Measurement and analysis of visually evoked magnetic fields to stimuli in apparent motion

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1 Introduction

Apparent motion is the experience of motion that occurs when at least two spatially separated visual stimuli are delivered under appropriate temporal conditions. In other words, this apparent motion is a psychological phenomenon created in the brain.

The apparent motion has attracted researchers over 100 years. In the last 25 years, two types of processes, a short-range and a long-range process, have been proposed in visual apparent motion [1, 2]. It has been found that the short-range process occurs only or relatively small displacement of less than 15 min of arc, and is associated with striate cortical cells. On the other hand, the long-range process has a larger spatial range of up to several degrees, and reflects the activity of more central processing [3,4].

So far most of the studies on apparent motion have been concerned with the estimation of the optimal stimulus conditions in psychophysical measurements. Cortical activation associated with apparent motion is poorly understood.

Recently, studies on source localization associated with apparent motion by electroencephalography (EEG) and magneto-encephalography (MEG) have been reported [5-8], however, there is still controversy about the source localization of apparent motion.

This study measures evoked magnetic fields in response to three vertically located visual stimuli to obtain distinct apparent motion perception and estimates the source localization of the neural activities of apparent motion in the brain by MEG measurement.

2 Methods

Evoked magnetic fields were measured in a magnetically shielded room with a 122-channel whole-head SQUID magnetometer (Neuromag-122™; Neuromag Ltd., Finland). Apparent motion stimuli were projected on a transparent screen. Fig. 1 shows a schematic illustration of the apparent motion stimuli, which were offset 3˚ to the left of the fixation point for the left visual field stimulation. Three circular stimuli with a radius of 0.5˚ were presented on a screen at a 100 cm viewing distance. Spatial separation between each stimulus is fixed at 2˚. The subject was asked to fixate on a fixation point located in the center of the screen. In the right visual field stimulation, the apparent motion stimuli were presented at a 3˚ offset to the right.

The sequence of stimulus presentation is shown in Fig. 2 Each stimulus duration and inter-stimulus interval was fixed at 50 msec and 10 msec, respectively, so the total stimulus duration from the onset of the first stimulus to the offset of the third stimulus was 170 msec. The timing of the presentation of the visual stimuli was controlled by a personal computer Trigger pulses for averaging the evoked magnetic field were synchronized and delivered with the onset of the first stimulus. The interval of the apparent motion stimulation was randomly varied from 2 sec to 2.5 sec to reduce background MEG activity.

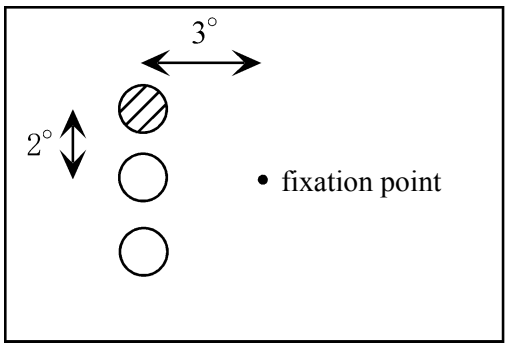


Figure 1: *Schematic illustration of the visual stimulus used to evoke apparent motion. Three visual stimuli are presented sequentially with a 50 msec stimulus duration and a 10 msec inter-stimulus interval.*

The MEG signals were sampled at 500 Hz, filtered with a band-pass of 0.5-40 Hz. Any epoch coinciding with magnetic signals exceeding 3,000 fT/cm were rejected from averaging to exclude artifacts

such as eye movements About 100 responses were averaged. Two visually normal subjects participated in the measurements. Simultaneous presentation of three stimuli was applied for the control. Each stimulus turns on and off simultaneously with a 50 msec stimulus duration and a 10 msec inter-stimulus interval. Motion can not be perceived in the control stimuli.

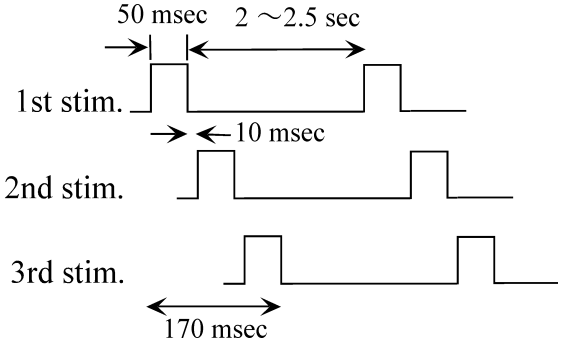


Figure 2*: Stimulus presentation of apparent motion stimuli. Three stimuli were delivered sequentially with a 50 msec stimulus duration and a 10 msec inter-stimulus interval. The stimulus interval was randomly varied from 2 to 2.5 sec*.

