Published in final edited form as:
Conf Proc IEEE Eng Med Biol Soc. 2011 ; 2011: 4917–4920. doi:10.1109/IEMBS.2011.6091218.

MEG-fMRI integration to visualize brain dynamics while perceiving 3-D object shape from motion

Sunao Iwaki[1], **Giorgio Bonmassar**[2], and **John W. Belliveau**[2]

Sunao Iwaki: s.iwaki@aist.go.jp; Giorgio Bonmassar: giorgio@nmr.mgh.harvard.edu; John W. Belliveau: jack@nmr.mgh.harvard.edu

[1]National Institute of Advanced Industrial Science and Technology (AIST), Ikeda, Osaka 563-8577, Japan. phone: +81-72-751- 8764; fax: +81-72-751-9517

[2]Massachusetts General Hospital, Boston, MA 02129 USA

[2]Massachusetts General Hospital, Boston, MA 02129 USA

Abstract

Here, we combine magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) to detect the dynamic brain responses to 3D-SFM. We manipulated the coherence of randomly moving dots to create different levels of 3D perception and investigated the associated changes in brain activity. Results of the fMRI analysis were used to impose plausible constraints on the MEG inverse calculation to improve spatial resolution of the spatiotemporal activity estimates. Time-frequency analysis was also employed to elucidate spatiotemporal dynamic changes in the spontaneous brain activities.

MEG-fMRI combined analysis showed that the activities the posterior infero-temporal (pIT), parieto-occipital (PO), and intra-parietal (IP) regions were increased at different latencies during highly coherent motion conditions in which subjects perceived a robust 3D object. Results of the time-frequency analysis indicated the suppression of alpha- and beta-band activities in these regions which reflect the commitment of these areas in the perception of 3D-SFM. Current results suggest that the interactions between the dorsal and ventral visual subsystems are crucial for the perception of 3D object from 2D optic flow.

Introduction

Recognizing three-dimensional structure of the object from two-dimensional retinal motion requires the visual motion to be integrated into the internal representation of the 3-D object. Many psychophysical studies have been made to investigate how the visual system extracts the three-dimensional structure of objects from the two-dimensional motion of random dots (structure-from-motion: 3D-SFM) [1]. Electrophysiological studies of non-human primates suggested the involvement of middle-temporal (MT) and medial-superior-temporal (MST) neurons in the perception of 3-D structure from the optical flow [2,3]. Recent neuroimaging studies using functional magnetic resonance imaging (fMRI) techniques suggested the involvement of the parieto-occipital junction (POJ), the superior-occipital gyrus (SOG), and the ventral occipito-temporal junction (OTJ) in the perception of 3-D structure from motion [4,5] though the neural dynamics underlying the reconstruction of a 3-D structure from optic flow is not fully understood.

Corresponding author: Sunao Iwaki, National Institute of Advanced Industrial Science and Technology (AIST), Ikeda, Osaka 563-8577, Japan. (phone: +81-72-751- 8764; fax: +81-72-751-9517; s.iwaki@aist.go.jp).

In this study, we used neuromagnetic measurement (magnetoencephalography: MEG) and fMRI to detect dynamic brain activities during the perception of 3D-SFM in human.

Methods

Subjects and Task

Nine normal right-handed subjects with no history of neurological disorders participated in the study as volunteers. Written informed consent was obtained from each subject prior to the experiment complying with the human research policies of internal review board of the National Institute of Advanced Industrial Science and Technology (AIST) and Massachusetts General Hospital.

The visual stimuli consisted of 1000 randomly-placed dots, which started to move 500 ms after the onset of presentation with various motion coherences. The coherence of the motion was controlled from 0 to 100 % (Fig. 1). A stimulus that is fully coherent had all the dots moving as if they belonged to a rotating spherical surface with a radius of 10 degree in visual angle. On the other hand, the 80, 60, 40, 20, and 0 % coherence stimuli contain dots having the same speed as the fully coherent stimuli but the directions of the 20, 40, 60, 80, and 100 % of the dots were randomized, respectively.

