognitive tasks even before the start of the task, which experimentalists would want to avoid. Another classification of attention would be (1) *Endogenous Attention,* and (2) *Exogenous Attention.* The former is a top-down approach, where the observer willfully focusses their attention at a particular location in space. The latter describes a bottom-up approach, wherein an involuntary system is involved to automatically orient the observer's attention to a particular location in space. Example: An endogenous attention is deployed to find a camouflaged butterfly amongst leaves (Fig. 1c), wherein the observer willingly searches for it. An exogenous attention is deployed when the observer's focus is involuntarily dragged to a brightly coloured yellow butterfly amongst purple flowers (Fig. 1d).

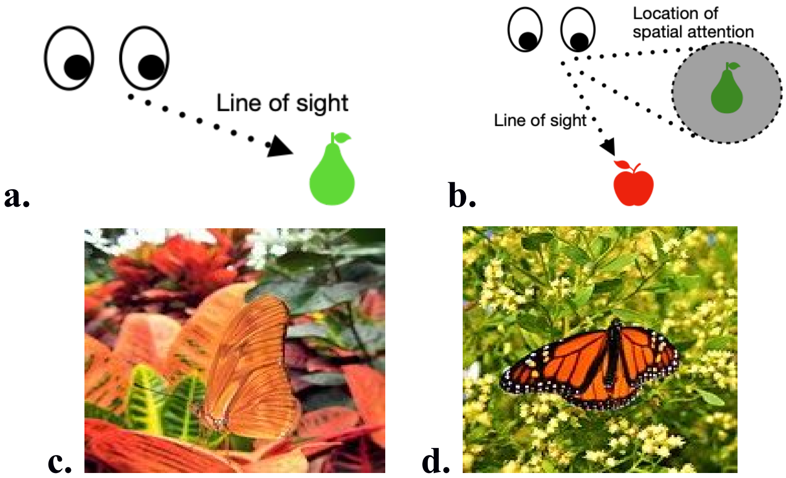


Figure 1. (a) Overt Attention (Source: Referenced from [15]).
(b) Covert Attention (Source: Referenced from [15]).
(c) Endogenous Attention. (Source: Rachel Kramer. *Camouflage butterfly.* 2012, March 1. Photograph. <https://www.flickr.com/photos/rkramer62/6947187657>. *Flickr.* Licensed under CC BY 2.0.)
(d) Exogenous Attention (Source: Lauraeleven11. *BRIGHT butterfly.* 2012, September 1. Photograph. <https://www.flickr.com/photos/laura1111/7909477970/>. *Flickr.* Licensed under CC BY-ND 2.0.)

1.2. Working Memory:

Working memory (WM) is a system dedicated to the short term maintenance and processing of information. It is not unknown in the field of cognition that working memory and attention have a great impact on each other. Though this statement holds a greater conceptual understanding over its empirical counterpart, over the course of several years, researchers have brainstormed several demonstrations to showcase a tight link between WM and attention.

Working memory is said to have a limited capacity. To compensate for this, attention acts as a selective process to store only certain task-relevant items into the WM. Just like how attention impacts WM, WM also impacts attention. The contents stored in WM can guide attention and perceptual processing in one's external space [12, 18]. One of the first few experiments, done by Graziano *et al.* (1997), demonstrated this concept where monkeys were able to locate various objects in the dark, whose location was previously spatially encoded in the presence of light [17]. The monkeys were able to do this without the cues given by visual attention, thus enforcing the theory that internal representations help guide attention and action in the external space. But, till date, there are no unequivocal theories to explain the neural basis of this behaviour of how only certain relevant internal representations are given importance over others, in specific situations. A few state the possibility of weights being attached to certain relevant features in the WM in order to deploy attention to a specific task or location [41, 21], while others show that constant maintenance of information in the WM brings forth a bias towards that internal representation in the WM, and a similar bias during the selection of an external stimuli [11, 21]. But, regardless, it is proven that attention and WM have bi-directional relationship, and hence one cannot be studied in isolation from the other. This binary relationship between attention and WM is pictorially depicted in Fig. 2.

1.3. Selection in Working Memory:

Now, we know that only task specific information is chosen from the WM, to bring out related internal representations. For this reason, a selection process occurs to pick out the most relevant item from the pool of information stored in the WM. This is, in essence, stated as *selection in working memory.* In further detail, it is possible to orient attention to certain spatial internal representations in the visual WM, thus enhancing memory representation of certain items [18, 20, 29]. Most experimentalists have proven this using a retro cue (or, retrospective cue) that is given to a subject after they are shown a few items, placed distinctly in space. This cue helps the subject to decide on the item that they will be attending to, in their WM, and it was observed that the subjects were able to better recall the attended objects. In another research, it was observed that, in retrospect, depending on the value an item holds to the objective of an

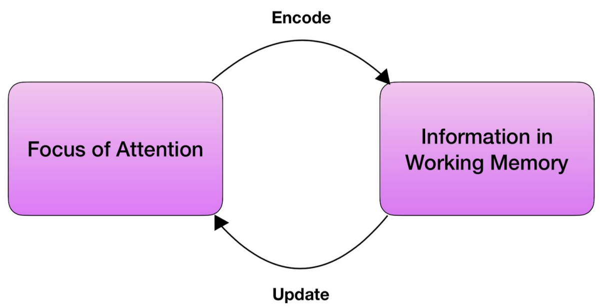


Figure 2. Binary relationship between Visual Attention and Working Memory. *Source: Referenced from [4].*

individual, attended items are stored in the WM for a longer time, in comparison to the unattended items in the WM [18]. Thus, such studies further suggests that endogenously attending to internal representations enhances the memory of the attended item in the WM. However, not much has been done in terms of exogenous, uninformative retro cues, and its effect on selection in VWM. Therefore, in this project, we will be exploring the effects that an exogenous, uninformative retro cue has on the selection in visual working memory.

1.4. Brief Introduction About WM Experiments Conducted in Cognitive Science:

1.4.1. Behavioural Experiments:

First and foremost, to observe the effect of exogenous attention on selection in VWM, the experiment will need to show firm behavioural evidence. Experiments related to behaviour include a human-computer interaction, where subjects are shown a series of screens on the computer. The primary aim for this is to initiate a memory storage and recall cycle, at the behest of the experimentalist, the events for which are programmed as a cycle of events, occurring repeatedly for a fixed number of trials, on the computer screen. When the subjects respond to a particular task on the screen, they are essentially asked to recall a certain memory in their past set of events shown on the computer screen. If the behavioural consequence of the experiment shows an increased memory performance for objects on the screen where there was an exogenous attention, in comparison to other objects, it would help us in forming the basis for the hypothesis of the project. Since the experiments are with respect to visual attention, it is assumed that information is stored spatially in the working memory. If this were the case, it would seem that exogenous attention does guide in selection of certain information from our WM.

1.4.2. Neurophysiological Evidence - EEG:

Following behaviour experiments, it is essential to back the results with necessary neural correlates.

A short note on EEG - Electroencephalogram, or EEG for short, is a non-invasive method to detect electrical activity in the brain. Our brain produces different kinds of signals, varying in frequency, during different activities, and at different parts of the brain. For example, during a resting state, there is an overall increase in the alpha waves detected through the EEG. This technique is more commonly being used in studying cognition, as of late, due to its non-invasive nature and high temporal resolution, as human subjects are, more often than not, being asked to perform various behavioural tasks while their brain activity is being recorded by EEG. The recorded activity consists of a time course (in milliseconds) of the neuronal activity in our brain, that are represented by continuous oscillations of voltage, measured in millivolts.

Most EEG studies involve the presentation of some stimulus to the subject at a particular time, and observing if this presentation involves an increase in the potential of electrical activity. For example, if a subject is visually focused on a blank computer screen, and suddenly they are shown a picture of a bright apple, it is expected to observe an increase in potential in the electrodes concerned with the visual cortex. This is, more often than not, referred to as *event-related potential (ERP)*, and it is time-locked to the stimulus presentation. Usually, a number of electrodes' potential values are grouped and averaged together in order to reduce the noise in the signals. While performing a task, when the subject happens upon a stimulus, there is

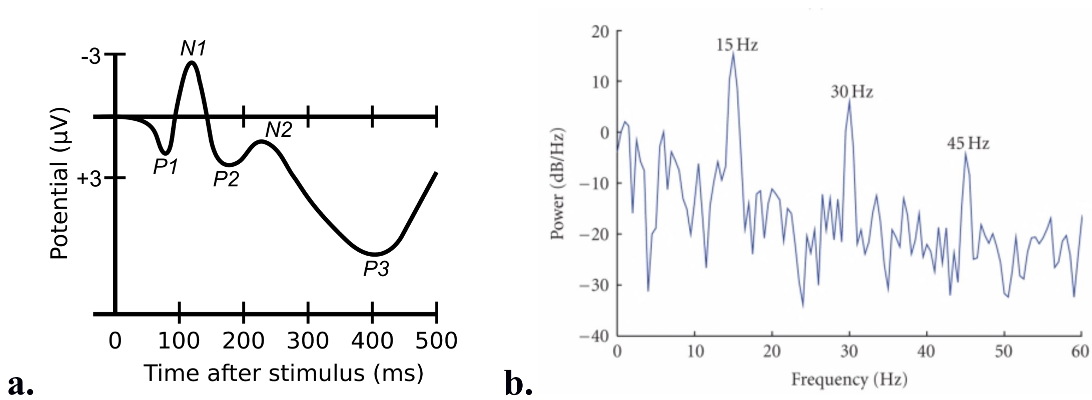


Figure 3. (a) Components of an Event-related Potential, locked to stimulus onset. Note that the ERP is plotted with negative voltages, which might be common but not universal. (Source: Choms, Mononomic. *Components of ERP.* 2008, December 21. Illustration. <https://commons.wikimedia.org/wiki/File:ComponentsofERP.svg>. Licensed under CC BY SA 3.0).
(b) Steady-state visually-evoked potential (SSVEP) during periodic visual stimulation at 15Hz. This plot shows the manifestation of SSVEP at 15 Hz, and its higher harmonics. Source: [42, Licensed under CC BY 3.0] .

an observable evoked potential, that determines that the subject has processed the information on the screen. This kind of information forms the primary neural consequence of a particular subject behaviour.

