Association Between Brain Activity of Dominant Ocular Mechanism and Visually Evoked Postural Responses

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Abstract. This study investigates the association between ocular dominance and brain function using functional magnetic resonance imaging (fMRI), focusing on the dominant eye's role in processing visual information and its effect on visually evoked postural responses (VEPRs). The research involved participants with identified dominant eyes, using tasks designed to engage peripheral vision and evoke postural changes. The fMRI results revealed increased cerebral activity in the precuneus and occipital lobe regions during dominant eye viewing, suggesting these areas' significant role in processing ocular dominance mechanisms. This activity was asymmetric, predominantly occurring in the left hemisphere, supporting theories of contralateral visual processing in the brain. The study also explored the relationship between ocular dominance and VEPRs. However, no significant correlation was found between the dominant eye and postural changes, indicating a complex interplay of visual processing that may not directly influence postural control. These findings contribute to the understanding of ocular dominance in brain function, highlighting specific brain regions involved in processing visual information from the dominant eye and providing insights into the neural mechanisms underlying ocular dominance and visual perception.

Keywords: Dominant eye · Brain activity · Visually evoked postural responses (VEPRs) · Postural changes · fMRI

1 Introduction

The concept of a dominant eye, or "preferred eye," refers to the eye that plays a primary role in processing visual information and determining the position of objects when viewing scenes or objects with both eyes. The dominant eye handles the majority of visual input, playing a crucial role in activities such as distance assessment and tracking targets. Identifying the dominant eye requires a clear definition of what constitutes a "dominant eye," and it is generally understood to be the eye that exhibits functional dominance. A simple method for determining the dominant eye is as follows [1] (Fig. 1):

1. Create a small 'window' using both hands.

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2. Focus on a distant object in the room through the window formed by the hands.
3. While maintaining focus, slowly bring the hands closer to the face without diverting the eyes from the distant object, continuing to view it through the window.
4. The eye towards which the hands naturally move, and which maintains clear vision of the object, is considered the dominant eye.

Fig. 1. A simple method for determining the dominant eye.

Interest in the dominant eye has been high historically, with extensive research conducted in various fields. For instance, studies have generally found no significant difference in sensitivity aspects such as vision between the dominant and non-dominant eyes [2], suggesting minimal functional differences between them as individual organs. In tasks involving eye tracking, such as following a moving object, no significant differences have been observed between the dominant and non-dominant eyes [3]. However, it has been established that the dominant eye processes visual stimuli 14 ms faster than the non-dominant eye [4].

Furthermore, the dominant eye plays a significant role in the development of a wide range of activities and skills. In sports performance, for instance, it is essential for accurately capturing targets and regulating movements. In reading and writing abilities, it enhances the recognition, understanding, and memory of letters and words. In driving skills, it contributes to the rapid and accurate processing of road information. In all these activities, the dominant eye enables precise and effective processing of visual information and fine-tuning of performance.

Information obtained through vision is integrated and processed along with information from other sensory organs. Notable examples of such integrated processing include the combination of visual, balance, and kinesthetic senses. Physical responses related to this processing include visually induced postural responses (VEPRs) [5] and visually induced self-motion perception (Vection) [6]. When viewing full-screen motion images, postural changes and sensations of self-motion occur due to the characteristics of the images or the observer. Experiments investigating VEPRs and Vection in the context of motion sickness suggest that these may be corrective responses to sensory discrepancies [7]. Figure 2 shows a scene from my previous study where the subject was watching a

3D movie with front-back directional motion. The subject's movements cycled in accordance with the global motion phase of the movie. This postural change is an example of a motile visually evoked postural response synchronized with the movement [8]. While research on the visual functions and activity factors related to the dominant eye has been conducted, sufficient investigation of the brain functions central to integrated understanding has not been extensive. Furthermore, there has been little verification of the relationship between the dominant eye and visually induced postural changes. Therefore, this study aims to provide a fundamental verification of the relationship between the dominant eye and brain functions. Using functional MRI (fMRI), a method of brain function imaging, we attempted to visualize brain activities related to the dominant eye mechanism and examine the relationship between the dominant eye and VEPRs.