3 Results

Visually evoked magnetic fields (VEFs) in response to apparent motion stimuli presented in the left visual fields of the subject were measured. Apparent motion stimuli were presented at a 3˚ offset to the left of the fixation point, as shown in Fig. 1. VEFs in response to apparent motion stimuli presented on the right visual field were also measured. Significant VEF waveforms appeared contralaterally in the occipital and temporal regions. VEFs in the right hemisphere in response to the left visual field stimulation showed clear and larger amplitudes than those responses in the left hemisphere to the right visual field stimulation. Contralateral responses to the left visual field stimuli were more dominant than those to the right visual field stimuli. Therefore, the left visual field stimulation was used for the VEF measurement to the apparent motion and the control stimulation.

VEFs in response to both the apparent motion stimuli and the control stimuli at the left visual field were measured. Figure 3 shows the VEF waveforms obtained from 52 channel SQUID sensors that were placed on the posterior half of each hemisphere. The waveforms of the lateral occipital area are enlarged, as shown in Fig. 3 (b) and (c). The thick line and the dotted line indicate VEFs in response to the apparent motion stimuli and the control stimuli, respectively.

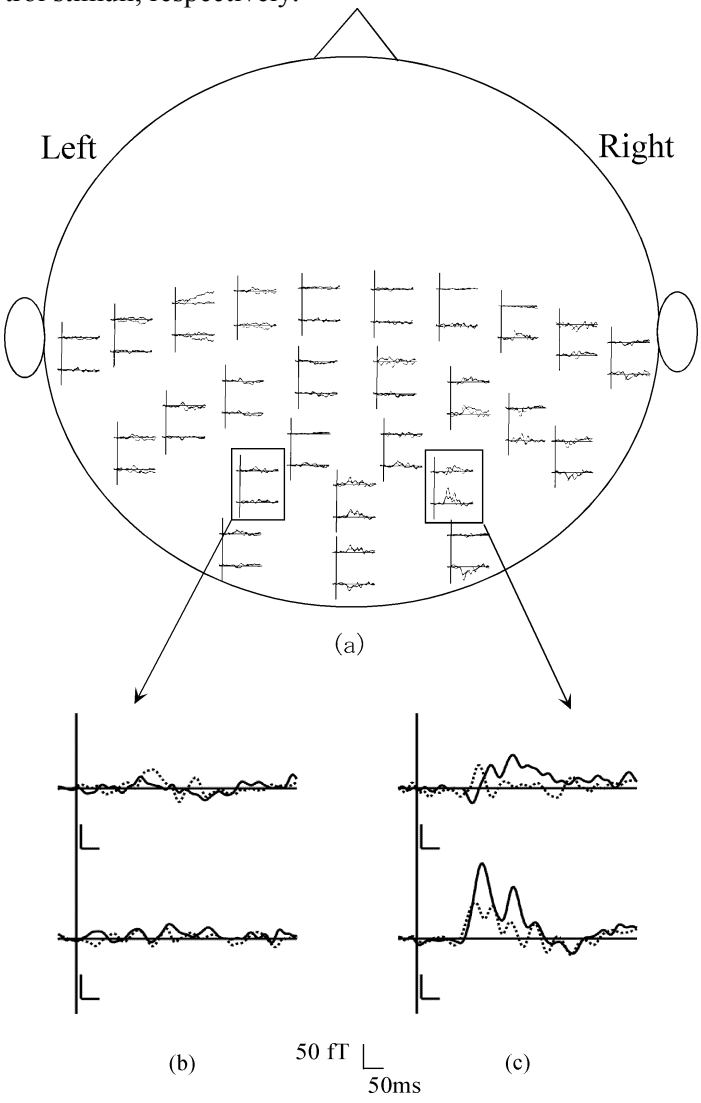
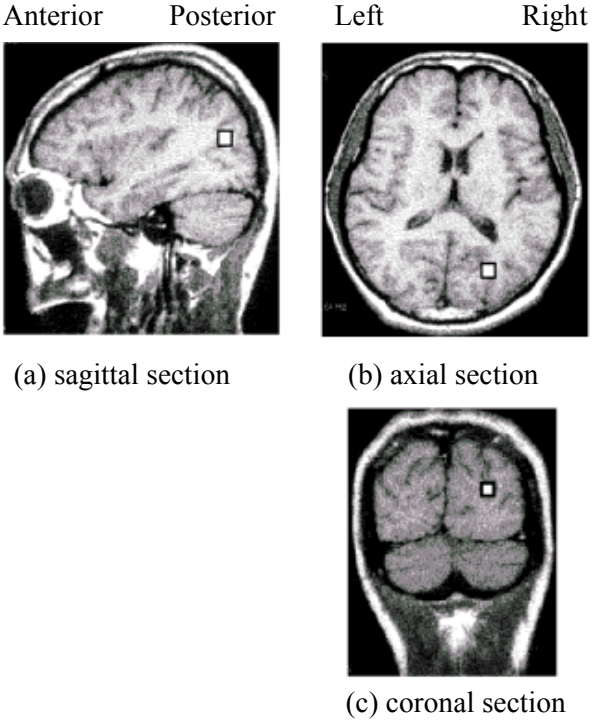