While ERPs are mostly related to transient responses recorded by the EEG, there is another set responses, denoted as, *steady state response (SSR)*, that are exhibited by the brain when a stimulus is shown periodically due to which there arises an evoked potential which 'constitute discrete frequency components [that] remain constant in an amplitude and phase over an infinitely long period of time' [16, 32]. Therefore, it can be said that ERPs are evoked by infrequent stimuli, while SSRs are evoked by rapidly periodic stimuli. When we plainly talk about ERPs and SSRs, SSRs sounds like the obvious result of ERPs, but one statement that I came across while doing my literature survey convinced me otherwise - ''*If the brain responded in a linear fashion, steady-state responses would be completely predictable from the transient response. However, the brain is not linear, and steady-state and transient responses therefore provide independent views of its function*'' [31]. So, traditionally, ERPs and SSRs are divided as two distinct literatures. But, interestingly, a recent study has hypothesised a possible link between the two [4], and another study has attempted to re-construct SSRs from transient ERPs [3]. In our study, we will be focusing on detection of ERPs.

Now, how will these ERPs help us in this project? Why is there a need for backing up a research with such an EEG study, or rather, any kind of neuroimaging technique? One thing we need to know is that performing only behaviour studies by itself is never enough of an evidence for explaining a phenomenon. A backing study that explores the neural bases of the cognitive system is as relevant as a shell is to a snail. Lack of electrophysiological evidence in a study gives way for misconceptions to arise, and it is as good an on-looker identifying a snail as a slug because of its lack of shell. In this project, the ERPs are being used to attain spatio-temporal information, along with identifying those regions of the brain that are being activated during the time of experimentation. This will help us to correlate this neural evidence to behavioural consequence.

2. LITERATURE REVIEW:

2.1. Orienting of Spatial Attention - External and Internal :

Several works in neuroscience have proven that cells of the parietal lobe are widely responsible for covert attention i.e. shift in attention without movement of eyes. Much of the studies on orientation of attention comes from the early research by Posner, where he explains his view on what 'orienting of attention' means - "*I will use the term orienting to mean the aligning of attention with a source of sensory input or an internal semantic structure stored in memory*" [33, page 4]. In the same paper, he continues to mention that orienting attention differs from 'detection' of target. Much of the research after this, follows a much similar pattern, where most experiments include a subject who is required to orient their attention to a specific location on a computer screen (spatial attention in the external visual space), and he/she is required to follow up this with a response task, involving one or more of the following - clicking of the mouse button, pressing down a key, verbal response, etc. This, in Posner definition, completes the detection of the target.

Posner, in his paper - 'Orienting of Attention' [34], shows that covert attention also helps in orienting attention spatially, i.e. attention can be guided without the movement of eyes, and he further posits that covert attention can also be measured with much efficiency. In his experiment, the subject was presented with a plus sign at the centre of a screen, where they would have to keep their eyes fixated. Any case or trial where eyes moved away from the plus sign was rejected. This movement was recorded by EOG (electrooculography). A detection stimulus would occur either to the right or left of the screen. When the plus sign changed to an arrow pointing to either one side, it gave an indication of where a particular detection stimulus is most likely to come up. The probability that this follows is 80%. In case, the stimulus came on the indicated side, it was called a valid trial, and if it came on the opposite side, it was called an invalid trial. These arrows are called 'cues', and this whole sequence is known by the name 'central cue experiment'. Each such set of events is named as a single 'trial', and the subject was shown several such trials. The bases for most experiments are derived from this model. Several modifications have occurred, over the years, that have helped quantify behaviour, in regard to covert attention, and this model still continues to help explore the conundrum that is cognition.

The above described was more in pertinence to spatial attention in the external space. On the other side of the coin, a few notable researchers have demonstrated that spatial attention can also be oriented to certain internal representations that are stored in the working memory, more specifically, visual working memory. In the research by Griffin and Nobre [17], they develop an experiment that presents certain cues to the subject, that would help them to orient spatial attention to certain locations in the working memory (internal representations in specific locations). Essentially, three kinds of cues are present. First, a pre-cue that is presented to a subject before a stimulus is displayed on the screen. This cue builds an expectation in the subject to predict a particular location to have a greater probability of being the target location for the stimulus presentation. Second, a retro-cue that is presented to a subject after the stimulus is presented. It attempts to make the subject recall certain visuospatial representations from within the working memory. While the former orients attention to the external perceptual space, the latter orients the attention to the internal representations. Third is a neutral cue, that does not provide much information about the stimulus display. These three cues are distinctly depicted as a representative diagram in Fig. 4.

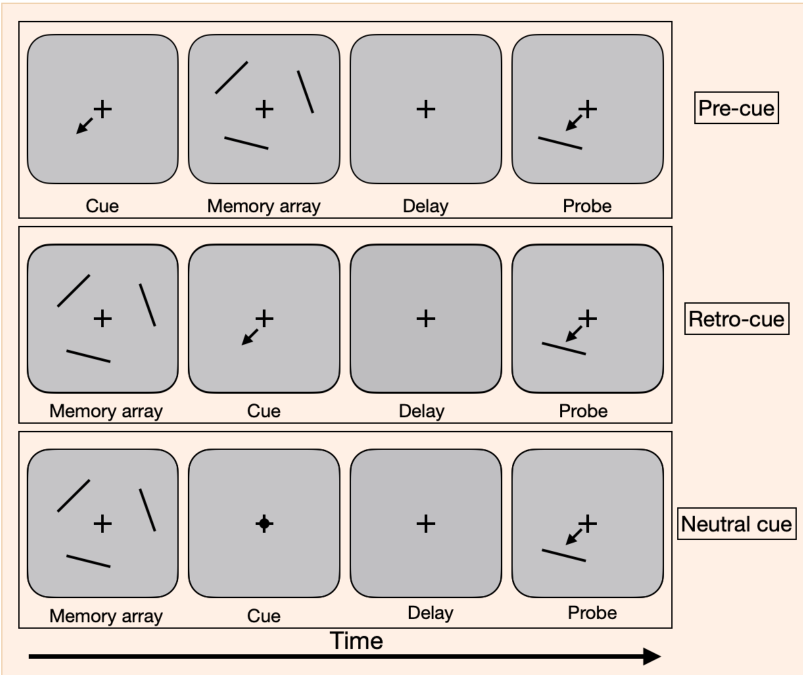


Figure 4. Example representations of the different kinds of cues - (1) Pre-cue, (2) Retro-cue, (3) Neutral Cue. *Source: Referenced from [18, figure 1].*

Griffin and Nobre's research aimed at demonstrating whether attention could be oriented to select locations in the working memory that are present as internal representations. In a three step experimentation procedure, they were able to arrive at three results: (1) As long as the number of items presented on the screen is within the processing and storage capacity of the working memory for a given amount of time, the subjects were able to orient their attention to internal representations in the working memory, as seen from the behavioural benefits seen in retro cue trials. It was noted that the cueing was advantageous to the subject, as the reaction time (RT) was lesser during valid trials, in comparison to invalid trials and no cue trials. A contrasting trend was seen for accuracy since it was much greater for valid trials than for invalid and no cue trials. (2) When peripheral probes are used, the subject has to make a decision whether a probe was present at the same location during stimulus presentation. This further confirms that subjects do orient their spatial attention, as is required for the experiment. RT and accuracy see a similar trend as that seen in the first experiment conducted. (3) In the third experiment, an EEG study was conducted and presence of ERPs were observed. When comparing the ERPs for pre-cue and retro-cue trials, there are certain obvious modulations in the waveform, primarily in the frontal region (F3, in the 10-20 international system) and parietal region (P1). It has already been observed in previous studies that there is an interdependence between frontal, pre-frontal and parietal locations of cortex for the working memory [6, 16, 35]. So, intuitively, this connection could possibly explain such modulations in waveform.

The reason why studying about this ability of humans to orient attention in both a perceptual space, and within the working memory, is simply to understand how humans guide their attention. Such studies affirm that attention does not solely correspond to events happening in our external environment, and that it is not exclusive to the consequence of visual processing, but rather, there is a kind of inherent interdependence between the external events and the internal state.