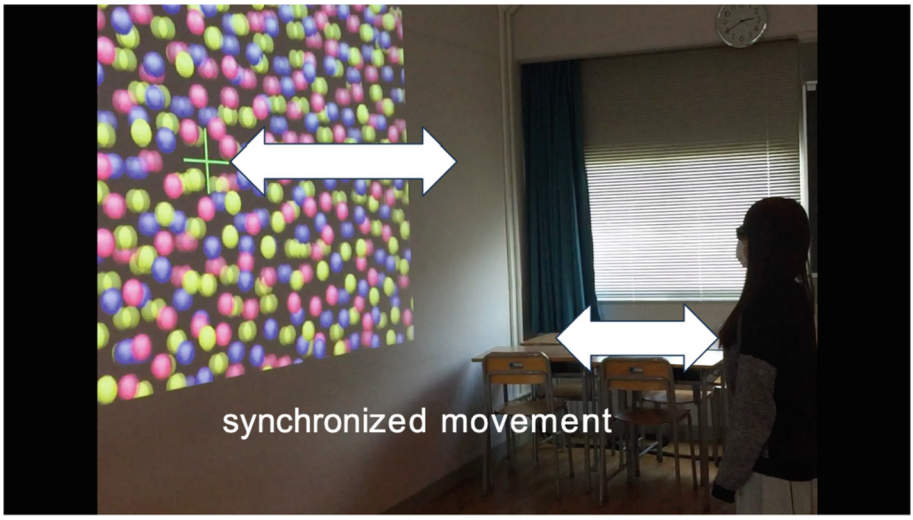

Fig. 2. Scene from my previous study where the subject was watching a 3D movie with front-back directional motion.

2 Methods

Gifu University of Medical Science Research Ethics Committee (Approval No. 2022-9) approved the participation of 14 individuals aged between 20 to 22 years old, comprising an equal number of males and females (7 each), who had no known issues with their vision or balance. Prior to the study, the dominant eye of each participant was determined using the Miles Method [1], revealing that 9 individuals had right eye dominance and 5 had left eye dominance. The study was rigorously carried out in strict accordance with the principles of research ethics and was conducted in conformity with the Declaration of Helsinki. The safety and rights of the participants were prioritized; comprehensive information was provided to all participants beforehand, and written consent was obtained. The research design was reviewed and approved by an independent ethics committee

from an ethical standpoint prior to the commencement of the study. The privacy of the individuals was stringently protected, and the data was handled with confidentiality, being anonymized for the purpose of the study.

2.1 Experiments on the Visualization of Brain Activity

In the field of brain function imaging, instead of directly recording the activity of individual cells, the identification of functions is commonly based on the phenomenon of neurovascular coupling (NVC). NVC refers to the phenomenon where an increase in neuronal activity leads to a corresponding increase in local blood flow shown in Fig. 3 [9]. This response serves to meet the increased demand for energy metabolism associated with neuronal activity. When neurons are active, chemical mediators such as nitric oxide (NO) and adenosine [10] are released, acting on nearby blood vessels to induce vasodilation. Consequently, the increased blood flow through the dilated vessels supplies the necessary oxygen and nutrients to the neurons, thus supporting the maintenance of neural activity and meeting energy requirements. By tracing this sequence of actions in reverse, we can arrive at brain imaging, a prime example of which is functional MRI (fMRI). fMRI visualizes changes over time in the blood oxygenation level dependent (BOLD) signal [11, 12]. This signal is a magnetic resonance signal from protons, varying according to the ratio of oxyhemoglobin to deoxygenated hemoglobin in the blood. An increase in the BOLD signal does not signify a higher ratio of deoxygenated hemoglobin due to neuronal activity; instead, it reflects an excess of oxyhemoglobin resulting from increased blood flow. Consequently, the surplus of oxyhemoglobin, a diamagnetic substance, alters the magnetization state of the surrounding tissue. This alteration reduces the ratio of deoxygenated hemoglobin, thereby enhancing the magnetic resonance signal of protons.