Figure 3: *Left visual field magnetic responses in response to both apparent motion and control stimuli. (b) and (c) show enlarged magnetic fields measured from lateral occipital areas. The thick line and the dotted line indicate VEFs in response to the apparent motion stimuli and the control stimuli.*

No significant difference was observed between contra-lateral hemisphere in control stimuli. Each stimulus of the apparent motion was presented sequentially, whereas the control stimuli were presented simultaneously. Therefore, the stimulus strength of the control stimuli was about three times stronger than the apparent motion stimuli. The peak amplitude of the control stimuli, however, was lower than the apparent motion stimuli, and the peak latency was about 30 msec shorter than that of the apparent motion stimuli. VEFs in response to

visual stimuli appear in the primary visual cortex at around 100 msec after the stimulus onset, after that reach visual association cortex. Apparent motion VEF exhibited a large peak at around 180 msec over the extrastriate area.
Moreover, other studies showed similar peak latency using other visual motion stimuli [6, 7]. Motion perception was recognized with the apparent motion stimuli, but no motion was perceived with the control stimuli.



(a) sagittal section (b) axial section

(c) coronal section

Figure 4: *Equivalent current dipole location after stimulation in the left visual field in the latency of 180 msec. The source was located in the right occipital and temporal regions, which might correspond to the extrastriate visual cortex*.

From these results, it was concluded that the VEFs appeared in the latency range of 170-190 msec might be the result of apparent motion perception. Another subject showed similar results though weaker responses.
We analyzed the peak VEF, which appeared at around 180 msec after the onset of the first stimuli. A single dipole model was used for source estimation. The localization of equivalent current dipoles was based on the spherical conductor model. Figure 4 shows the dipole location after stimulation in the left visual field in the latency around 180 msec for one subject. The square mark in MRI image shows the source location. The source was located in the right occipital and temporal regions, which might correspond to the extrastriate visual cortex.

4. Discussion

Stimuli used in this study belong to the long-range process because the spatial separation of the apparent motion stimuli was 2˚ in visual angle. Psychophysical measurements suggested that the long-range process in apparent motion was affected by more central processing [3]. Equivalent current dipole location in the latency of 180 msec after the left visual field stimulation was estimated. The source was located in the right occipital and temporal regions, which might correspond to the contra-lateral extrastriate visual cortex.
It has been demonstrated that two major visual pathways, the parvocellular pathway and the magnocellular pathway [8-10]. The parvocellular pathway mainly processes color and form perception, whereas the magnocellular pathway processes depth and motion perception. The magnocellular pathway include V1, V2, V3, V5(MT), and MST areas, and it reaches the parietal association area. Motion sensitive cells have been identified in the visual area V1, V2, and the middle temporal area of the macaque monkey [10]. If the visual process of the human brain is homologous to that of the monkey, the extrastriate cortex must be sensitive to the apparent motion stimuli.
Manning et al. measured visually evoked potentials in response to the alternation of motion stimuli and suggested that motion processing occurred within the occipital lobe and after that took place within temporal and parietal lobes [5]. Kaneoke et al. measured the magnetic fields evoked by two sequentially presented line stimuli, and reported the presence of a localized cortical area, which was exclusively sensitive to apparent motion stimuli [7]. Whereas, Tobimatsu measured VEF responses to horizontal or vertical motion stimuli presented at 2˚ from the fixation point [8]. The current source related to apparent motion perception was estimated in the V1 area at around 120 msec after the stimulus onset. There is still controversy about the source localization in a long-range process, however, it is concluded that the dipole location estimated by some researchers might reflect the activities of the magnocellular pathway.
In conclusion, our results suggest that the border between the occipital and the temporal areas in the contra-lateral hemisphere, which corresponds to the extrastriate visual cortex, are associated with apparent motion processing. Apparent motion stimuli activate the motion sensitive neurons in the magnocellular pathway.

Acknowledgements

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