

Neural correlates of imagery induced by the ambient sound

Akiko Callan^{†,‡} and Hiroshi Ando^{†,‡}

[†]National Institute of Information and Communications Technology, Japan

[‡]ATR Cognitive Information Science Laboratories, Japan

{acallan@atr.jp, ando@atr.jp}

Abstract

Based on the assumption that better imagery while listening to the sound is related with higher sense of presence, neural correlates of imagery induced by the ambient sound that represents scenery (e.g. ocean waves, river stream, jungle, city traffic) were investigated by functional Magnetic Resonance Imaging (fMRI). During the fMRI experiment, brain activity was recorded while participants listened to the sound with eyes closed. Their button responses indicating the imagery levels were also recorded. Enhanced activities for the ambient sound condition relative to the noise condition were found in brain regions involved with auditory perception (the superior temporal gyrus). Imagery level correlated activities were found in brain regions involved with simulation of both biological and non-biological events (the lateral premotor cortex, the inferior frontal gyrus, and the inferior parietal lobe). The present study suggests that the level of imagery induced by the ambient sound is related with the level of neural activity in brain regions involved with the events simulation. The possibility of measuring the level of presence by assessing neural activity is implicated.

Keywords--- fMRI, neural correlates, imagery, sound, simulation..

1. Introduction

Using imagination, people can feel as if they were in another place rather than in their actual physical location. The goal of a virtual environment (VE) technology is to make users experience this sensation. Measuring of the degree of “feeling of being there” or “presence” is very important in order to construct effective VE systems. In general, presence is measured by comparing several VE systems. The degree of presence of one VE system is measured relative to other VE systems by using questionnaires, behavioral observation, and physiological measures. However, if we can find out neural mechanism of presence, we may be able to measure users’ presence level by measuring brain activity. Moreover, not only relative presence level but also absolute presence level may be able to be obtained.

In order to investigate neural mechanism of presence, neural imaging such as functional magnetic resonance

imaging (fMRI) is necessary. Then, the sense has to be induced in the MRI scanner. The sense of presence can be induced either externally by using high fidelity stimulation or internally by using imagination. We call externally induced presence as “exogenous presence” and internally induced presence as “endogenous presence”. An example of endogenous presence is when one becomes engrossed in a book. It is very difficult to externally induce the sense of presence in fMRI because there are many restrictions. For example, no magnetic devices can be used, experiments are performed in a noisy environment (in general, mechanical noise by MRI scanner is >100 dB SPL), participants have to lie down on the bed and have to stay still, and sample data for each condition have to be collected many times in order to reduce effects of noises in data. High technological VE devices can not be used if they are magnetic. On the other hand, endogenous presence is convenient for fMRI research because high technological devices are not necessary and because stimuli are easier to prepare. Another thing to consider for fMRI research is a research topic. In order to run meaningful fMRI experiments, the research topic should be simplified. Presence is a very difficult concept and the definition is still controversial [23]. Therefore, it is necessary to narrow down the topic into manageable pieces. It is also important to make each experimental trial short because they have to be repeated many times for the fMRI experiment. In order to do that, the duration of stimulus presentation has to be short and the response task has to be simple.

In our fMRI experiment, imagination triggered by the ambient sound was investigated. Have you ever had the experience that you feel like being there when you listen to a certain sound while closing your eyes? For example, you may feel like you were on the beach when you listen to the sound of ocean waves even if you are in your room which is located very far from the ocean. It is assumed that people can picture the scene better by listening to the sound if their sense of presence is higher. Based on this assumption, the level of endogenous presence can be measured by imaginability of the scene while listening to the sound.

Many researchers study the sense of presence externally induced by vision in the virtual environments (i.e. visual virtual reality (VR) simulations)[e.g. 1,15,16]. This is probably because this type of research is needed for improvement of visual based VR applications. Although the vestibular cues and tactile cues can be used to enhance the

sense of presence, it is too complex and expensive to run experiments using those cues. Auditory cues are less expensive and easier to use for experiments. However, compared to vision, the sense of presence induced by audition has not been studied to a great extent. Moreover, most previous auditory related presence research investigates the influence of auditory cues on the self-motion illusion (vection) [14, 18]. In our knowledge, no study has been performed to investigate the auditory induced sense of presence irrelevant to vection. This type of study is important to develop our knowledge about the sense of presence, and the knowledge can be applied to measure the sense of presence.