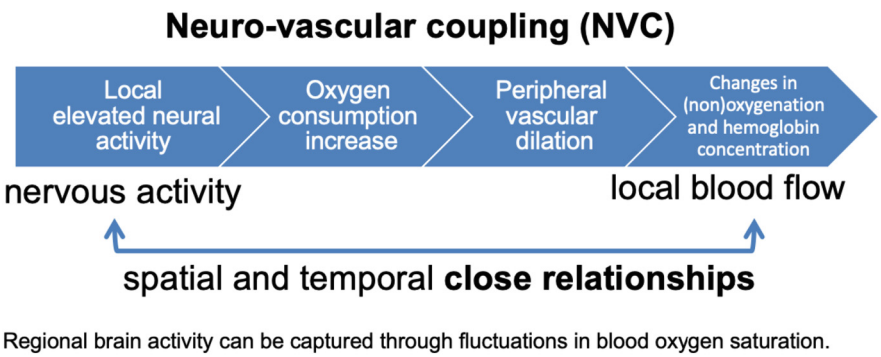

Fig. 3. Diagram of neurovascular coupling (NVC)

Visual Presentation and Observation Method

Our visual stimulus consisted of a display filled with spheres randomly distributed across it. These spheres moved synchronously in a sinusoidal pattern on all axes at a frequency

of 0.25 Hz, as depicted in Fig. 4. The observation setup involved positioning a mirror at approximately a 40° angle and at a distance of 15 cm from the participants' eyes, placed above the head coil. This arrangement enabled participants, lying reclined in the gantry, to see the screen positioned at the lower end of their visual field. A video was displayed on this screen, located near their feet (as outlined in Fig. 5 for an overview). Participants were instructed not to focus on any individual sphere but to view the entire array peripherally. Additionally, participants realized right eye, left eye, and binocular vision by covering one eye with an opaque cloth, thus enabling each visual condition to be tested in isolation.

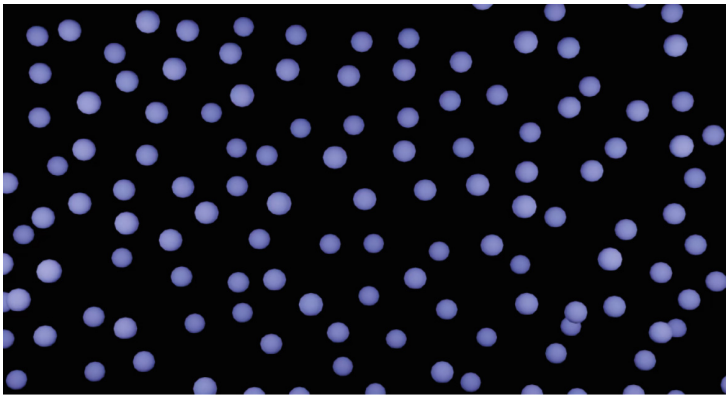

Fig. 4. Experimental movie as a visual stimulus.

