Brain activation in response to randomized visual stimulation as obtained from conjunction and differential analysis: an fMRI study

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Abstract. The objective of this multiple-subjects functional magnetic resonance imaging (fMRI) study was to identify the common brain areas that are activated when viewing black-and-white checkerboard pattern stimuli of various shapes, pattern and size and to investigate specific brain areas that are involved in processing static and moving visual stimuli. Sixteen participants viewed the moving (expanding ring, rotating wedge, flipping hour glass and bowtie and arc quadrant) and static (full checkerboard) stimuli during an fMRI scan. All stimuli have black-and-white checkerboard pattern. Statistical parametric mapping (SPM) was used in generating brain activation. Differential analyses were implemented to separately search for areas involved in processing static and moving stimuli. In general, the stimuli of various shapes, pattern and size activated multiple brain areas mostly in the left hemisphere. The activation in the right middle temporal gyrus (MTG) was found to be significantly higher in processing moving visual stimuli as compared to static stimulus. In contrast, the activation in the left calcarine sulcus and left lingual gyrus were significantly higher for static stimulus as compared to moving stimuli. Visual stimulation of various shapes, pattern and size used in this study indicated left lateralization of activation. The involvement of the right MTG in processing moving visual information was evident from differential analysis, while the left calcarine sulcus and left lingual gyrus are the areas that are involved in the processing of static visual stimulus.

1. Introduction

Since the discovery of blood oxygenation level dependent (BOLD) effects [1], fMRI has become a standard experimental technique in accessing brain activity, among others, in response to visual stimuli [2]. This technique allows the presentation of visual field in human occipital cortex to be studied non-invasively [3]. The fMRI technique is also suitable for studying the properties of the visual area of subjects suffering from ocular abnormalities [4].
Human visual system has a limited processing capacity. Previous information about visual image processing in human brain was obtained mainly from psychophysical studies [5]. Nowadays, fMRI technique has proven to be very useful in studying human brain function related to visual processing [6]. Visual processing system has to compete for cortical representation when multiple stimuli are simultaneously presented [7]. As a result, stimuli with a variety of features color or motion produces brain activation that are more prominent than stimuli that did not have any specific features [8].

In a study using a moving action visual stimulus [9], it was found that activation occurs in premotor cortex, superior parietal lobe and superior temporal sulcus. This was discussed as due to the fact that human brain can anticipate the movement as a result of motor stimulation. In other words, human brain may have the ability to simulate the performance of action being observed [10].

To date, a vast number of study on how human brain responded to visual stimuli have been conducted. Among others are facial recognition [6], stimulus in motion [9] and attention and memory [11]. Accompanying these studies are those conducted on patients with ocular abnormalities such as glaucoma [12] and chronic bilateral vestibular failure [13].

Ocular abnormalities have apparent effects on brain activation. However, neuroimaging data about the ocular characteristics of healthy participants are still lacking to be compared with data for patients with ocular pathology. The objective of this multiple participants’ functional magnetic resonance imaging (fMRI) studies was to investigate the brain activation characteristics of healthy participants when they view stimuli of various shapes, pattern and size. Specifically, this study will determine the common activated areas, the areas that are more active in processing moving stimuli than static stimuli and the area that are more active in processing static stimuli than moving stimuli. Data obtained from healthy participants will serve as baseline for future studies on patients with ocular abnormalities.

2. Method

2.1 Participants
Sixteen healthy adult participants (9 males and 7 females) participated in this study. This study has been approved by the Institutional Ethics Committee of the Universiti Kebangsaan Malaysia (Ref No: NN-073-2011). All participants were above 40 years old (mean = 48.7 years, standard deviation = 6.4 years) with normal vision and no history of ocular disorder. All participants gave their informed written consent. They were required to undergo a comprehensive vision test conducted by qualified optometrist at Ophthalmology Clinic in Selayang Hospital. Visibility of the participants should be better than 6/12 without full refractive correction.

2.2 fMRI scan
The fMRI scans were performed in the Department of Radiology, Universiti Kebangsaan Malaysia Medical Centre (UKMMC) using a 3-T Siemens Magnetom Verio scanner. A standard BOLD imaging protocol with gradient echo planar imaging (EPI) pulse sequence was used with imaging parameters as follows: acquisition time (TA) = 3000 ms, echo time (TE) = 50 ms, field of view (FOV) = 192×192 mm, flip angle (α) = 90°, matrix size = 3×3×3 and slice thickness = 3 mm.

2.3 Stimuli
Visual stimuli generated by a computer were projected onto the translucent screen via a liquid crystal display (LCD) projector. The non-metallic screen was fixed inside the magnet room while both the projector and the computer were placed on the control panel. The participants viewed the stimuli on the screen via a mirror that was attached to the head coil. Five types of stimuli were used in this study; i)
growing ring (A), ii) rotating wedges (B), iii) hourglass/bowtie (CD), iv) quadrant arc (EF) and iv) checkerboard pattern (G), see Figure 1 and [14]. All stimuli have black-and-white checkerboard pattern. Each stimulus has an element of movement except stimulus G which is static. Stimulus C & D and E & F flipped when displayed to the participant.