The subjects were instructed to respond by pressing buttons using their index or middle finger when they saw 3-D rotating sphere or randomly moving dots, respectively.

Data Acquisition

The subjects were required to perform the same 3-D SFM task both in the MEG and the fMRI scanners.

1. *MEG:* Neuromagnetic signals were measured while the subjects viewed the visual stimuli using a whole-cortex type SQUID system with either 122 or 306 planar gradiometers. The stimulus-related epochs of 2000 ms, including a 1000 ms pre-stimulus baseline, were recorded with a sampling rate of 600 Hz. More than 80 epochs were averaged for each condition. Electro-oculogram (EOG) was simultaneously recorded and the epochs with EOG signal change exceeded 150 mV were discarded to eliminate artifacts. Subjects were asked to react as soon as the motion stimuli disappeared by lifting their index finger when they perceive rotating 3-D sphere or by middle finger when they saw random-motion.
2. *fMRI:* The fMRI scanning was conducted using a 3 Tesla scanner. For functional imaging, the single shot echo-planer imaging (EPI) sequence was used with the imaging parameters TR 3000 ms, TE 40 ms, FA 90 deg, 40 axial slices, 3 mm thickness with 0 mm gap, 64×64 matrix, and FOV 220 mm, which covered the entire brain. Three 14-min functional scans were divided into 12-second phases, randomly alternating between different stimulus (coherency) conditions and resting (fixation) periods. Within each phase, motion stimuli were presented every 4 s. Subjects' task was the same as that in the MEG experiment

Data Processing

3-D reconstruction of the cortical surface was performed using Freesurfer software [6,7] for each subject. Statistical Parametric Mapping (SPM) was used to infer statistical significance of the signal changes in fMRI data [8]. The BOLD images obtained during fMRI scanning were realigned using the first image as a reference and spatially smoothed using Gaussian kernels of 6 mm. A boxcar wave function was applied as a reference function, and a statistical parametric map was generated for each voxel using general linear model (GLM).

The results of the fMRI analysis were used to impose plausible constraints on the MEG inverse calculation using 'weighted' minimum-norm approach [9,10] to improve spatial resolution of the spatiotemporal activity estimates. In this study, we introduced fMRI weighting, which was determined by thresholding the fMRI statistical parametric map for each condition vs. fixation condition at $p<0.001$ (FDR (False Detection Rate) corrected), on the minimum L2-norm linear inverse operator used to map measured MEG signal into estimated neural source distributions [10].

The event-related time-frequency wavelet decomposition (using Morlet's wavelet basis) [11] of the recorded MEG raw signals between 5 and 60 Hz was used to assess event-related changes in spontaneous oscillatory brain activity, and the time-frequency energy of each single trial was averaged separately for each stimulus condition in the time-frequency domain.

Results

Behavioral Results

Figure 2 shows the behavioral results obtained during MEG and fMRI acquisitions. In the 100 and 80 % coherent conditions, the subjects perceive rotating 3-D spherical surface in the most of the trials, whereas 3-D object was rarely perceived in the 0 and 20 % conditions.

Spatiotemporal Synamics of the Event-related Responses

Figure 3 shows the results of the fMRI group statistics, in which fMRI contrasts between the 3-D perception condition (100 and 80 % coherent conditions) vs. the random motion condition (0 and 20 % coherent conditions) were depicted. Increased brain activities were observed in the parieto-occipital (PO), the intra-parietal (IP), and the posterior inferior temporal (pIT) regions as well as the motion sensitive MT area in the 3-D perception condition.