In this study, neural correlates of imaginability of the scene while listening to the ambient sounds that represents certain sceneries (e.g. ocean, river stream, jungle, city traffic) were investigated by fMRI. During the fMRI experiment, a level of imagery for each sound was recorded in 3 scales (high, middle, and low) by pressing a corresponding button and brain activity positively correlated with those responses were investigated. Instead of the degree of presence, the degree of imagery (i.e. how well they could picture the scene) was asked because it is straight forward to participants.

2. Hypotheses

Two main hypotheses on mental imagery caused by auditory stimuli were investigated in this study.

Hypothesis 1: Visual perception based imagery

The overlap between the neural mechanisms of visual perception and visual imagery has been reported [10-13,17]. Epstein and Kanwisher reported a ventromedial cortical region responds strongly to images of indoor and outdoor scenes depicting the layout of local space, but not at all to human faces and called the region the 'parahippocampal place area' (PPA) [4]. The brain activations in the PPA were found in visual imagery experiments using houses [11] and familiar places [17]. If higher imagery corresponds to higher activation in brain regions involved with place perception, enhanced activation in the PPA is expected.

Hypothesis 2: Simulation (internal forward model) based imagery

The activation in the lateral premotor cortex and in the parietal areas has been reported for motor imagery [3,6,9,20]. The same areas have been found in motor irrelevant cognitive tasks [8,20-22,25]. Schubotz proposes that the lateral premotor cortex acts as an emulator or internal forward model to simulate both biological and non-biological events [19]. The emulator that runs 'offline' can account for imagery via efference copies [5]. If higher imagery corresponds to higher activation in brain regions which

involve with event simulation, enhanced activation in the lateral premotor cortex and the parietal areas are expected.

3. Material and methods

3.1. Participants

Fourteen adults (8 male; 20-47 years of age, mean 27.4) with no neurological or psychiatric history participated in this study. All participants gave written informed consent for experimental procedures approved by the ATR Human Subject Review Committee.

3.2. Stimuli and procedure

30 sound files that represent various sceneries (e.g. ocean, river stream, jungle, city traffic) were downloaded from internet sites (<http://www.partnersinrhyme.com/>). All sounds were re-sampled at 22 kHz with 16 bit and matched their duration in 3 sec. Those modified sounds were used as ambient sound stimuli. Based on those stimuli, 30 white noises that have same amplitude contours as the ambient sound stimuli were created and used as noise stimuli. The intensity of the stimuli was adjusted to yield equivalent root-mean-square (RMS) power.

During each of the two functional imaging runs, participants performed 30 sec blocks of the ambient sound condition alternating with 30 sec of the noise condition. Stimuli were presented randomly at a rate of one every 6 sec via MR-compatible headphones (Hitachi Advanced Systems' ceramic transducer headphones; frequency range 30–40,000 Hz., approximately 20 dB SPL passive attenuation). Participants were instructed to picture scenery while listening to a sound and press one of three buttons to indicate how well they could picture it after the sound ended. They only use their left thumb to press button. Three buttons were corresponding to 1) I could not picture it (i.e. the imagery level was low), 2) I could picture it all right (i.e. the imagery level was middle), and 3) I could picture it very well (i.e. the imagery level was high). All participants were given a practice session outside of the scanner on a subset of the stimuli to familiarize themselves with the experiment.

3.3. MRI data acquisition and preprocessing

For structural and functional brain imaging, Shimadzu-Marconi's Magnex Eclipse 1.5T PD250 was used at the ATR Brain Activity Imaging Center. Functional T2*-weighted images were acquired using a gradient echo planar imaging sequence (TR = 3000 ms, TE = 49 ms, flip angle = 90°, field of view = 192 x 192 mm, matrix size = 64 x 64 pixels, slice thickness = 4mm, gap = 1 mm). Thirty axial slices were taken, oriented in parallel to the AC-PC line, and covered the cortex and cerebellum. Before the acquisition of functional images, T2-weighted anatomical images were acquired in the

same plane as the functional images (voxel size = 0.75 x 0.75 x 6 mm).