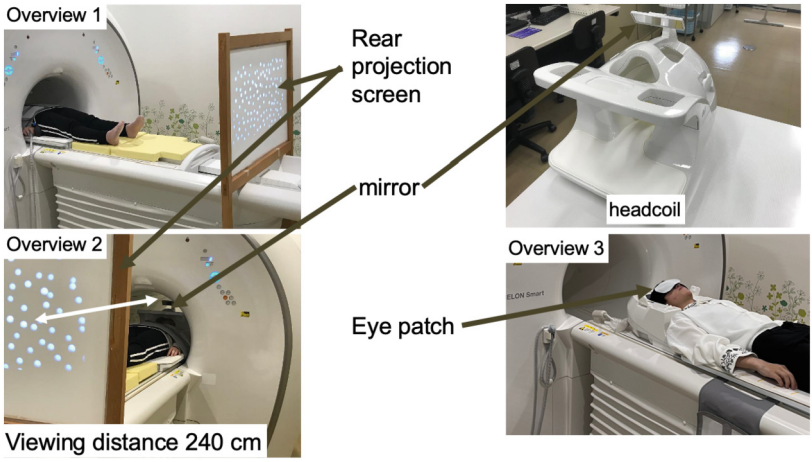

Fig. 5. Experimental setup

Experimental Design and Imaging Conditions
Participants were randomized to observe with the left eye, right eye, and both eyes in a predetermined sequence to mitigate any order effects. We employed a block design task, widely used in brain function imaging, which entailed alternating between periods of video stimulus observation (lasting 64 s) and rest phases with a black screen (lasting 32 s) over the course of three sets, as depicted in Fig. 6. The imaging protocol utilized a GRE-EPI sequence, specified by a TR of 4,000 ms, TE of 40 ms, 40 multislices, slice thickness of 3.8 mm, a matrix size of 128 × 128 pixels, and an FOV of 224 mm.

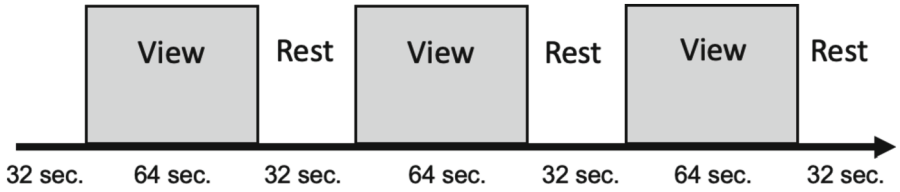

Fig. 6. Experimental task design

Analysis
The acquired brain function images were processed using the Statistical Parametric Mapping 12 (SPM 12) software [13]. This process included motion correction, linear and non-linear normalization to the Montreal Neurological Institute standard brain [14], and spatial smoothing. Significant activations were detected at the cluster level with a familywise error (FWE) correction, maintaining a 5% significance threshold, and were time-locked to the task. For the group analysis (2nd-Level), individual comparisons were compiled, and paired t-tests were performed at a 5% significance level.

2.2 Relationship Between the Dominant Eye and VEPRs

To measure visually induced postural changes, we assessed the sway of the center of posture (CoP) during upright image viewing.

Visual Presentation and Observation Method
The visual stimulus was identical to that depicted in Fig. 4, featuring numerous spheres positioned randomly, moving simultaneously in a sinusoidal pattern across all directions at 0.25 Hz. The observation method is detailed in the experimental setup presented in Fig. 7. Participants were instructed to maintain a Romberg posture on a stabilometer while peripherally observing images on a 42-inch LCD monitor situated 100 cm in front of them.

Experimental Design and Measurement
The experimental task design, as demonstrated in Fig. 8, entailed the use of an eye patch (supplied by Taiyo Pharmaceutical Co., Japan) to occlude one eye, thus permitting monocular viewing (left or right eye). Participants were randomly assigned to observe