Averaged MEG waveforms for the 100 and 60 % coherent conditions measured in the typical subject were shown in Fig. 4. Increased amplitudes of the MEG event-related components were observed in the parieto-occipital and the bilateral inferior occipito-temporal channels in the latency range more than 200 ms after the onset of motion. The spatiotemporal activity estimates obtained from the fMRI-weighted MEG inverse analysis were shown in Fig. 5, which were the results of the inter-subject averaging of the activity estimates by using spherical morphing technique. Increased neural activity in the PO area was observed both in the 3-D perception (100 and 80 % coherence) conditions and the intermediate (60 % coherence) condition in the latency range between 220 and 300 ms, while the activities in the IP and the pIT regions were observed only in the 3-D perception conditions in the latencies between 340 and 450 ms after the onset of motion. Also, the activity in the primary visual areas during earlier latencies were decreased in the 3-D perception conditions compared to the random motion and intermediate (0, 20, 40, and 60 % coherent) conditions.

Event-related Changes in the Spontaneous Activities

Statistical significance of the event-related suppression of the spontaneous activities from the pre-stimulus baseline was assessed by inter-subject t-test, in which spectral power decrease at each time and frequency in the 3-D perception condition was tested (Fig. 6).

Suppression of alpha- and beta-band activities started around 300 ms after the onset of random dot motion in SFM condition at occipital, bilateral occipito-temporal and occipito-parietal recording channels.

Discussion

The results shown here indicate that the PO, IP, and pIT regions play an important role in the perception of 3-D object structure from random-dot motion. These results are in agreement with those from the previous studies of 3-D SFM using fMRI [4,5] in terms of their locations, and add further insight into the temporal characteristics of the neural activities in these regions.

At the same time, the event-related suppression (event-related desynchronization: ERD) of alpha- and beta-band spontaneous brain activities was detected in the occipital and parieto-occipital regions. The suppression of spontaneous activities was observed about 300 ms after the onset of random-dot motion which was used as a cue for 3-D shape perception. Local suppression of alpha- and beta activity in occipital and parieto-occipital area was thought to indicate the engagement of these regions to the relevant sensory or cognitive functions, which is in agreement with the results obtained by MEG-fMRI combined analysis of event-related responses to 3D-SFM stimuli.

The change in the neural activities in the MT area in conjunction with the perception of global motion is reported in the previous fMRI studies [12], the PO areas were known to be involved in the integration of spatial aspects of the visual motion [13], the IP region processes the mental imagery [14,15], and the pIT regions are responsible for the object recognition [16]. Together with these previous findings, the current results suggest that the perception of moving 3-D objects from the 2-D retinal motion depends on the higher visual processing in the dorsal visual pathway, i.e., (a) the global motion processing in MT, (b) the spatial integration of the global motion in the PO region, and (c) the mental imagery processing in the IP region, as well as the ventral object recognition system in the pIT.

Conclusion

We used MEG-fMRI combined analysis and time- frequency analysis of MEG data to visualize dynamic brain activities during the perception of 3D-SFM. The results suggest that the perception of moving 3-D object from 2-D random-dot motion includes both perception and integration of global motion and 3-D mental image processing as well as the object recognition, that are accomplished by the cooperative engagement of both the ventral and the dorsal visual information processing streams.

Acknowledgments

This work was supported in part by the Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan #22650056.

References

1. Wallach H, O'Connell DN. The kinetic depth effect. J Exp Psychol. 1953; 45:205–217. [PubMed: 13052853]
2. Bradley DC, Chang GC, Andersen RA. Encoding of three-dimensional structure-from-motion by primate area MT neurons. Nature. 1998; 392:714–717. [PubMed: 9565031]
3. Sugihara H, Murakami I, Shenoy KV, Andersen RA, Komatsu H. Response of MSTd neurons to simulated 3D orientation of rotating planes. J Neurophysiol. 2000; 87:273–285. [PubMed: 11784749]
4. Orban GA, Sunaert S, Todd JT, Van Hecke P, Marchal G. Human cortical regions involved in extracting depth from motion. Neuron. 1999; 24:929–940. [PubMed: 10624956]