In a follow-up study by Nobre *et al* [30], he and his team investigated this link by comparing the neural systems involved when orienting spatial attention to working memory events and when orienting spatial attention to items in the visual field. The experimental task was quite similar to the one they had used in their earlier study, and the behaviour results also complied with the trends they saw in their previous study. They, then, carried out MRI scans in order to identify the regions in the brain that get activated during spatial orienting. It was observed that the pre-cues primarily activated the right inferior posterior parietal region, while the retro-cues activated multiple regions in the frontal lobe of the brain, and this is rightfully so because visual attention has always been associated with the parietal region [40], and working memory has been studied to have activated regions in the prefrontal and frontal lobe [36, 40]. Interestingly, it was also seen that certain regions in the parietal cortex were activated by both pre and retro cues. While this is not the first time a link between parietal and frontal has been observed, with respect to attention, this was the first study that had studied the neuroanatomy of attention and working memory, with respect to their possible dependency on each other. This goes on to tell that there exists a network of frontal and parietal areas that works to create a harmony between spatially orienting attention in the external world and in the working memory. Such studies motivates the idea of attention being a large-scale multimodal network.

2.2. Prioritization of Information in Working Memory - Attended vs. Unattended Stimuli:

The previous section gave an overall insight on a few experimental paradigms that lead to orienting attention either externally, or internally. In this section, I will go in-depth about the retrospective effect of cues, and their implications on the information stored in the working memory. Our working memory has a limited capacity, and therefore, not all the visual information is stored in WM. Due to this, there arises a certain prioritization of information based on the requirement of the observer, and the concept of attention is central to this prioritization. Selective attention helps us to focus on task specific items, and these items are then eventually stored in our working memory. This information is again processed in a selective manner, for efficient task implementation (like problem solving, context-based visual search, etc.). Such selective storage and processing of information have shown enhanced performance of subjects in memory related tasks [17, 28, 19, 30], as this brings their focus to what they think might be rewarding for their task. While much is known about the selective processing of information into the working memory, an interesting body of research also deals with the events that might be occurring after the storage of information. Typically, sustained information and inhibition of distraction are said to be two factors contributing to the performance of working memory [9]. But, research points to evidence of humans' ability to focus attention on a particular item in our working memory, and this has been elaborated upon in the previous section, under orienting attention internally, where the subjects in the experiments were able to perform better based on the information provided by the retro-cue, and biasing their attention in the direction of the cue (see section 2.1). This 'prioritization' of information leads to the concept of 'selection in visual working memory' that is the core topic that this project is based on.

To explain this prioritization, let us take an example of a typical change detection task (this is similar to the paradigms demonstrated in the previous section). Imagine, we have 4 different coloured items at 4 different locations on the screen (Fig. 5), this forms the initial WM array, that is to be memorised. Later on in the experiment, the subject would be shown another set of arrays, where they will be probed for a change at one of the 4 locations. In the case of a neutral (no cue given) trial, the subject would essentially give equal weightage to all locations. Now, let us assume a cue to be given, after the incidence of the memory array, indicating that the red bar is more likely to be probed. Knowing such information before the probe array, lets the subject allocate attention to the cue-associated information, during the memory maintenance period, because they now realise that doing so will get them a better probability of getting the task correct. This bias towards allocating more resources to a particular location in comparison to others leads to the concept of attended and unattended items in the working memory, wherein, in terms of the experiment, the cued item was attended, and rest were unattended. This re-focusing of attention in WM has been studied for several decades now, and there has been no conclusive theory explaining this phenomenon. Most agree on the fact that there is active retention and firing of neurons associated with the attended stimuli [8, 24]. Evidence points to an increase in the alpha

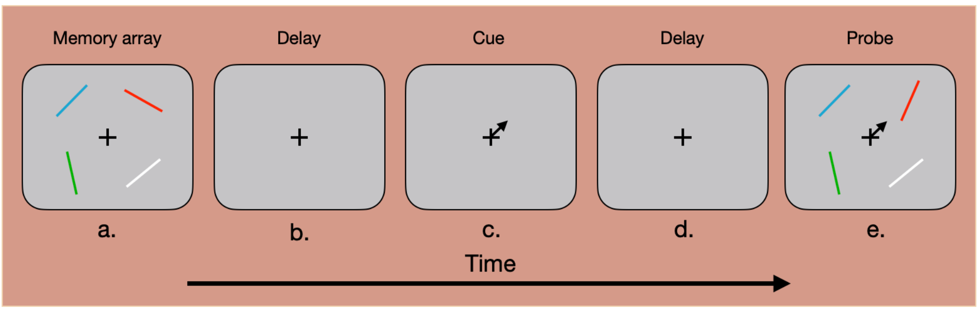


Figure 5. Retro cueing of an item in the visual working memory. This is an example of an experimental design for selection of information in the VWM. *Source: Referenced from [17, figure 1].*

power, detected by MEG (magnetoencephalogram), on the hemisphere of the brain corresponding to the side on which the target stimuli appeared on the screen (ipsilateral side), and a consequent decrease of the same on the opposite hemisphere (contralateral side) [32]. In fact, when an MVPA (multivariate pattern analysis) was conducted on EEG signals, it was possible to only decode the presence of the cued information during the maintenance period, after the incidence of the cue [23], and information that was not in the line of attention was left undetected.

There is plenty of such evidence in regard to attended stimuli but the majority of the conflict arises with respect to the unattended stimuli. What happens when items in the working memory are left unattended? Are they somehow lost, and not retrievable anymore? Or, are they just sitting in the back burner of the brain, and can also, at some point, be the centre of attention in the working memory? Some state that the neurons associated with the unattended items may be in an 'activity-silent' state [13, 23], which is to say that though the memory of such items may not be of prime importance at a given instance, it is not totally erased from the WM. It is very much possible to guide our attention to those unattended items when cued for them, and inactive maintenance of such information does not correlate to loss of that information in the short term memory [23, 39]. So, what happens during an invalid trial (when a subject is probed on the uncued side)? Do subjects perform worse in such trials? In another research, it was pointed out that there was no evidence for a negative correlation between recalling an unattended item and recalling a retro-cued item [28], though there are plenty which state some sort of resource allocation biases between attended items and their counterpart. In another study [8], the researchers contradict the activity-silent synaptic method of prioritizing, but positing that there might exist some selective recruitment of specific parts of the brain that might be responsible for representing attended and unattended memories. Three regions of interest or ROIs were considered - (1) visual cortex areas (V1 - V4), (2) intraparietal areas (IP), and (3) frontal eye fields (FEF). Each played a unique role in representing attended and unattended items. It was observed that the visual cortex seemed to play the main role in retaining attended memories.

More often than not, it is observed that subjects perform better not only on the cued location, but there is a general increase in sensitivity at the side of the stimuli where the cued location is present, though not strictly true. So, when a cue is given for a specific location, our spatial attention is automatically being employed to process the information on that respective side. Adding a few technical terms, all the information in the same hemified as the cue is processed by one hemisphere of the brain, while the other hemifield information is processed by the other hemisphere (Fig. 6a). The cued side is known as the *ipsilateral* side while the uncued side is known as the *contralateral* side.

With respect to a basic change detection task with 4 stimuli on the screen, let us say that a cue was given pointing to the top left corner of the screen. Then, in technical terms, the same location will be the *cued location*, the bottom left will be the *ipsilateral location*, the top right will be the *contralateral location*, and finally, the bottom right will be the *opposite location* (Fig. 6b).

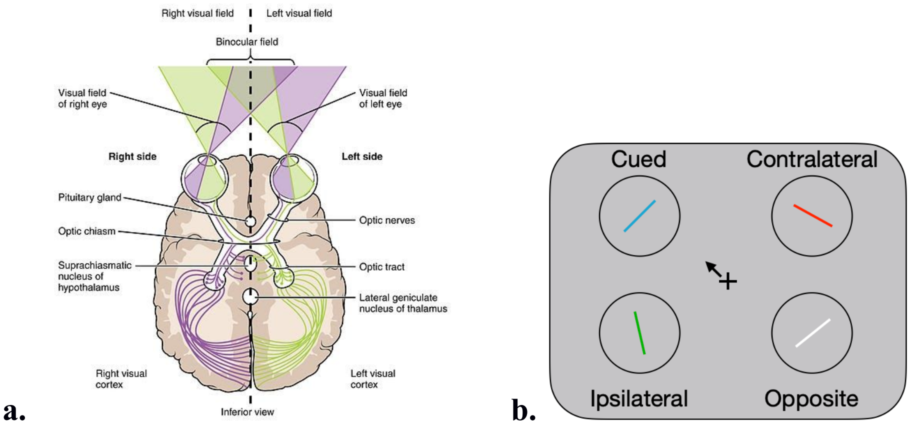


Figure 6. (a) A paradigm for 'divided visual field'. As an example, let us say that the cue is pointing at an object in the left visual field. Then, that side would become the ipsilateral side, while the right visual field would become the contralateral side. Objects in the same visual field are said to be in the same hemifield (Source: OpenStax College. *Optical Fields*. 2013, May 28. Illustration. <http://cnx.org/content/col11496/1.6/>. Licensed under CC BY 3.0).
(b) Representative example of the different locations and their respective names, when a cue is given for a particular location. *Source: Referenced from [2, Figure 1d].*

2.3. Quantification of Behaviour - Signal Detection Theory:

In order to correctly study human (or any animal) behaviour, it is very important to quantify it, so that it becomes easier to fit mathematical models to observe any trends in the responses given by the subject. For this quantification to happen, signal detection theory plays an important role to analyse data on the basis of distinction between information bearing patterns, and patterns that are of little significance to the aim of the study. It was originally developed for studying the electromagnetic signals, specifically radar signals, but realising its value in cognitive science, researches quickly adapted the theory to suit the needs of their science.

