5-4 Perceptual and Cognitive Mechanisms of Presence and its Evaluation Technology

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This paper first describes the evaluation indexes of presence, i.e., the components and factors of presence, and the measurement and evaluation methods of presence. Second, as a presence-evaluation technique, we describe the development of evaluation technology which can measure human brain activities when large-field 3D images are shown. We also describe the quantitative evaluation methods of human sense of surface quality, especially glossiness, and the results of psychophysical experiments. Finally, future issues of perceptual and cognitive mechanisms of presence and its evaluation techniques are discussed.

Keywords
Presence, Evaluation methods, Brain activity imaging, Psychophysics, Glossiness

1 Introduction

In order to construct an “ultra-realistic communication system” which causes people to feel a strong sense of presence, it is necessary to analyze in depth what the nature of presence as felt by people. In human beings, information received from the outside world through the sensory receptors of their five senses is transmitted to their brains, the information then undergoes complex perceptualand cognitive information processing to be felt as presence. As such, in order to clarify the sense of presence felt by humans, we need to investigate the perceptual and cognitive mechanisms of the brain and neural system that allow humans to accurately interpret the realities of the external world.

If the mechanisms of the sense of presence that humans feel were able to be scientifically clarified and presence accurately measured and evaluated, it would have a huge value in constructing an “ultra-realistic communication system”. The first is the significance of the safety of an ultra-realistic communication system. An ultra-realistic communication system is an artificial system which can convey to humans information for which there is no actual substance as if there were, and there is a possibility that such systems could harm the brain or neural system of a human unnoticed. In order to safely convey presence without causing physical or mental discomfort or fatigue to humans, the presence felt by humans must be accurately and quantitatively evaluated. Another meaning of the clarification and evaluation of presence is that it may lead to the discovery of delivering presence to humans. For example, by using the photoreceptors equipped in the human eye, which have the sensitivity characteristics to sense the three colors (red, green and blue), video displays can cause a person to sense all possible colors through combinations of the aforementioned three colors. If the perceptual and cognitive mechanisms of all five senses were able to be clarified in this way, people could be made to feel presence in an efficient and effective manner without faithfully recreating all physical properties. The “ultra” in ultra-realistic communication system can be thought of as implying that the aim is to construct a new realism system that uses human perceptual and cognitive mechanisms to surpass simply faithfully recreating physical information.

This paper first describes the evaluation indexes of presence felt in section **2**, and the evaluation methods of presence. Second, as a presence-evaluation technique in section **3** we describe the development of evaluation technology which can measure human brain activities when large-field 3D images are shown. In **4**, we also describe the development of quantitative evaluation methods of human sense of surface quality, and the results of psychophysical experiments. Then in **5**, future issues of perceptual and cognitive mechanisms of presence and its evaluation techniques are discussed. And finally in **6** this paper’s conclusions are presented.

2 Presence evaluation indexes and evaluation techniques

2.1 Presence components and factors

Presence felt by humans can be said to be “feeling as if they were in the actual place”, however if one more deeply delves into the concept of presence, one will find that rather than being a single sense, presence is actually composed of multiple sensory components. Therefore as shown in Fig. 1, when analyzing presence, we analyze it using 3 components of spatial components, temporal components and physical components as evaluation indexes[1].

First, the senses of 3D, surface quality and surroundness can be used as spatial components for presence. The sense of 3D is a sense related to the depth (distance from the observer) and shape of an object existing in a space. The sense of surface quality is a sense related to the roughness of the surface of an object (texture), an object’s hardness/softness (elasticity), glossiness (surface reflectivity), transparency and temperature (heat transfer coefficient), and from this information humans infer the material (metal, wood, rubber, etc.) of an object. Surroundness is a sense where one senses the spatial extent of the area around oneself, the sense of immersion in that space and in addition the sense of the atmosphere of a place can also be considered one form of a sense of surroundness.