Images were preprocessed using programs within SPM2 (Wellcome Department of Cognitive Neurology, University College, London). Differences in acquisition time between slices were accounted for, movement artifact was removed, and images were spatially normalized (voxel size 2 x 2 x 4 mm) by using a template defined by the Montreal Neurological Institute (MNI) and were smoothed using a 6 x 6 x 10 mm FWHM Gaussian kernel. The MNI coordinates were converted to Talairach coordinates [24] using a nonlinear transform method (<http://www.mrc-cbu.cam.ac.uk/Imaging/Common/mnispac.shtml>).

3.4. fMRI data analysis

Preprocessed MRI data were analyzed statistically on a voxel-by-voxel basis using SPM2. The time series for each voxel was high-pass filtered to 1/128 Hz, serial correlations were corrected by an autoregressive AR(1) model, and global signal changes were removed by scaling. The stimulus related neural activities were modeled with a box-car function convolved with the hemodynamic response function and subject's button responses were added as a regressor of interest. For each participant, an ambient sound-minus-noise contrast and a positive linear correlation with the behavioral regressor was assessed. Then the participant specific contrast images of parameter estimates were used as inputs for the second (random-effect) level analysis. At the second level, one-sample t-tests were conducted and a height threshold of $p < 0.05$ (FDR corrected) and an extent threshold of $p < 0.05$ (uncorrected) were employed.

4. Results

4.1. Behavioral data

Mean percentages of responses for each condition are plotted in Fig. 1. Paired t-tests were performed for each response type. Participants chose the "I could picture the scenery very well" response significantly ($t(15) = 8.68, p < 0.001$) more when the stimulus was the ambient sound (63%) than the noise (12%). On the other hand, they chose the "I could not picture the scenery" response significantly ($t(15) = 5.54, p < 0.001$) more when the stimulus was the noise (59%) than the ambient sound (13%). There was no significant difference on choosing the "I could picture the scenery all right" response (ambient sound 24% and noise 28%).

4.2. fMRI data

The brain areas that were more active for the ambient sound condition than for the noise condition are plotted in Fig. 2. The result indicates differential activity in regions of the brain known to be involved with auditory perception

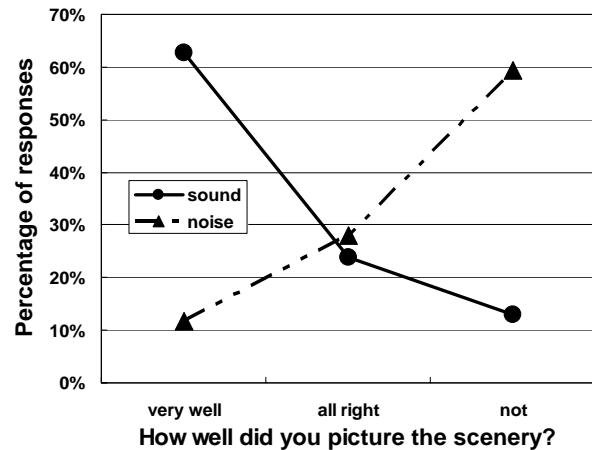


Figure 1: Subjects' button press responses

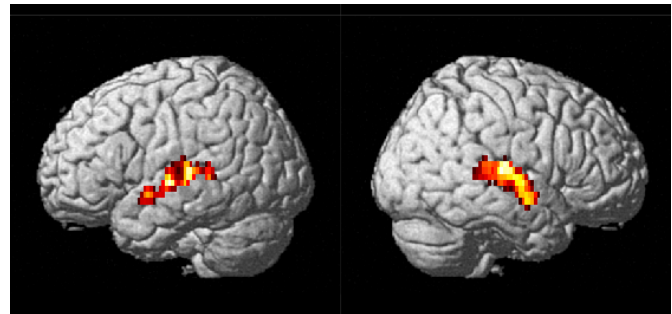


Figure 2: Enhanced neural activity for the ambient sound relative to the noise was found in the superior temporal cortex known to involve with auditory perception.