5. Paradis AL, Cornilleau-Peres V, Droulez J, Van de Moortele PF, Lobel E, Berthoz A, Le Bihan D, Poline JB. Visual perception of motion and 3-D structure from motion: an fMRI study. Cereb Cortex. 2000; 10:772–783. [PubMed: 10920049]
6. Dale AM, Fischl B, Sereno MI. Cortical Surface-Based Analysis I: Segmentation and Surface Reconstruction. Neuroimage. 1999; 9:179–194. [PubMed: 9931268]
7. Fischl B, Sereno MI, Dale AM. Cortical Surface-Based Analysis II: Inflation, Flattening, and a Surface-Based Coordinate System. Neuroimage. 1999; 9:195–207. [PubMed: 9931269]
8. Friston KJ. Imaging neuroscience: principles or maps? Proc Natl Acad Sci USA. 1998; 95:796–802. [PubMed: 9448243]
9. Hamalainen M, Hari R, Ilmoniemi RJ, Knuutila J, Lounasmaa OV. Magnetoencephalography - theory, instrumentation, and application to noninvasive studies of the working human brain. Rev Mod Phys. 1993; 65:413–497.
10. Dale AM, Liu AK, Fischl BR, Buckner RL, Belliveau JW, Lewine JD, Halgren E. Dynamic statistical parametric mapping: combining fMRI and MEG for high-resolution imaging of cortical activity. Neuron. 2000; 26:55–67. [PubMed: 10798392]
11. Tallon-Baudry C, Bertrand O, Delpuech C, Pernier J. Stimulus specificity of phase-locked and non-phase-locked 40 Hz visual responses in human. J Neurosci. 1996; 16:4240–4249. [PubMed: 8753885]
12. Vaina LM, Belliveau JW, des Roziers EB, Zeffiro TA. Neural systems under-lying learning and representation of global motion. Proc Natl Acad Sci USA. 1998; 95:12657–12662. [PubMed: 9770542]
13. Hotson JR, Anand S. The selectivity and timing of motion processing in human temporo-parieto-occipital and occipital cortex: a transcranial magnetic stimulation study. Neuropsychologia. 1999; 37:169–179. [PubMed: 10080374]
14. Iwaki S, Ueno S, Imada T, Tonoike M. Dynamic cortical activation in mental image processing revealed by biomagnetic measurement. Neuroreport. 1999; 10:1793–1797. [PubMed: 10501577]
15. Jordan K, Heinze HJ, Lutz K, Kanowski M, Jancke L. Cortical activations during the mental rotation of different visual objects. Neuroimage. 2001; 13:143–152. [PubMed: 11133317]
16. Haxby JV, Grady CL, Horwitz B, Underleider LG, Mishkin M, Carson RE, Herscovitch P, Schapiro MB, Rapaport SI. Dissociation of object and spatial visual processing pathways in human extrastriate cortex. Proc Natl Acad Sci USA. 1991; 88:1621–1625. [PubMed: 2000370]

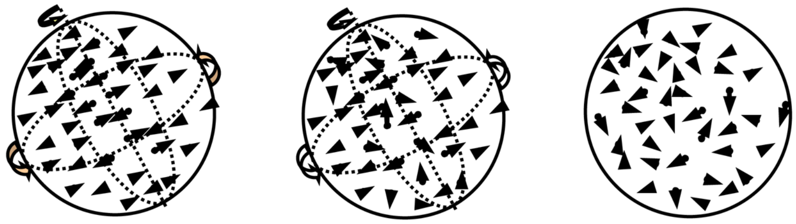

Fig. 1.

Examples of the random-dot motion stimuli used in this study. Coherence of the motion was changed from 100 % to 0 % to generate different 3-D object perception.