Next, sense of movement, sense of causality and sense of simultaneity can be used as temporal components for presence. The sense of movement is a sense which takes in temporal changes in the environment, which allows humans to quickly estimate the movement (speed/direction) of objects in the external word. Causality is a sense that feels that some phenomenon is the cause of another and gives rise to a result. Simultaneity is a sense that allows one to feel that separate phenomena are occurring simultaneously. For example, an image of two items touching and a sound of collision would be felt as being simultaneous and humans feel that these would be the result of the same physical factors.

And finally, sense of self existence, sense of interactivity and affection can be used as body-related components for presence. Even if a person accurately takes in the environment spatially and temporally, this does not mean that they necessarily sense themselves. When an individual sense their own physicality together with the environment, they sense presence more strongly. Sense of self existence is a sense where a person senses the condition (position, direction, movement) of their entire body or part of their body (arms, legs, head, etc.). Interactivity is a sense of interaction where one feels they can obtain a specified reaction by acting on objects or other people within the environment in a given manner. Affection is a pleasurable or unpleasurable sensation felt by the body in response to a subject, and people sense presence more strongly when experiencing these types of emotion.

Humans integrate various sensory components described above to sense presence. Moreover, these sensory components are not necessarily always independent of each other, but reciprocally related and matched, and it can be assumed when presence sensory components

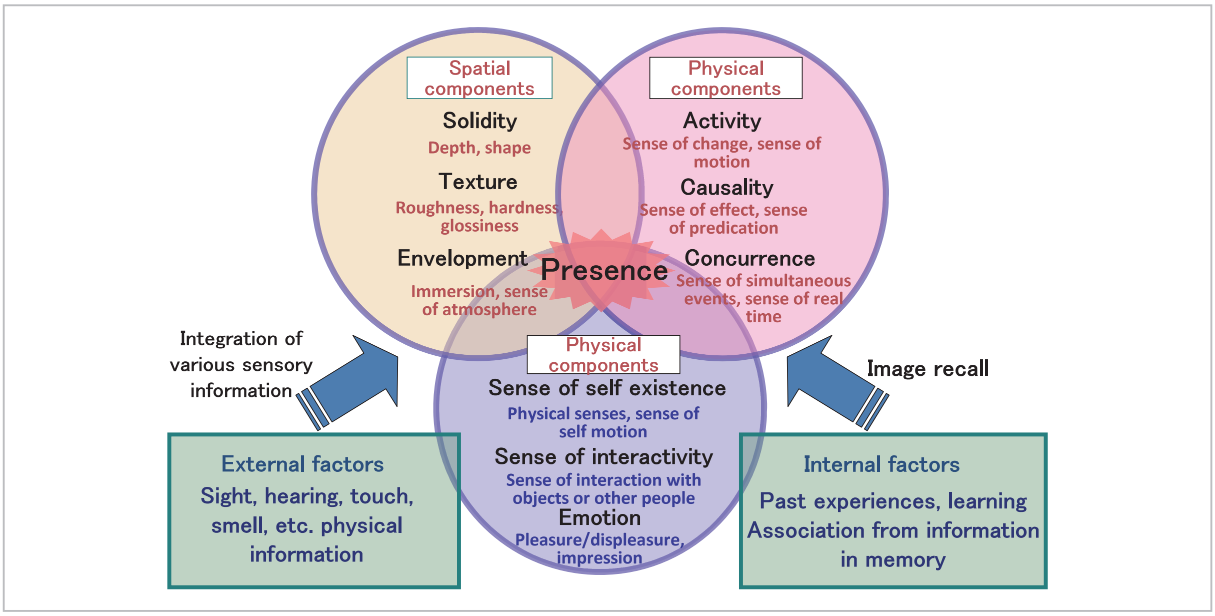

Fig.1 *Presence indexes (components and factors)*

are provided in a complex manner synergistic effects can be obtained. On the other hand, if several of these sensory components are missing, or inconsistent with each other, this can also sometimes lead to the creation of a unique type of presence. For example, if a person observes or experiences a virtual stereoscopic image, which has no tactile response even if touched with the hand, this leads to the individual feeling surprise. This can be thought of as providing a type of presence to people which is a virtual duality of "there is something there that shouldn't be".