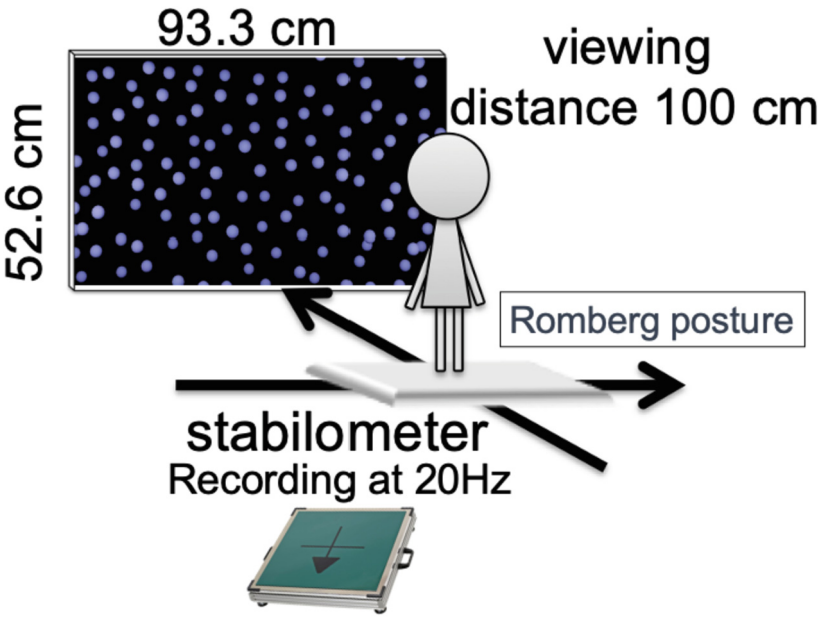

Fig. 7. Experimental setup.

with their left eye, right eye, and both eyes in sequence, with each viewing lasting 120 s. The CoP measurement device (provided by Takei Scientific Instruments Co., Japan) recorded the CoP continuously at 20 Hz during the image viewing.

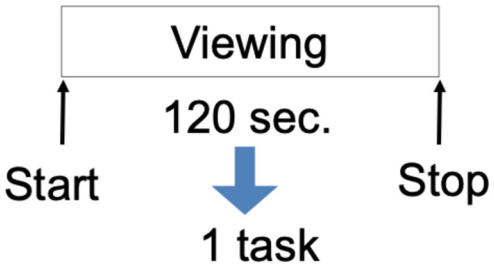

Fig. 8. Experimental task design.

Analysis

The analysis was confined to the left-right directional shifts in the CoP time series data over the initial 60 s. The standard deviation of the left-right CoP time series data was computed. Additionally, frequency analysis was conducted to determine the amplitude of the 0.25 Hz component, which was indicative of body sway. Task comparisons were made using the Wilcoxon signed-rank test, with a significance threshold of 5%.

3 Results

The results of the group analysis are depicted in Figs. 9 and 10. Figure 9 uses the non-dominant eye as a baseline for comparison, highlighting regions where activity significantly increased in the dominant eye ($p < 0.05$). Anatomically, significant increases in activity were noted in several regions, particularly in the precuneus and areas of the occipital lobe. This significant activity was asymmetrical, with a more pronounced distribution on the left side. Figure 10 displays the activity results for the right eye with the left eye serving as a reference. In these results, no significant increase in activity was detected. A similar lack of significant activity increase was observed when comparisons were made using the right eye as the reference.

Next, Fig. 11 includes a representative example of CoP sway for each condition (22-year-old female, right-eye dominant). The graphs sequentially wider extent the sway results for the left eye, right eye, and both eyes. It is apparent that the left-right sway trajectory is elongated in all graphs, with a notably wider extent in the conditions involving the right eye and both eyes. Figure 12 illustrates the mean standard deviation of the CoP's left-right directional data. While the results for the dominant eye were marginally higher, they did not reach significance. Lastly, Fig. 13 presents the amplitudes of the 0.25 Hz component ascertained through frequency analysis. Although the results for the non-dominant eye were somewhat greater, no significant differences were discerned. The same was true for binocular vision; no significant changes were detected.