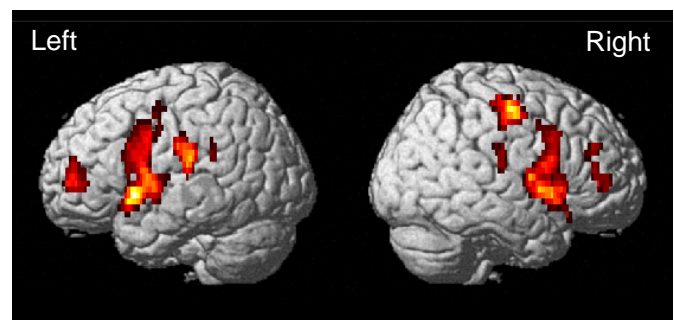


Figure 3: The brain areas that were positively correlated with the imaginary level were found in the lateral premotor area, the inferior frontal cortex, and the parietal lobe

Table 1: Brain areas activated more during the ambient sound condition than the noise condition

Regions (Brodmann area)	Coordinates			Z value
	x	y	z	
R primary auditory cortex (42)	59	-19	8	5.23
R middle temporal gyrus (21)	55	-4	-7	4.76
R superior temporal gyrus (22)	61	-12	1	4.72
L primary auditory cortex (42)	-61	-25	5	4.69
L superior temporal gyrus (22)	-57	-12	1	4.66
L middle temporal gyrus (21)	-53	0	-7	4.58

Table 2: Brain areas positively correlated with the level of imagery

Regions (Brodmann area)	Coordinates			Z value
	x	y	z	
L inferior frontal gyrus (44)	-48	12	-4	5.52
L premotor cortex (6)	-58	5	15	4.90
R premotor cortex (6)	50	4	0	5.20
R inferior frontal gyrus (44)	55	13	18	4.43
Amygdala	26	-1	10	4.38
Medial frontal cortex (6)	-8	4	48	5.04
L middle frontal gyrus (10)	-30	51	1	4.99
R primary motor cortex (4)	34	-15	45	4.89
L primary somatosensory cortex (1)	-57	-17	27	4.61
R inferior parietal lobe (40)	46	-22	27	4.59
L anterior cingulate gyrus (32)	-6	27	32	4.33
L Putamen	-18	7	-7	4.16
R Claustrum	34	-13	8	3.94
R inferior frontal gyrus (46)	48	39	9	3.88
Caudate head	-4	-8	4	3.88
L superior frontal gyrus (6)	-8	-3	63	3.81
R middle frontal gyrus (10)	32	42	24	3.76
Cerebellum	-6	-55	-4	3.71
L inferior parietal lobe (40)	-63	-40	20	3.60
Thalamus	18	-16	1	3.36
R anterior cingulate gyrus (32)	8	31	28	3.33

bilaterally (the superior temporal gyrus—including primary auditory cortex and Wernicke’s area) (Table 1). The brain areas that were positively correlated with the imagery level (i.e. they were activated more when subject could picture the scenery better) are plotted in Fig. 3. Response correlated activations were found in regions known to be involved with events simulation (the lateral premotor cortex, the inferior frontal gyrus, and the parietal lobe) (Table 2).

5. Discussion

In order to investigate a neural mechanism of presence, the endogenous presence using imagination was studied by

fMRI. Specifically, neural correlates of the imagery induced by the ambient sound were investigated. Results from behavioral data show that subjects could picture the scenery better for the ambient sounds than for the noises.

Enhanced activities for the ambient sound relative to the noise were found in bilateral brain regions known to be involved with auditory perception (the superior temporal gyrus—including primary auditory cortex (BA42) and Wernicke’s area (BA22)). Enhanced activity in these regions for speech relative to noise is well known. Since the ambient sounds used in this study are very different from speech sound, enhanced activation for the ambient sound relative to the noise may indicate that these areas become more activated for meaningful stimuli. However, even meaningless speech sounds (e.g. /a/, /i/) activate these regions compared to non-speech sounds [2]. Moreover, modulation of brain activity by task effects (i.e. active vs. passive listening task) in these areas has been reported [7]. Therefore, differential activation in BA42 and BA22 in this study may indicate that degrees of attention paid were different between the ambient sounds and the noises.