Next, let's consider where presence comes from and the factors involved. It is necessary to consider external factors and internal factors as factors that cause presence sensory components (Fig. 1). Presence resulting from external factors is presence which is based on physical information from the external world which is detected by visual, auditory, somatosensory (haptic), olfactory, gustatory and other sensory organs. On the other hand, presence resulting from internal factors is presence that is generated in the brain based on memories of senses accumulated in the brain through past experiences and learning. For example, if an individual hears the sound of a wave, they may see the scenery of the ocean, however this is a sensory image recalled from past experiences. In addition, people can also recall vast amounts of images from text information as when an individual reads stories or poetry.

It can be thought that not only do people analyze information from the external world and store it in their brains for recreation in this manner, but that they can also use information accumulated from learning and experiences to interpret and supplement information from the external world to create that sense of existence. This shows just how important it is to refer to how to increase presence by drawing on information stored in the brainwhen constructing an ultra-realistic communication system.

2.2 Presence evaluation methods

How can accurately measuring and evaluating presence, which is composed of a variety of sensory components, be accomplished? There are five methods for measuring presence as felt by people, 1) subjective evaluation (impression rating), 2) psychophysical evaluation, 3) brain activity imaging, 4) biosignal measurement and 5) behavioral measurement. The characteristics and merits/demerits of each of these evaluation methods are shown in Table 1.

Subjective evaluation is normally a method whereby subjects self assess their impressions

Table 1 *Presence measurement and evaluation methods*

	Characteristics/type	Merits	Demerits
Impression assessment (Subjective assessment)	-Statistic analysis method SD method, pair comparison method, factor analysis, etc.	- Can be easily carried out using only questionnaires and no special measuring equipment -Suitable for sensibility evaluations	-Issues with reliability, reproducibility and individual differences in introspection (making meaningful) -Necessary to statistically analyze the data of large numbers of people to improve reliability
Psychophysical experiments	-Clarifies human response characteristics to physical stimuli Just Noticeable Differences (JND) Point of subjective equality (PSE) etc.	-More objective and quantitative measurement of senses/perceptions possible -Easy to match with physiological data and suitable for verification of perceptual mechanisms	-Difficult to apply to stimuli for which physical information is hard to control -Response is the final output so direct measurement of brain processes is difficult
Brain activity imaging	-fMRI (functional magnetic resonance imaging) -MEG (magnetoencephalogram) -EEG (electroencephalogram) -NIRS (near-infrared spectroscopy)	-Allows for measurement of internal brain activity (blood flow, electromagnetic fields) -Contributes to clarification of higher order human functions not possible in animal testing	- Limits on spatial and temporal resolution -Strict control of stimuli and problems required for interpretation of brain activity -Data analysis methods are still in development
-Data analysis methods are still in development	- heartbeat (pulse wave) – breathing - pupils – palpebration - electrodermal activity (GSR)	-Easy to handle emotional reactions and level of alertness which cannot be consciously controlled	-The neural processes which generate biosignals have not all necessarily been clarified
Behavioral measurement	-Physical (eyes – hands – head – body, etc.) activity measurement - body sway	-Allows for handling of unconscious behavioral responses - Suitable for analysis of social interaction, etc.	-The causes drawing forth behaviors are generally very complex, and identifying factors can be difficult

in response to presented words (adjective pairs, etc.). Impression rating can be easily carried out using only questionnaires and no special measuring equipment. However, it is not necessarily easy for one to accurately introspect (consciously make) impressions that they are perceiving. Therefore, it is necessary for subjects to be strict in their selection of words in preliminary tests, etc. and data must be statistically analyzed to obtain the highest reliability possible. In addition, when carrying out precise sensory evaluation, practice and training is also important to ensure that stable reactions are displayed when subjects are faced with specific stimuli.

In contrast, psychophysical evaluation is a method whereby people's response characteristics to physical stimuli are quantitatively measured. For example, "point of subjective equality", where a subject displays the same feelings under differing presented conditions and "just noticeable differences" where a subject begins to display different feelings can be found as physical numerical values through carrying out psychophysical experiments. When using psychophysical evaluation, it is also possible to deepen subconscious processes, and obtain quantitative and highly reliable results by linking with the physical dimension. However, it is difficult to manage this physical link with higher order cognitive senses through the psychophysics method.