The basic premise is that when we get response data from the subjects, it may contain useful information, which will henceforth be called, *signal*, and unwanted random information, which will henceforth be called, *noise*. It is required to separate the signal and noise data, so that we get the necessary analysis done, and for this, SDT provides a neat probabilistic method to represent both these information. For example, consider a change detection task, where the subject is presented with, say, 4 stimuli on the screen. The subject is required to indicate whether some change has occurred in a target stimulus, which they will be probed for. If the change occurred at the target, it would be considered as a signal trial, otherwise, a noise trial. Relative to a fixed subject-determined *criterion*, the subject presents a *decision variable* with respect to his choice which, if greater than the criterion, the subject response is that a signal was shown, otherwise, the subject response is that a noise was shown. This is represented in Fig. 7(b-e). In the figure, there are 2 separate normal distributions - (1) Signal distribution, and (2) Noise distribution, each formed by the probabilities of their respective decision variable.

On the basis of the response given by the subject, there are 4 sections that the data can be uniquely divided. Considering the example above, if the subject reports a change at the probed location when the change, indeed, occurred, it is called a *hit*. If the subject reports a change when it had actually not occurred, it is called a *false alarm*. Alternatively, if the subject reports a no change when a change had occurred, it is called a *miss*, while if they report a no change when the change had, indeed, not occurred, it is called a *correct rejection*. All these responses are calculated as probabilities and reflected under the signal and noise distribution curves (Fig. 7). The probabilities corresponding to the hit rate is represented in Fig 7b as the area under the signal distribution curve that is greater than the criterion (beta) (Fig. 7b, in green), while the probabilities for false alarm rate is represented by the area under the noise distribution curve that is greater than the criterion (Fig. 7c, in red). Similarly, the probabilities corresponding to the misses is the area under the signal curve that is lesser than the criterion (Fig. 7b, in red), while the probabilities for the correct rejections are represented by the area under the noise curve that is lesser than the criterion (Fig. 7c, in green). The values for these responses can be jotted down in the form of a contingency table, that will record the frequency distributions and analyse the relationship between the true response, expected from the subject, and the response given by the subject.

One of the main properties that can be calculated from the signal distribution is *sensitivity*, represented by d′. The difference in the standard deviations (z-scores) of the probabilities of the hit rates and false alarm rates gives the sensitivity value which reflects the distance between the signal and noise distribution.

$$d' = Z(P_{hit}) - Z(P_{FA});$$

where Z is the inverse of the standard normal curve, evaluated at the probability

Sensitivity is important for one main reason - it is independent of the criterion, and therefore this property is not affected by a subject's bias.

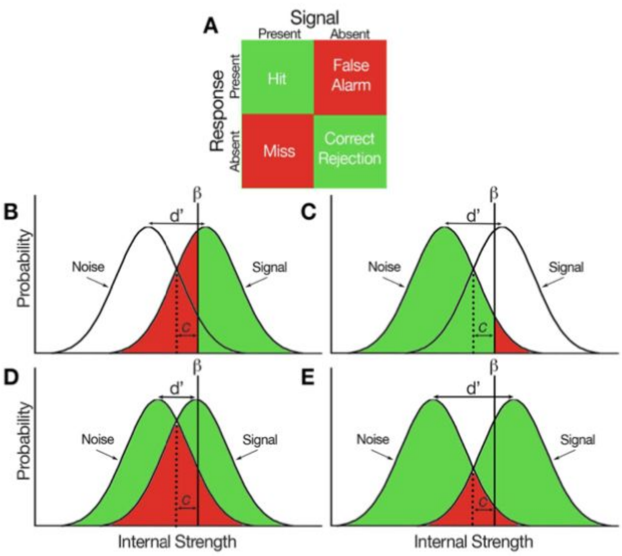


Figure 7. (a) Matrix of all the responses that a subject could possibly report. (b) Hit rates and Misses represented under the signal curve, indicated as green and red, respectively. D′ denotes the sensitivity and c represents the choice criterion (also denoted as cc). (c) False alarm rates and Correct rejections represented under the noise curve, indicated as red and green, respectively. (d) Represents a hypothetical situation where the sensitivity value is low, indicating that there is a small difference between hit rate and false alarm. (e) Represents a hypothetical situation where the sensitivity value is high, indicating a large difference in hit rate and false alarm. *Source: Referenced from [1,* Licensed under CC BY 4.0*]*.

Another important property that can be obtained from the 2 distributions is the subject's bias, or more specifically called choice criterion (cc). This is calculated as the difference between the criterion of the subject and the criterion of the 'ideal' subject, who would get equal proportions of misses and false alarms. More formally, the formula is as given below.

$$cc = -\left(Z(P_{hit}) + Z(P_{FA})\right) / 2;$$

where Z is the inverse of the standard normal curve, evaluated at the probability

3. METHODS & MATERIALS:

3.1. EXPERIMENT 1:

This experiment entails the study of the effect of exogenous visuospatial attention in an uncontrolled environment, where the subject performs tasks using a remote server, in the comfort of their home. The subjects are in the presence of various distractors that may influence their response, though a calm and noise-free environment was informed to create for themselves before they start the experiment. Also, the absence of a psychophysical observer may also affect the resultant data. This experiment is aimed at studying how an uninformed exogenous retro cue would affect the selection in working memory in such conditions.

3.1.1. Participants:

Seven healthy volunteers (ages: 21-25) participated in the experiment. All participants had either normal or corrected-to-normal vision. Participants gave informed consent before participating in this experiment. The details of the task were explained to them clearly before conducting the experiment, and the experiment was immediately stopped at any point in time upon their request.

3.1.2. Apparatus Setup:

The task was designed using HTML, assisted by the Javascript library, jsPsych [10], that helps conduct behavioural experiments on a web browser. The tool, JATOS [22], was used to export the program in an online setup in order to conduct experiments remotely. The local server with the experiment was exposed to the public internet using ngrok cloud service, and a link was given to the subject which led them to the task in their respective web browser (recommended browser was google chrome). The graphics of the task was designed using Snap.svg, which helps build scalable vector graphics. The experiment was conducted in a dimly-lit room. The participants performed the experiment in an upright position, and they were requested to maintain eye fixation throughout the trial. The stimuli were presented to them on the subject's laptop screen placed at an arm's length in front of them. Response of the subject was recorded using the subject's keyboard keys.

3.1.3. Task:

The background was set to a shade of grey, hex code - #666666. All trials consisted of a central fixation point (diameter: 16 px), and the subjects were required to fixate their eyes on the point, throughout the trial. This screen appeared for 450 - 500 ms, and was followed by another screen which comprised four circular placeholders of diameter 140 px, the centres of which were placed at 4 corners of an imaginary square of length 300 px. Each placeholder had a randomly oriented bar, sampled from a uniform distribution, and this bar was of length 140 px each, drawn along the diameter of the placeholder. This screen was displayed for 200 ms, within which the subjects had to try to memorise the orientation of the bar at each location, guided by their covert attention, following which a noise mask appeared within the placeholders, replacing the bars, for 50 ms. This noise mask, more famously known as the backward visual mask, consists of pixels of randomly assigned colour from the grey scale (RGB codes (0, 0, 0) to (255, 255, 255)), sampled from a gaussian (normal) distribution.

After the noise mask, a period of delay was presented for a time ranging from 100 ms to 1500 ms, and it correlates to the memory maintenance period. Shortly, an uninformative retro cue appears in the form of a flash at any one of the arcs located adjacent to the placeholder, and it lasts only for 50 ms, following which another delay period with a variable time of minimum 200 ms is presented. A single trial may or may not have a retro cue, and when it appears in a trial, there is an equal probability (20%) of this cue coming up at any one of the locations. The trials which are not cued are said to have a neutral cue.