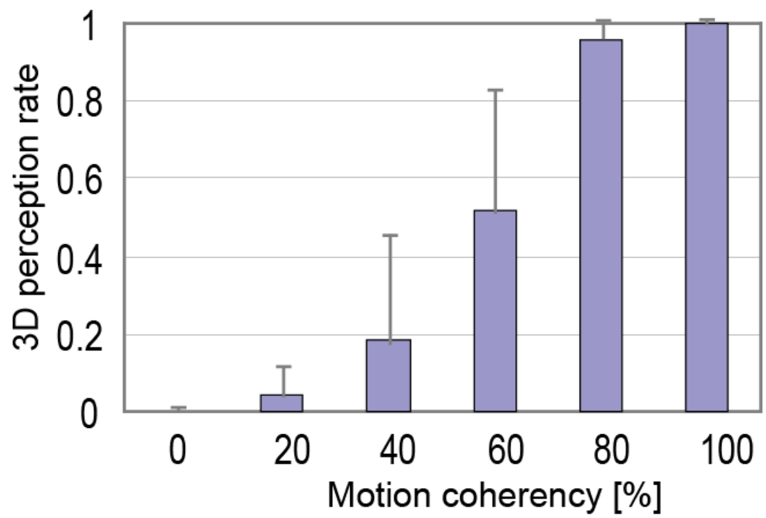

Fig. 2.
Subjects' behavioral performance during the MEG and fMRI experiments. In the 100 and 80 % coherent conditions, rotating 3-D sphere was perceived in more than 95 % of the trials, while 3-D object was not perceived in the most of the trials in the 0 and 20 % coherent conditions.

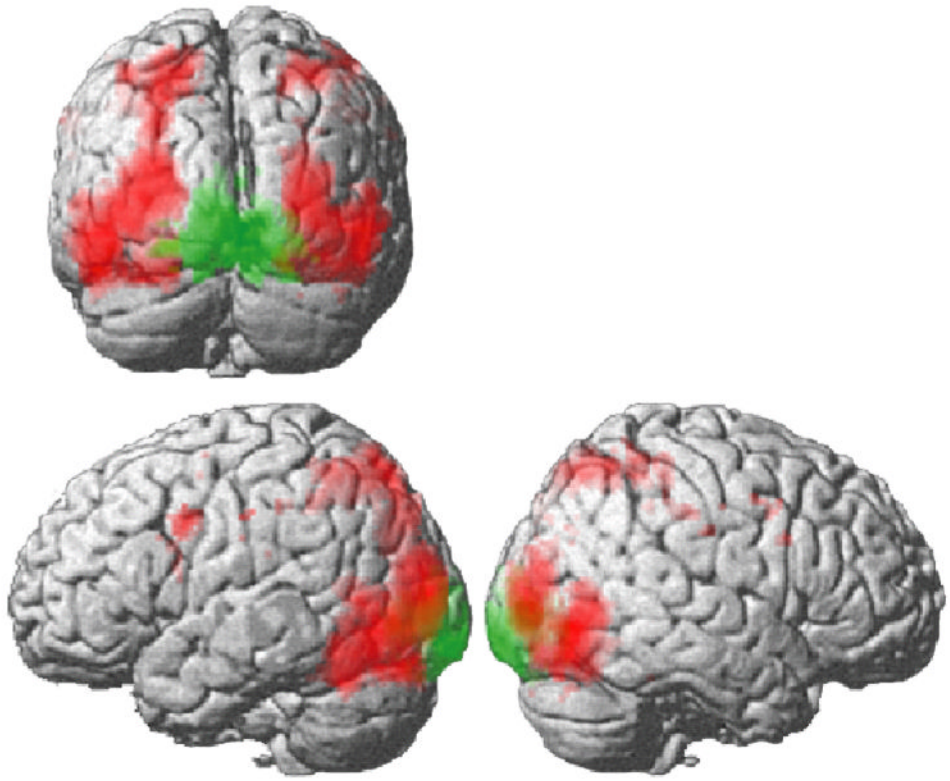

Fig. 3.
Results of the fMRI group statistics depicting the contrasts between the 3-D perception (100 and 80 % coherent) conditions and the random motion (0 and 20 % coherent) conditions (3D vs.2D). This figure is included to show results from fMRI analysis of the difference between the conditions (3D vs. 2D). The fMRI weighting of the MEG inverse operator was done by using the contrasts between each stimulus condition and the fixation (baseline) condition.