On the other hand, neural activities positively correlated with the imagery level were found in brain regions known to be involved with event simulation (the lateral premotor cortex (BA6), the inferior frontal gyrus (BA44), and the parietal lobe (BA40)). This fMRI result supports the second hypothesis, “simulation (internal forward model) based imagery”. Enhanced activity in brain regions involved with event simulation was positively correlated with better imagery. In contrast, results that support the first hypothesis, “perception based imagery” were not found in this experiment. Based on this hypothesis, differential activity in the parahippocampal place area (PPA) that is associated with place perception was expected but it was not found. We consider three possible reasons. Firstly, the lack of activation may be caused by the lack of non-imagery baseline. Even though behavioral data indicated that the participants could not picture the scenery well for the noise condition, they actually might have imaged scenery enough to activate the PPA while listening to noises. In order to test this possibility, non-imagery baseline condition has to be included in the future study. Secondly, the lack of activation in this study contrasting with previous ones may be because a different type of imagery was studied. In previous visual imagery research, names of familiar places were used as auditory stimuli and visual perception of still pictures was compared with visual imagery [17]. On the other had, we consider that the ambient sound used in this study created a movie like dynamic image of scenery (i.e. the flow of river, the motion of ocean waves). The contrasting results of our study and previous ones using still pictures may be one of dynamic versus static processing. Differential activity in the premotor cortex in this study is consistent with the notion that the premotor cortex is involved in non-biological dynamics [25]. Thirdly, the lack of activation in the PPA may be because participants visualized themselves in the picture, such as

walking by the beach, or walking around the busy city, instead of visualizing scenery. Since we did not ask “were you visualizing yourself in the picture” after the experiment, we can not deny this possibility. However, the reported premotor area in this study is located differently (more inferior) from a foot represented (by execution, imagery, and observation) premotor area [19].

Differential activity in the lateral premotor cortex, the inferior frontal gyrus, and the parietal lobule for imagery was found in this study. This finding is in agreement with Schubotz’ studies [19-22] that propose the involvement of those brain regions in simulation of non-biological events. If the imagery level corresponds to the endogenous presence level, it may be possible to measure the endogenous presence level by assessing neural activity in brain regions involved with event simulation. The relation between neural mechanisms for the endogenous presence and the exogenous presence is not clear. Further research to investigate the relation is planned.