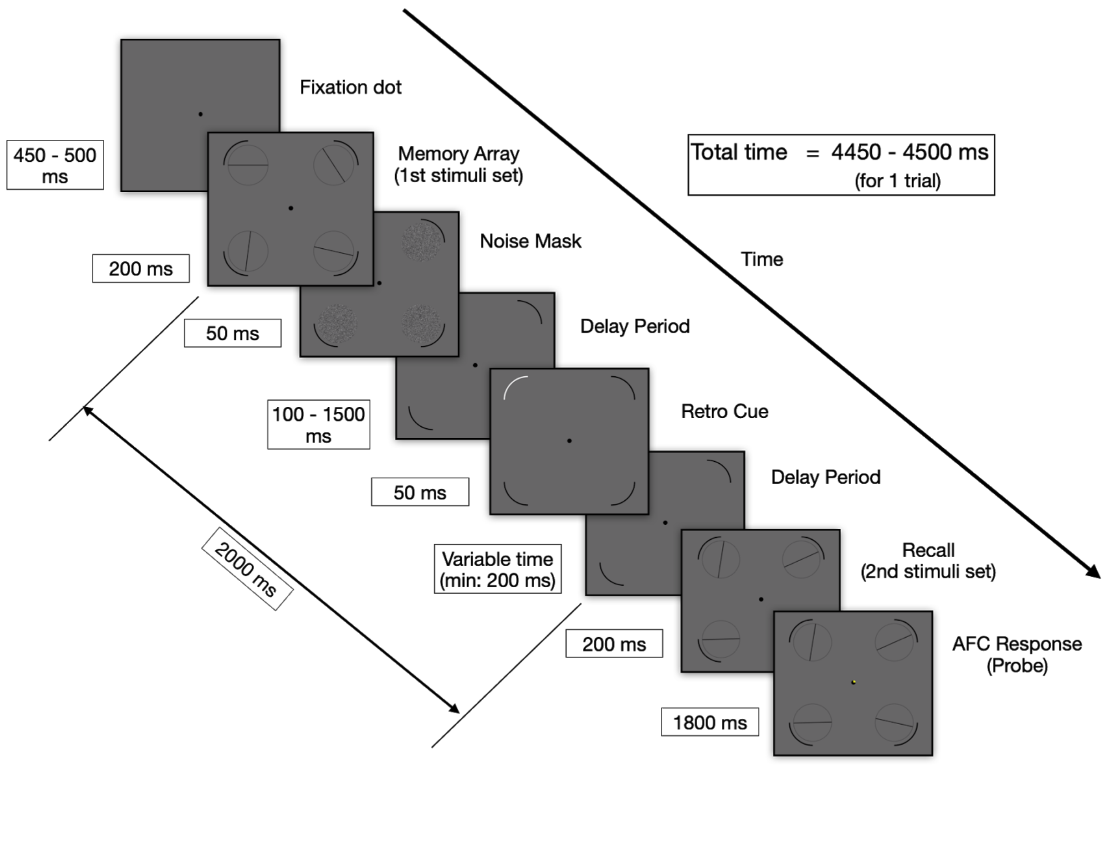


Figure 8. Experiment 1 Task Design

After the incidence of the delay period, the screen was replaced with another set of 4 oriented bars within their respective placeholder, presented for 200 ms. In this case, at least one or none of the bars would have had a change in the orientation angle when comparing them to the first set of stimuli. The change angle was set to 30 degrees, and so if the change occurred, the bar would rotate clockwise or anticlockwise by an angle of 30 degrees. In the same screen, the central fixation point changes to have one of the quadrants turned yellow. This indicates the location where the subject is being probed. They were required to recall the orientation of the bar that was presented during the memory array at the location where the probe is spatially aligned, and determine whether the bar shown in the second set of stimulus had changed orientations from the bar shown in the first set of stimulus. The subject presses the right arrow key if they report a 'change', and a left arrow key if they report a 'no change'. If the subject failed to respond, the trial was not taken into consideration.

The above is the description for one whole trial (Fig. 8). The experiment was divided into 8 blocks, each block consisting of 40 trials (320 trials per subject). Each trial takes 4450 - 4500 ms to complete.

3.1.4. Analysis of the Subject Data:

The subject data is recorded in JATOS trial by trial, such that the data across all blocks will be combined at the end of the experiment. This can be downloaded in the form of .txt file with the data formatted as JSON. A python code was written to convert the data format to .csv, which can, then, be easily imported into MATLAB, for further analysis.

Separate confusion matrices were created for cued trials (probe was in the same spatial field as cued location), ipsilateral trials (probe was in the same hemifield as the cued location), contralateral trials (probe was in the location adjacent to the cued), and opposite trials (probe was diametrically opposite to the cued location). This was done to find out the performance of the subject for these separate trial conditions, by comparing the subject responses against true responses. A trial is considered to be a hit if the subject reports a change at a location where a change occurred, while it is considered to be a false alarm if the subject reports a change at a location where no change occurred. Similarly, a trial is considered to be a miss if the subject reports a no change at a location where a change occurred, while it is considered a correct rejection if the subject reports a no change at a location where no change occurred.

From the contingency table (formed as a confusion matrix) of subject responses and true responses, it is possible to find out the hit rate, false alarm rate, miss rate, and correct rejection rate. The difference of the inverse of normal cumulative distribution function evaluated at the probability of hit rate and false alarm gives the sensitivity of the subject at a particular location. Similarly, the subject's bias towards a particular location was quantified to analyse the effect that the retro cue had on the subject's decision to report a change given a location. Plots of the hit rates, false alarm rates, sensitivity and choice criterion (cc) were generated.

3.2. EXPERIMENT 2:

This experiment is aimed at studying the effect of exogenous visuospatial attention on the orienting effect of attention in the working memory, when the subject performs the task in a controlled lab environment, where their movements are restricted in the presence of a psychophysical observer.

3.2.1. Participants:

Five healthy volunteers (ages: 21-27) participated in the experiment. All participants had either normal or corrected-to-normal vision. Participants gave informed consent before participating in this experiment. The details of the task were explained to them clearly before conducting the experiment, and the experiment was immediately stopped at any point in time upon their request.

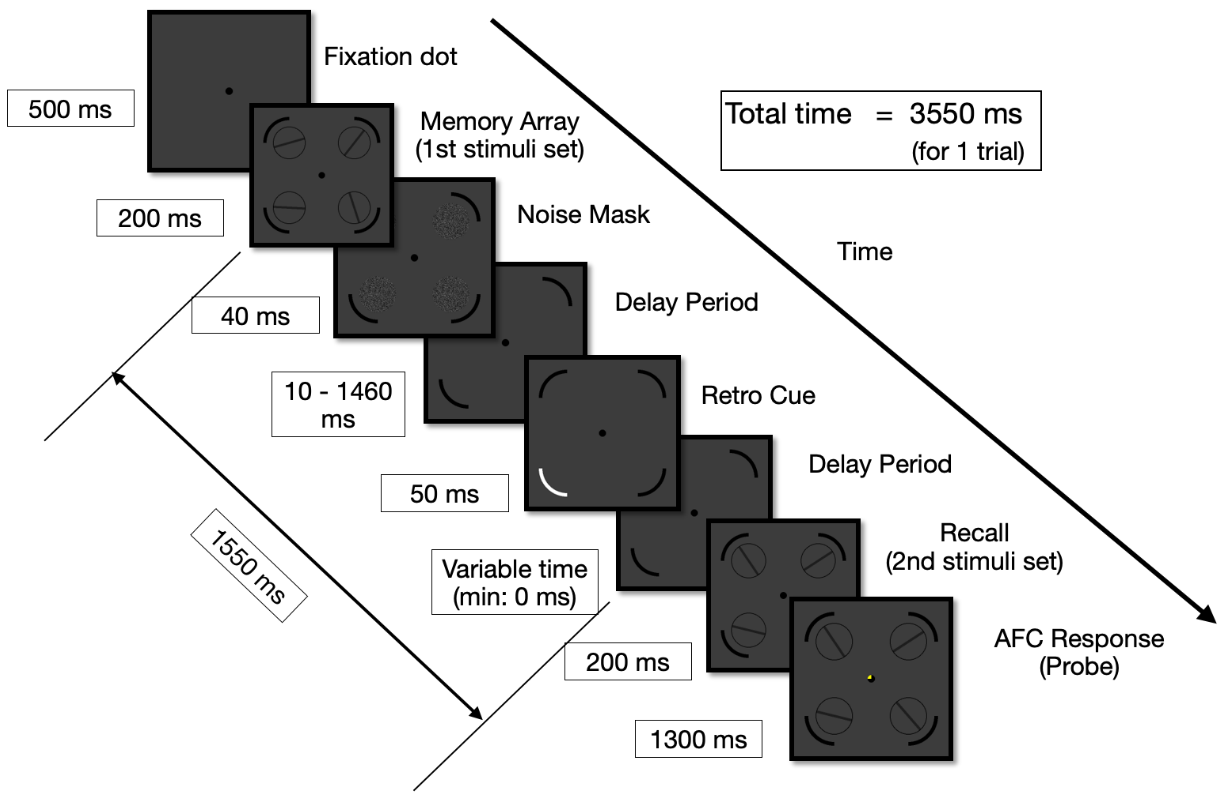
3.2.2. Apparatus Setup:

The task was designed using Psychtoolbox, and it was compiled and executed on MATLAB. The experiment was conducted in a dimly-lit room, and the participants were required to place their chin on a headrest to restrict head movement during the course of the experiment. They were requested to maintain eye fixation throughout the trial. The stimuli were presented to them on a stimulus display screen placed 60 cm in front of them. The subjects used a Cedrus response box to record their response.