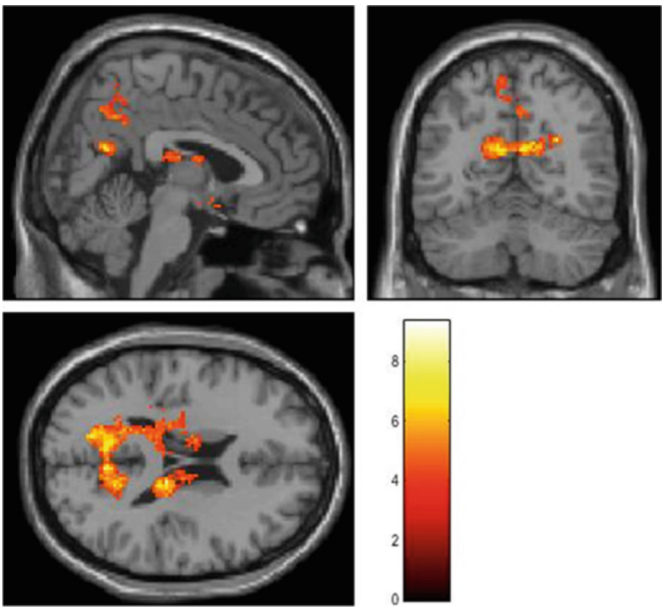

Fig. 9. Result for anatomical brain activity. (dominant eye vs non-dominant eye)

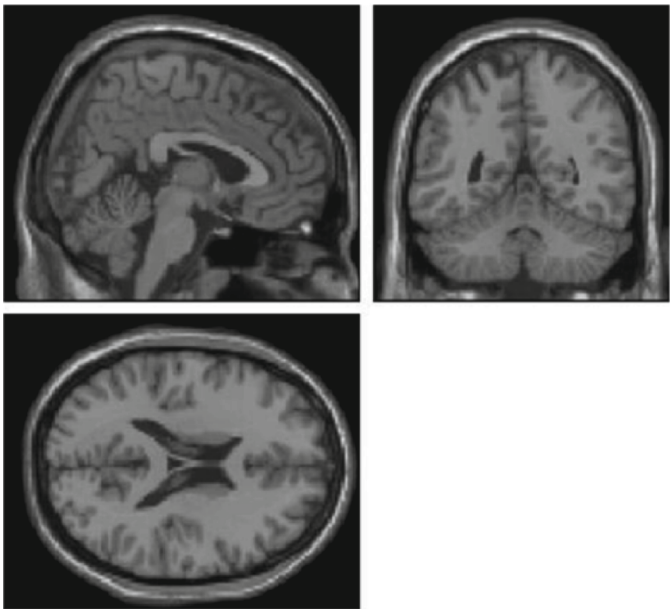

Fig. 10. Result for anatomical brain activity. (right eye vs left eye)

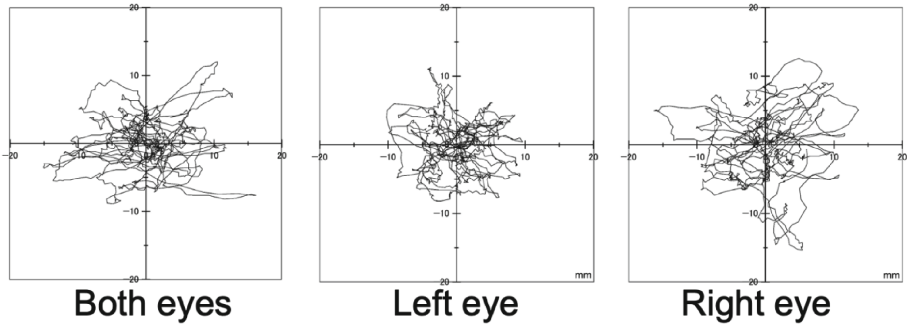

Fig. 11. Example of center of pressure sway (22-year-old female, right-eye dominant).