References

- [1] R. M. Baños, C. Botella, M. Alcañiz, V. Liaño, B. Guerrero, and B. Rey. Immersion and Emotion: Their Impact on the Sense of Presence. *CyberPsychology & Behavior*, 7(6):734-741, 2004.
- [2] D. E. Callan, K. Tajima, A. M. Callan, R. Kubo, S. Masaki, and R. Akahane-Yamada. Learning-induced neural plasticity associated with improved identification performance after training of a difficult second-language phonetic contrast. *NeuroImage*, 19:113-124, 2003.
- [3] J. Decety, D. Perani, M. Jeannerod, V. Banttinardi, B. Tadary, J. C. Mazziotta, R. Woods, and F. Fazio. Mapping motor representation with positron emission tomography. *Nature*, 371: 600-602, 1994.
- [4] R. Epstein and N. Kanwisher. A cortical representation of the local visual environment. *Nature*, 392:598-601, 1998.
- [5] R. Grush. The emulation theory of representation: Motor control, imagery, and perception. *Behavioral and Brain Sciences*, 27: 377-442, 2004.
- [6] H. H. Ehrsson, S. Geyer, and E. Naito. Imagery of voluntary movement of fingers, toes and tongue activates corresponding body-part-specific motor representations. *Journal of Neurophysiology*, 90: 3304-3316, 2003.
- [7] D. A. Hall, M. P. Haggard, M. A. Akeroyd, A. Q. Summerfield, A. R. Palmer, M. R. Elliott, and R. W. Bowtell. Modulation and task effects in auditory processing measured using fMRI. *Hum Brain Mapp*, 10(3):107-19, 2000.
- [8] T. Hanakawa, M. Honda, T. Okada, H. Fukuyama, and H. Shibasaki. Differential activity in the premotor cortex subdivision in humans during mental calculation and verbal rehearsal tasks: a functional magnetic resonance imaging study. *Neuroscience Letters*, 347: 199-201, 2003.
- [9] T. Hanakawa, I. Immisch, K. Toma, M. A. Dimyan, P. V. Gelderen, and M. Hallett. Functional properties of brain areas associated with motor execution and imagery. *Journal of Neurophysiology*, 89: 989-1002, 2003.
- [10] A. Ishai, J. V. Haxby, and L. G. Ungerleider. Visual imagery of famous faces: Effects of memory and attention revealed by fMRI. *NeuroImage*, 17: 1729-1741, 2002.
- [11] A. Ishai, L.G. Ungerleider, and J. V. Haxby. Distributed neural systems for the generation of visual images. *Neuron*, 28: 979-990, 2000.
- [12] G. Kreiman, C. Koch, and I. Fried. Imagery neurons in the human brain. *Nature*, 408:357-361, 2000.
- [13] S. Lambert, E. Sampaio, Y. Mauss, and C. Scheiber. Blindness and brain plasticity: contribution of mental imagery? An fMRI study. *Cognitive Brain Research*, 20: 1-11, 2004.
- [14] P. Larsson, D. Västfjäll, and M. Kleiner. Perception of self-motion and presence in auditory virtual environments. In *Proceedings of the 7th Annual Workshop of Presence*, 2004, pages 252-258.
- [15] R. Ma and D. B. Kaber. Presence, workload and performance effects of synthetic environment design factors. *International Journal of Human-Computer Studies*. 64(6): 541-552, 2006.
- [16] S. Nichols, C. Haldane and J. R. Wilson. Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies*, 52(3): 471-491, 2002.
- [17] K. M. O’craven and N. Kanwisher. Mental imagery of faces and places activates corresponding stimulus-specific brain regions. *Journal of Cognitive Neuroscience*, 12: 1013-1023, 2000.
- [18] B. E. Riecke, J. Schulte-Pelkum, F. Caniard, and H. H. Bühlhoff. Influence of Auditory Cues on the visually-induced Self-Motion Illusion (Circular Vection) in Virtual Reality. In *Proceedings of the 8th Annual Workshop of Presence*, 2005, pages 49-57.
- [19] R. I. Schubotz. Prediction of external events with our motor system: towards a new framework. *TRENDS in Cognitive Science*, 11(5): 211-218, 2007.
- [20] R. I. Schubotz. Sequences of abstract nonbiological stimuli share ventral premotor cortex with action observation and imagery. *Journal of Neuroscience*, 24: 5467-5474, 2004.
- [21] R. I. Schubotz and D. Y. von Cramon. A blueprint for target motion: fMRI reveals perceived sequential complexity to modulate premotor cortex. *NeuroImage*, 16:920-935, 2002.
- [22] R. I. Schubotz, D. Y. von Cramon and G. Lohmann. Auditory what, where, and when: a sensory somatotopy in lateral premotor cortex. *NeuroImage* 20: 173-185, 2003.
- [23] K. M. Stanney, G. Salvendy, J. Deisigner, P. DiZio, S. Ellis, E. Ellis, et. al. Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda. Report sponsored by the Life Sciences Division at NASA Headquarters. *International Journal of Human-Computer Interaction*, 10(2), 135-187.
- [24] J. Talairach and P. Tournoux. Co-Planar Stereotaxic Atlas of the Human Brain. New York: Thieme Medical; 1988.
- [25] U. Wolfensteller, R. I. Schubotz, and D. Y. von Cramon. Understanding non-biological dynamics with your own premotor system. *NeuroImage*, 36: T33-T43, 2007.