3.2.3. Task:

The task design is similar to the one in experiment 1, though the versions may be different. All components in the task were centralized on the screen. All trials consisted of a central fixation point, and the subjects were required to fixate their eyes on the point, throughout the trial. This screen appeared for 500 ms, and was followed by another screen which comprised four circular placeholders, the centres of which were placed at 4 corners of an imaginary square. Each placeholder had a randomly oriented bar, sampled from a uniform distribution, each drawn along the diameter of the placeholder. This screen was displayed for 200 ms, within which the subjects had to try to memorise the orientation of the bar at each location, guided by their covert attention, following which a noise mask appeared within the placeholders, replacing the bars, for 40 ms. This noise mask, more famously known as the backward visual mask, consists of pixels of randomly assigned colour from the grey scale (RGB codes (0, 0, 0) to (255, 255, 255)), sampled from a gaussian (normal) distribution.

After the noise mask, a period of delay was presented for a time ranging from 10 ms to 1460 ms, and it correlates to the memory maintenance period. Shortly, an uninformative retro cue appears in the form of a flash at any one of the arcs located adjacent to the placeholder, and it lasts only for 50 ms, following which another delay period with a variable time of minimum 0 ms is presented. A single trial may or may not have a retro cue, and when it appears in a trial, there is an equal probability (20%) of this cue coming up at any one of the locations. The trials which are not cued are said to have a neutral cue.



Experiment 9. Experiment 2 Task Design

After the incidence of the delay period, the screen was replaced with another set of 4 oriented bars within their respective placeholder, presented for 200 ms. In this case, at least one or none of the bars would have had a change in the orientation angle when comparing them to the first set of stimuli. The change angle was set to 30 degrees, and so if the change occurred, the bar would rotate clockwise or anticlockwise by an angle of 30 degrees. In the same screen, the central fixation point changes to have one of the quadrants turned yellow. This indicates the location where the subject is being probed. They were required to recall the orientation of the bar that was presented during the memory array at the location where the probe is spatially aligned, and determine whether the bar shown in the second set of stimulus had changed orientations from the bar shown in the first set of stimulus. The subject records his/her response in the cedrus box by pressing the appropriate key. If the subject failed to respond, the trial was not taken into consideration.

The above is the description for one whole trial (Fig. 9). The change angle of the bars were staircased across blocks, depending on the performance of the subject. The experiment was divided into 10 blocks, each block consisting of 40 trials (400 trials per subject). Each trial takes 4450 - 4500 ms to complete.

3.2.4. Analysis of the Subject Data:

The subject data across all blocks is combined for further analysis in MATLAB. The analysis method for this experiment follows the same procedure as in section 3.1.4.

4. RESULTS AND INTERPRETATIONS:

The purpose of this behaviour analysis is to identify any modulation in sensitivity of the subject at each of the locations due to exogenous visuospatial attention. The effect of the cue on the hit rate, false alarm rate, sensitivity and choice criterion is described below.

4.1. Experiment 1:

Firstly, the hit rates and the false alarm rates were calculated for each subject across all 4 locations i.e. cued, ipsilateral, contralateral, and opposite. These values were used to calculate the sensitivity and the choice criterion (cc) values of the subjects. These values are represented in the form of boxplots in Fig. 10, 11, 12, and 13, for hit rates, false alarm rates, sensitivity and cc, respectively. The numbers in the boxplots represent subject ID numbers. The horizontal edges of the box represent the lower and upper quartile range, the red line in the middle represents the median of the subject data, and finally, the points outside the box represent outliers. It was observed that even though a particular trend was being followed by the subjects individually, there was still large standard deviation in the performance of the subjects. For this reason, the values across the different properties were normalised on a scale of 0 to 1, with respect to each subject.

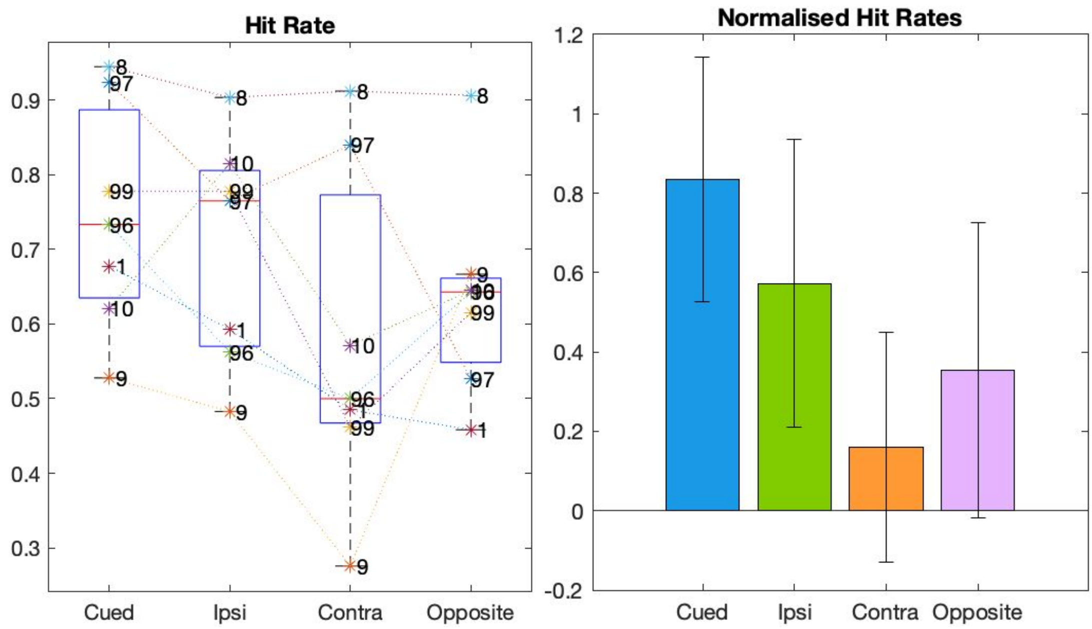


Figure 10. Boxplot of the hit rates of the subjects on the 4 locations separately (picture on the left). The values were normalised and the mean of the performance on each location was plotted (picture on the right) on a bar graph with error bars.

These normalised values were averaged across locations and their standard deviation calculated, and this was plotted on a bar graph with error bars. The hit rate was the highest at the cued location (z-score values - Cued: 0.3; Ipsi: 0.36; Contra: 0.28; Opp: 0.37), which might suggest that most of the subjects performed better at the cued location. But, this information includes the inherent bias of the individual, and therefore, the plots for false alarm rates were observed. There does not seem to be any significant observation from the plot of false alarm rate (z-score values - Cued: 0.41; Ipsi: 0.39; Contra: 0.36; Opp: 0.37). This could be a consequence of conducting the experiment in an uncontrolled environment.

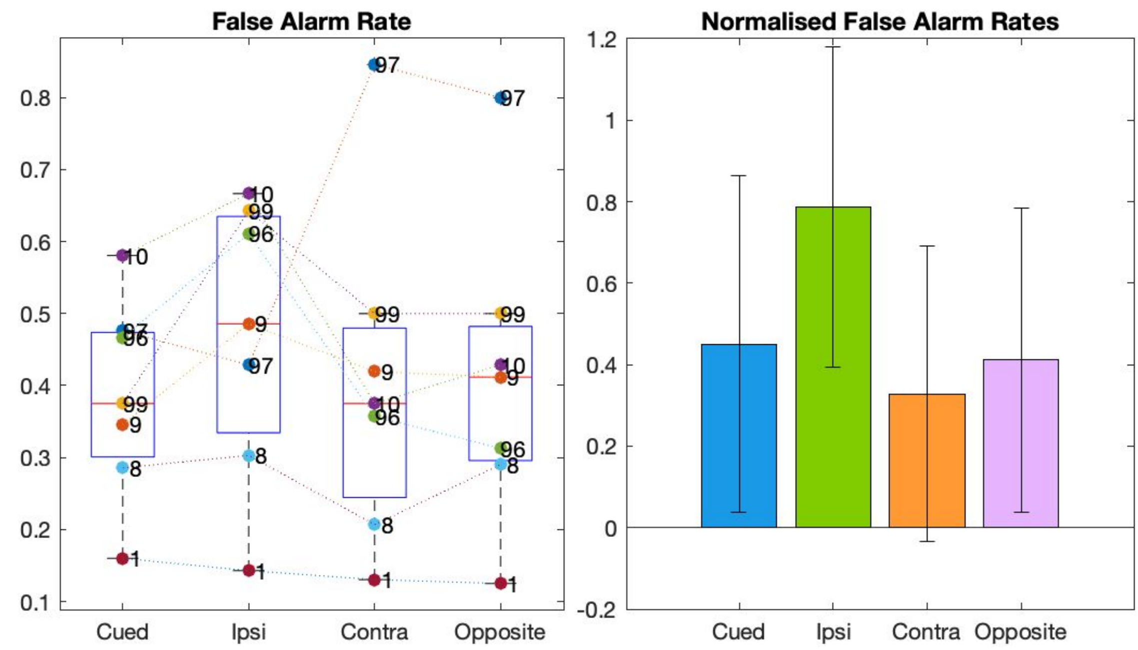


Figure 11. Boxplot of the false alarm rates of the subjects on the 4 locations separately (picture on the left). The values were normalised and the mean of the performance on each location was plotted (picture on the right) on a bar graph with error bars.