![Visual stimuli](image)

**Figure 1:** Visual stimuli used in this study. The participants were required to focus their sight onto a dot (indicated by the arrows) during the fMRI scan.

### 2.4 fMRI paradigm and image processing

This study used a block-fMRI paradigm [15]. For the active state (stimulus shown), a number of 20 scan volumes were collected while for the rest state (participant viewing a white screen) a number of 10 scan volumes were collected. There were 80 scan volumes for each stimulus type and 160 scan volumes for rest state. The sum of all scan volumes is 480. All the A, B, CD, EF and G stimuli were projected in rotation during the active state. All participants were required to respond by squeezing the rubber bulb as they view the white screen. This is to ensure that the participants remain conscious and awake throughout the scans.

### 2.5 Post processing

The fMRI data were analyzed using MATLAB 7.4 – version R2010a (Mathworks Inc. MA, USA) and Statistical Parametric Mapping (SPM12b) programming software. Functional images in each measurement were realigned using the 6-parameter affine transformation in translational (x, y and z) and rotational (pitch, roll and yaw) directions. The normalization procedure used a 12-parameter affine transformation. The images were then smoothed using 8 an 8-mm full-width-at-half-maximum (FWHM) Gaussian kernel. Low-frequency responses caused by aliased biorhythms, cardiac effects and other oscillatory signal variations were removed using a high-passed filter. Conjunction analysis [16] was used to determine commonality of activation due to all stimulus types i.e. A ∧ B ∧ CD ∧ EF ∧ G. The brain activation was thresholded at α = 0.001. The areas in the brain that were more activated for moving stimulus as compared to static stimulus, and vice versa, were determined using the combination of differential and conjunction analysis i.e. (A > G) ∧ (B > G) ∧ (CD > G) ∧ (EF > G). The activation was also threshold at α = 0.001. The activation areas obtained from the analyses above were confirmed using Anatomy Toolbox [17].
3. Results and Discussion

Figure 2 shows the activated areas obtained from conjunction analysis mentioned above. The activated areas are left precentral gyrus (lPCG), left post central gyrus (lPostCG), left superior temporal gyrus (lSTG), left occipital gyrus (lOG) and middle cingulate cortex (MCC).

![Figure 2](image.png)

**Figure 2:** Maximum intensity projection in coronal orientation obtained from conjunction analysis, \( A \land B \land CD \land EF \land G \), at \( \alpha = 0.001 \). L: left, R: right

The results shown in Figure 2 indicated three important information when the participants viewed the visual stimuli of different shapes and size; i) the existence of common activated areas, ii) left lateralization of activation and iii) the existence of common activated areas outside visual cortex. The stimuli used in this study would be able to characterize visual world, visual field and visual space [14]. It is suggested that the variability of the function of stimuli and their unique ability to evoke responses in multiple brain areas have resulted in the activation in the visual cortex as well as outside the occipital cortex such as PCG, postCG, STG and MCC. The results also supported the functional integration concept which states that a particular brain area might have more than one function, for example, the PCG [18], postCG and STG [19] which have been found to be involved in working memory. The activation in MCC have not been reported to be specific for visual processing but it was found to be activated during learning processes [20], formation and processing of emotion [21] and working memory [22] which could occur during the task performance.

The involvement of right MTG in the processing of moving stimuli is evident in Figure 3(a) and is supported by previous study [9] which reported that MTG was significantly activated when the participants viewed capoeira movements and ballet dancing. MTG, also known as BA21, is located in between the STG and inferior temporal gyrus (ITG). The exact function of this area is inconclusive but is commonly related to distance estimation, face recognition and evaluation of meaning of words. It has also been related to motion perception and contrasting motion signals [23]. It has also been thought to play a major role in the perception of motion, the integration of local motion signals into global percept, and the guidance of eye movements [24]. The brain areas that are more active towards static stimuli as compared to moving stimuli are left calcarine sulcus and left lingual gyrus (Figure 3(b)). The calcarine sulcus is where the primary visual cortex (V1) is concentrated. V1 has a very well-defined map of the spatial information. Participants in this study viewed complex visual stimuli thus activating fusiform, lingual and occipital gyrus significantly. Lingual gyrus has been known to play an important role in vision, recognition and identification [25].
4. Conclusion
Visual stimulation of various shapes, pattern and size used in this study indicated left lateralization of activation. The involvement of the right MTG in processing moving visual information was evident from differential analysis, while the left calcarine sulcus and left lingual gyrus are the areas that are involved in the processing of static visual stimulus.

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