4 Discussion

In summary, the results of this study suggest the presence of specific brain regions that process peripheral visual information recognized through the dominant eye, with predominant activity in the precuneus and upper regions of the occipital lobe. The precuneus,

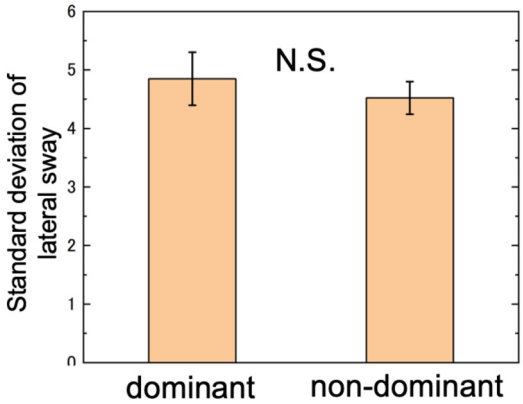

Fig. 12. Summarized result for standard deviation of the CoP's left-right directional data.

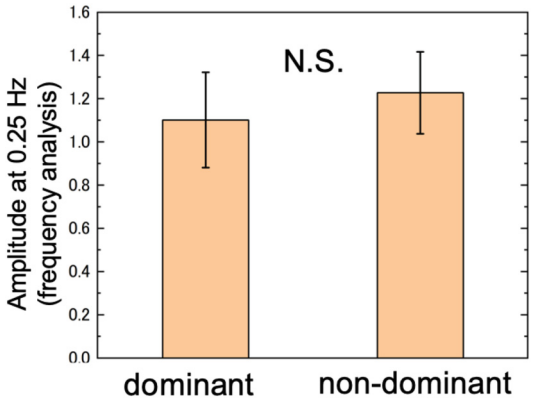

Fig. 13. Summarized result for amplitudes of the 0.25 Hz component.

which resides within the parietal lobe and is nestled between the cingulate and parieto-occipital sulci, plays a role in functions related to attention, cognition, and the spatial processing of visual information [15]. In this experiment, participants were exposed to images that generated a sense of depth through motion parallax during peripheral viewing, in alignment with the timing of the tasks. Peripheral viewing, as opposed to foveal viewing, tends to elicit a more potent spatial perception [16], indicating that the processing of visual information via the dominant eye was actively involved, considering the nature of the images and tasks presented.

The 2nd-Level analysis indicated an asymmetry in activity between the cerebral hemispheres, with a marked increase in the left hemisphere. This heightened activity is strongly believed to result from the brain's tendency to process visual information in the hemisphere opposite the eye receiving the input [17]. The transmission of visual information to the left hemisphere through the optic chiasm—and the prevalence of right-eye dominance in the study's participants—likely contributed to this finding. It is

therefore postulated that processes such as object identification, motion detection, and color discrimination from the right eye occurred in the left occipital lobe. Hence, the amplified activity in the left occipital lobe in response to specific visual stimuli viewed by the right eye can be interpreted as a natural outcome of the brain's visual information processing mechanism.

In terms of the connection between the dominant eye and visually induced postural changes (VEPRs), no differences attributable to the dominant or non-dominant eye were noted. Although the underlying reasons for this result warrant further investigation, considering that VEPRs constitute a complex, coordinated reaction, it is conjectured that disparities in visual input are integrated during processing, thereby not impacting the manifestation of postural changes.

5 Conclusion

As a fundamental examination of the relationship between ocular dominance and brain function, we employed Functional Magnetic Resonance Imaging (fMRI), a technique for brain function imaging, to visualize the cerebral activities associated with the mechanism of ocular dominance. Additionally, we sought to investigate the correlation between ocular dominance and visually induced postural changes. The findings indicated an increase in activity in the precuneus and occipital lobe during the viewing with the dominant eye, hinting at the presence of specific brain regions involved in the processing of ocular dominance mechanisms. On the other hand, the assessment of the relationship between ocular dominance and visually induced postural changes did not reveal any significant associations.

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Disclosure of Interests.. The authors declare that they have no relevant financial or non-financial interests to disclose.

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