On the other hand, a method based on the brain activity imaging method can also be considered as a method where presence is directly measured. In recent years non-invasive brain activity measurement technologies have developed quickly. For non-invasive brain activity imaging there are fMRI (functional magnetic resonance imaging) and NIRS (near-infrared spectroscopy), which handle changes in the blood flow (metabolism) of the brain, and EEG (electroencephalogram) and MEG (magnetoencephalogram) which handle neural activity as magnetic changes. In addition, biosignal (heartbeat, galvanic skin response, breathing, pupil diameter, etc.) and behavioral (eye movement, accommodation, body sway, bodily action, etc.) measurement methods can also be useful in order to handle unconscious changes that occur in a person's body.

As summarized in Table 1, each of the presence evaluation methods has their own characteristic advantages and limitations, and there is no perfect measurement method at present. As such, it is necessary to select these methods as appropriate to the evaluation targets and objectives, and integrate multiple methods in order to improve measurement and evaluation reliability.

3 Large-field 3D image brain activity evaluation technologies

There is a desire for the development of evaluation technologies that objectively and quantitatively evaluate what effect 3D images (binocular disparity images) have on human beings. The authors are developing technologies for evaluating the effect of large-field 3D images on humans using fMRI brain activity imaging. In general, if images are presented in a wide visual field, presence greatly improves, and senses of surroundness and immersion are invoked. On the other hand, watching images with very sharp movements on a large-field can increase a feeling of discomfort called visually-induced-motion-sickness.

In order to evaluate the positive and negative effects created by these large-field 3D images, a device for presenting large-field 3D images to subjects is necessary. However, on MRI equipment up until now, it was only possible to present images of a narrow horizontal visual field of about 20 degrees. This made the area around the head of the subject extremely tight and this is because there was not yet any technology for generating large-field 3D images. Generally, watching high definition (HDTV) images at a standard distance (3 times the height of the display) provides a horizontal visual field of view of 33 degrees. As such, it was not possible to recreate the viewing environment of a standard television inside of an MRI machine up until now. Further, for giant screen theaters (IMAX®) where viewers can enjoy very powerful images, the horizontal viewing angle from the center seats is approximately 70 degrees. The recommended horizontal viewing angle for the images for the super high vision currently being developed by the NHK Science & Technical Research Laboratories is 100 degrees for the most effective viewing. Presenting this type of large-field image to a subject and carrying out fMRI brain activity imaging has been impossible up until now.

In response, the authors of this paper have developed the technology of a super wide angle ocular lens which will allow viewing of images inside of an MRI machine at a horizontal visual field of 100 degrees (Fig. 2)[2]. In general, MRI generates a high magnetic field, so LCD panels and other magnetic bodies cannot be taken inside an MRI unit. However, even if the area around the head is a high magnetic field (3 Tesla which is 70,000 times the standard geomagnetism rate), the magnetic field drops drastically in corners of the room (to about 0.0005