The resultant calculation of hit rate and false alarm rate gives us the bias-free property - sensitivity. As observed in Fig. 20, the precision at the cued location was the highest out of all locations (z-score values - Cued: 0.36; Ipsi: 0.32; Contra: 0.41; Opp: 0.48). Following this the choice criterion quantifies the bias of the individual, and Fig. 21 plots show a decreased choice criterion values at locations that are in the same hemifield as the cue i.e. cued and ipsilateral location (z-score values - Cued: 0.28; Ipsi: 0.35; Contra: 0.37; Opp: 0.31). A low choice criterion value at a particular location means that the subject is more biased towards reporting a change at that location. Therefore, it might be observed that most of the subjects are more biased towards the hemifield on the cued side.

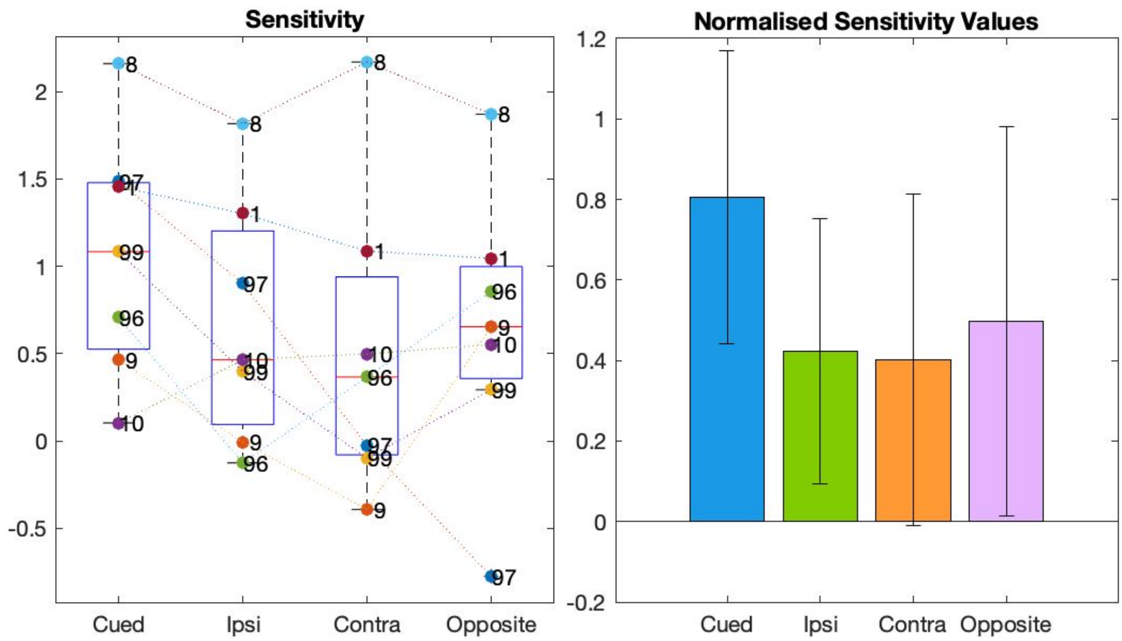


Figure 12. Boxplot of the sensitivity values of the subjects on the 4 locations separately (picture on the left). The values were normalised and the mean of the performance on each location was plotted (picture on the right) on a bar graph with error bars.

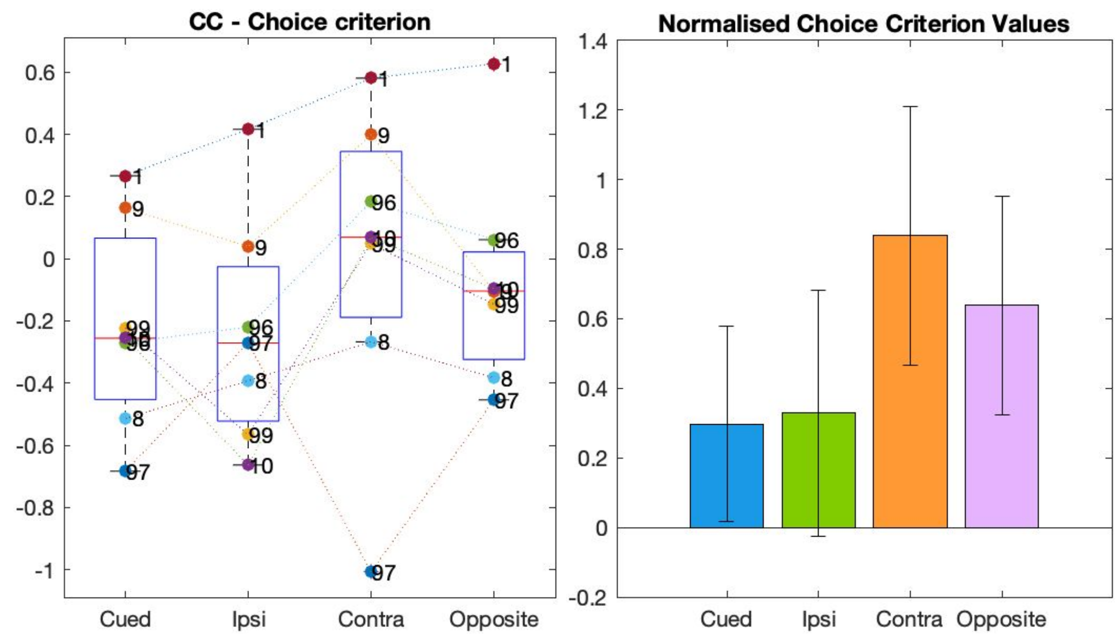


Figure 13. Boxplot of the choice criterion values of the subjects on the 4 locations separately (picture on the left). The values were normalised and the mean of the performance on each location was plotted (picture on the right) on a bar graph with error bars.

4.2. Experiment 2:

This experiment corresponds to the task conducted in the controlled, lab environment. In this series of results, there was no normalisation required since the tasks were staircased when the subjects performed the task. This means that the change angle was increased or decreased step by step every block during the training blocks till an angle was reached when they could comfortably detect the changes with respect to the bars. Fig. 14-15 consists of the plots of all the major properties that could be used to draw conclusions for the study. The hit rates were the highest at the cued location, more so than the neutral cue condition. Following this, the false alarm rates did not seem to give any significant trend. But, because the hit rates were so high, it had a meaningful impact on the sensitivity, since the precision of almost all the subjects were observed to max at the cued location. Another point of observation was that the sensitivity at the other locations seem to be lower than the neutral cue condition, suggesting the possible loss of fidelity at these locations due to prioritization of information at the cued location. Most of the subjects were also, seemingly, more biased at reporting a change at the cued location, suggesting the possible effect that the exogenous cue plays in modulating the bias of the individual.

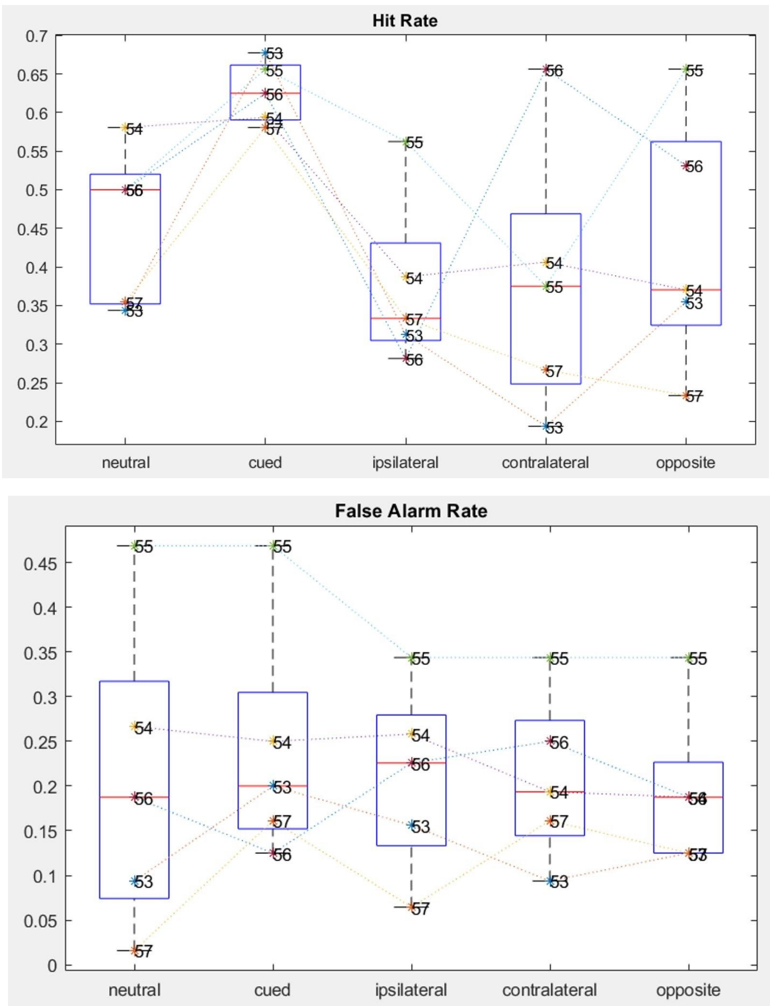


Figure 14. Boxplot of the hit rates and false alarm rates of all subjects at the 4 locations.