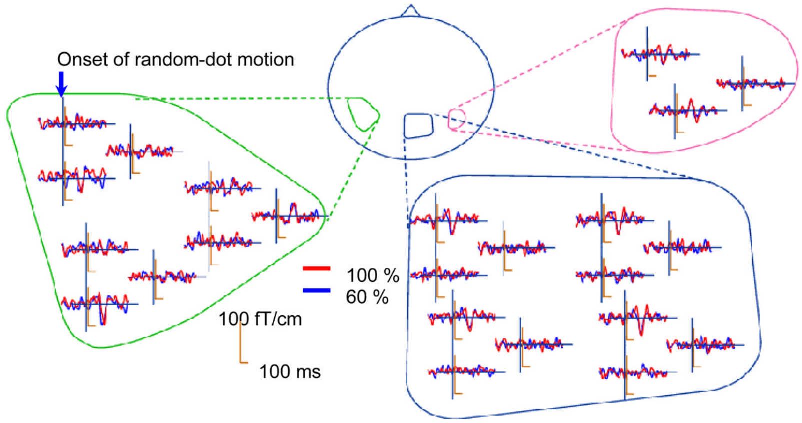

Fig. 4.
Averaged MEG waveforms corresponding to the 100 and 60 % coherent conditions in the typical subject.

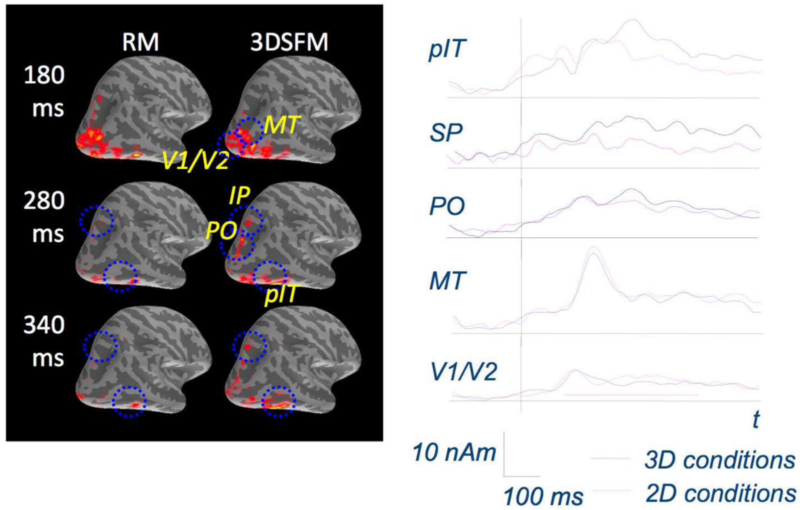

Fig. 5.

The results of the inter-subject averaging of the activity estimates for random motion (RM: 0 and 20 %) condition and 3-D structure- perception-from-motion (3D-SFM: 80 and 100 %) condition averaged over all seven subjects. The blue circles denote the sites where we observed the major changes between the conditions.

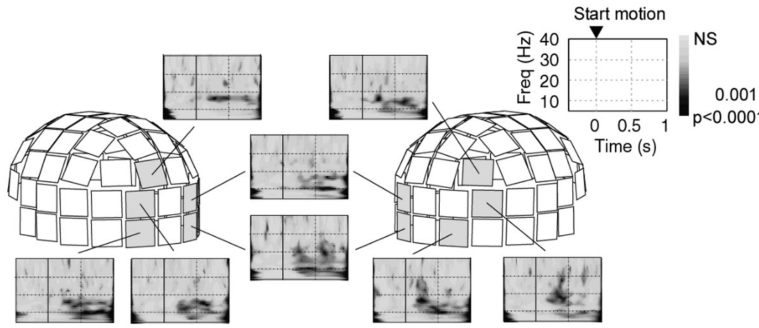

Fig. 6.
Results of inter-subject t-test to detect the statistically significant suppression of the time-frequency energy from the pre-stimulus baseline during SFM condition.