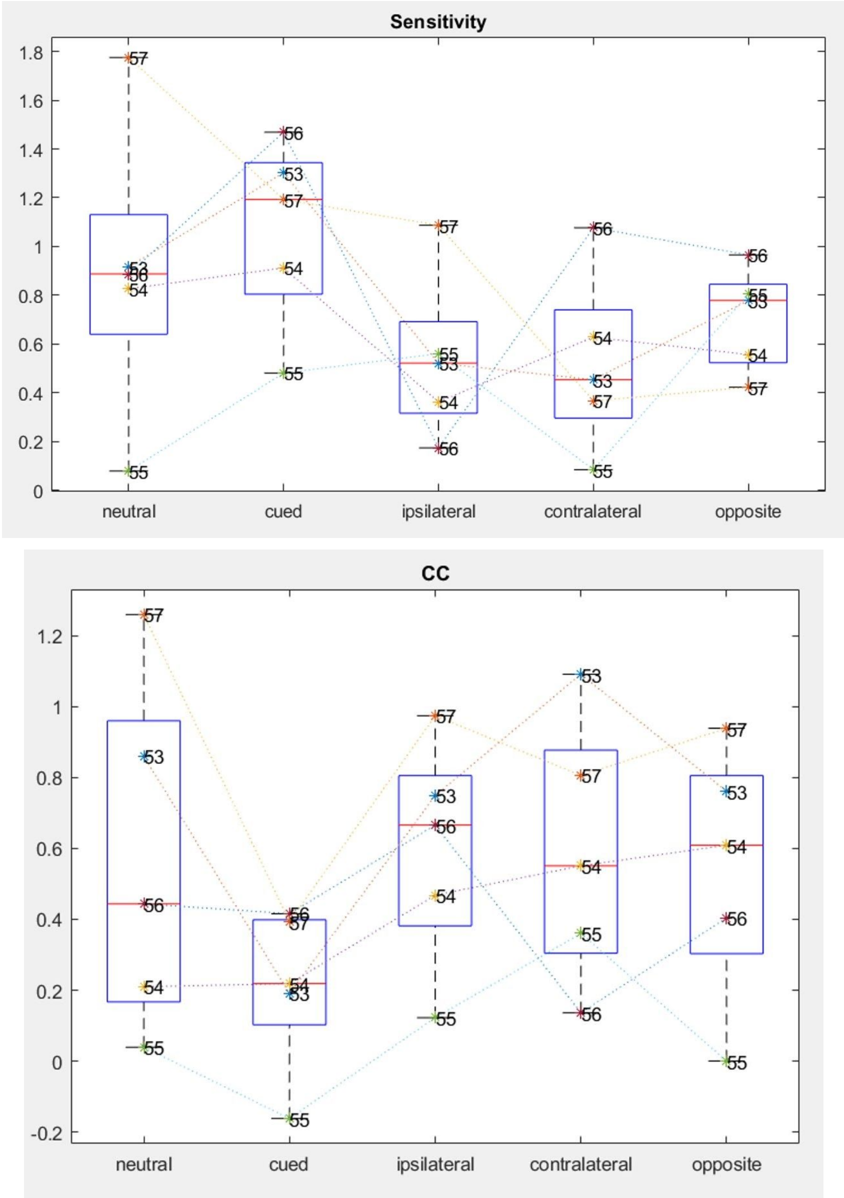


Figure 15. Boxplot of the hit rates and false alarm rates of all subjects at the 4 locations.

5. DISCUSSION:

Prioritizing of information has been claimed to be of benefit for the efficient processing of task-relevant information, and there is enough evidence in relation to this [18, 12, 30]. In this project, the effect of exogenous visuospatial attention on the orienting effect of attention in the working memory, with the help of retrospective (in short, retro) cues that also functions to involuntarily drag the subjects' spatial attention (exogenous) to the incidence of the cue.

5.1. Performance of the subjects - Behaviour Analysis:

Ideally, due to the uninformative nature of the exogenous retro cue, which acts like a distractor, dragging the subjects' covert attention involuntarily at a particular location, the cue should pose no effect on the selection in working memory. And therefore, essentially, the sensitivity or the performance of the subject should be similar across all the locations. Previous studies have shown us that when exogenous cues were presented to a subject, it systematically enhanced perceptual sensitivity and the subject's choice bias [37]. We set out to find if a similar exogenous cueing modulates the sensitivity of the subject towards the cued location. In experiment 2, when the tasks were conducted in a controlled setting, we notice that the sensitivity at the cued location is the highest for most of the subjects, suggesting the unconscious role that exogenous attention may play in prioritizing information in the working memory, leading to improved performance at target location [7, 14], and this is in spite of mentioning to the subjects that the exogenous cue did not hold any relevance to the task. The high sensitivity at the cued location may also indicate a seeming protection of fidelity of the information at that location due to deployment of attention [20], while the lower sensitivity values at the uncued locations, which were lower than the one for the neutral cue condition could, possibly, indicate the loss of fidelity of information at the other locations when an exogenous cue appears [17]. It could also be noticed that the choice criterion is found to be the lowest at the cued location for most of the subjects, indicating that the subjects are more biased towards reporting a change at the cued location. Such results could possibly suggest a link between selection in WM and exogenous attention.

Furthermore, we set out to find if a similar result could be reproduced in a remote uncontrolled environment, in the absence of a psychophysical observer. In experiment 1 results, when we look at individual subject performance, the sensitivity is highest at the cued location for most, if not all, subjects, suggesting the improved performance of subjects at the cued location, possibly due to an enhanced internal representation of the target in the working memory. An interesting result to note is subject no. 10, whose cued location has the lowest sensitivity value, in comparison to other locations. Though it might seem like an outlier, there is evidence in literature that sometimes with the incidence of an exogenous cue or a subliminal cue, there is a brief facilitation of the target location, followed by an inhibition of the target, leading to low performance at the cued location [25-27], though this occurs at delayed time intervals between the cue incidence and the target stimuli. Perhaps, by running the task on more number of subjects, we might be able to conclude on two kinds of effect that the exogenous attention may impose on the subject - one having an increased sensitivity at the cued location, while the other having a decreased sensitivity at the cued location. With respect to the choice bias results in experiment 2, we observe a hemifield-specific increase in choice bias (indicated by the low values of choice criterion in the cued and ipsilateral locations). This is something that is not observed in the experiment 1 results, and needs to be studied further.

It should be noted that most of the subjects who performed the task in experiment 1 were naive subjects i.e. they have never done cognition based tasks before. So, there is a higher possibility for error to creep into the data due to the lack of experience. This might also be one of the reasons for a large range of standard deviation in the data. But, in spite of that, we have observed a significant trend if individual subject data were studied in isolation. This further underlines the effect of the exogenous retro cue.

These results are in positive light to imply the relationship between visuospatial attention and working memory, and for the first time, the possible modulating effect of uninformed, exogenous retro cues on the selection in working memory is demonstrated, which is reflected by the modulating effect of selection in external visual space.

5.2. Limitations and Future Work:

The study did not examine the reaction times of the subject at each location, and further extension in relation to this could provide us with more insights. Secondly, there seems to be a huge standard deviation in the sensitivity and choice bias values across subjects in experiment 1, and thus, it signifies the importance of dynamically tuning the task to make it comfortable for all kinds of subjects to perform the task with ease. Another interesting aspect that could be studied is the possible inhibitory effect of the exogenous cue on the target representation, during extended delays between the changed stimuli and cue.

The next challenge of this project is to expand on this finding by providing neurophysiological evidence that could purpose the behaviour results by identifying neural correlates of behaviour. This challenge drives the future work of this project and might perhaps bring conclusive results for the title of this project.

6. CONCLUSIONS:

With this study, we were able to explore the possible link that exogenous visuospatial attention could possibly have with selection in working memory, by which certain information gets prioritized, leading to an improved memory recall of that internal representation. Our research demonstrates that with the incidence of an uninformative retro cue, the subjects were able to recall the representation at the target location better when the target and the cue were spatially aligned. This was indicated by the improved sensitivity values of the subjects at the cued location, and since sensitivity is a property free from the inherent spatial bias of a subject, we can take this result at face value. Furthermore, it was also inferred that subjects tended to be more biased in reporting a change at the cued location, in comparison to other locations, illustrated by the apparent drop in the choice criterion values. This was a trend seen for most of the subjects, and therefore provides additional support that uninformative, exogenous retro cues indeed have a modulating effect on orienting attention in our working memory. An expansion of this research into finding neurophysiological evidence through EEG, could further provide evidence for the same. The research also demonstrates the importance of studying working memory and attention as a combined concept because of the obvious effect one has on the other. Research in cognition has reached new heights, as of late, and this is in time with the ever-expanding technological advancements. New developments take place everyday, and the possibility of acclimatising the same for research in cognition is an interesting endeavour.

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