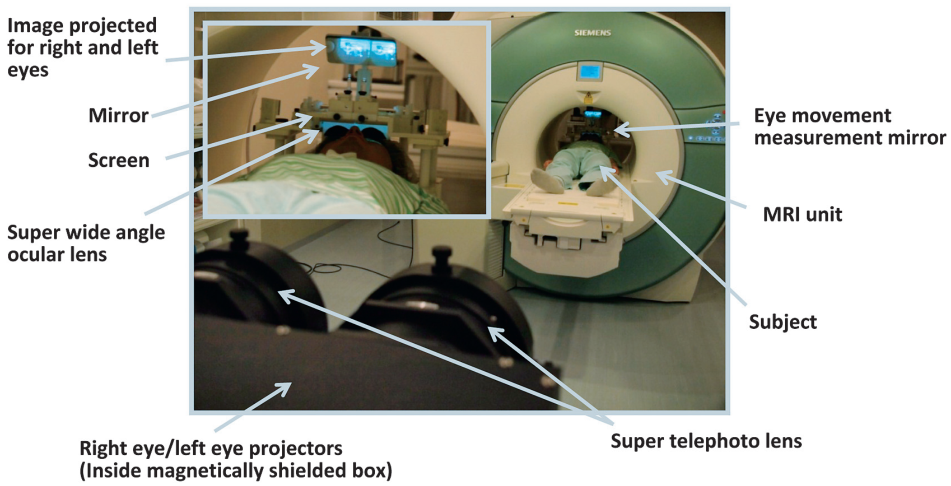

Fig.2 *Large-visual-field 3D image evaluation equipment*

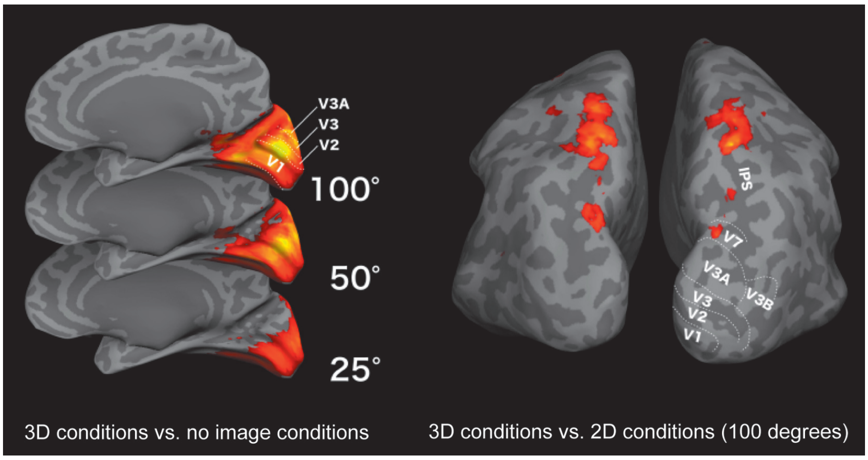

Fig.3 *Brain regions activated by large-visual-field 3D images*

Tesla). Here we places 2 projectors, one for the left eye and one for the right, in the corners of the room in magnetically shielded boxes, and used a super telephoto lens to project the images onto a small screen (13cm width) inside the MRI machine. Having the subject view this screen through the super wide angle ocular lens provides them with a horizontal visual field of 100 degrees. The lens materials were carefully selected so as not to cause any noise in the brain activity images. In addition, this equipment allows for obtaining the eye movement of the subject from both eyes. Measurement of eye movement was accomplished through reflection of several small mirrors by 2 CCD cameras installed behind the subject's head and analyzing this movement in real-time.

The results of the fMRI brain activity imaging on the effects of the 100 degree horizontal viewing angle on the brain of using this large-field 3D image evaluation equipment are shown in Fig. 3. For this experiment, a video of multiple randomly placed dots moving back and forth was used for visual stimulation. The left of Fig. 3 shows the regions of the brain activated by the 3D viewing conditions vs. the conditions with no image shown. As the horizontal field of view of the image was increased from 25 degrees, to 50 and 100, the visual cortex (each region of V1, V2, V3 and V3A) in the occipital region of the brain was seen to be activated in a larger range. This is because the visual cortex neurons have a receptive field relative to the position of the retinas. The right of Fig. 3 shows comparison between the activated brain regions when 2D images and 3D images were shown (with a horizontal visual field of 100 degrees for both). These results show that when viewing 3D images, the region from the occipital to parietal regions of the brain was strongly activated. The results of this experiment show that the brain regions activated when viewing a large-field 3D can be accurately measured using fMRI brain activity imaging with the equipment we have developed.

Hereafter, we plan to clarify the details of the positive (the sense of 3D, immersion, etc.) and negative (discomfort, visually-induced-motion-sickness, etc.) effects on the brain by large-field 3D images through researching the corresponding relationships between brain activity and psychological reactions when watching large-field 3D images.

4 Quantitative and objective evaluation of presence

We have explored the perceptual and cognitive mechanisms created by presence from various sensory information using quantitative and objective evaluation methods; for example, psychophysical experiments[3] and brain activity imaging[4] on perceived surface quality (glossiness), neural correlates of imagery in-

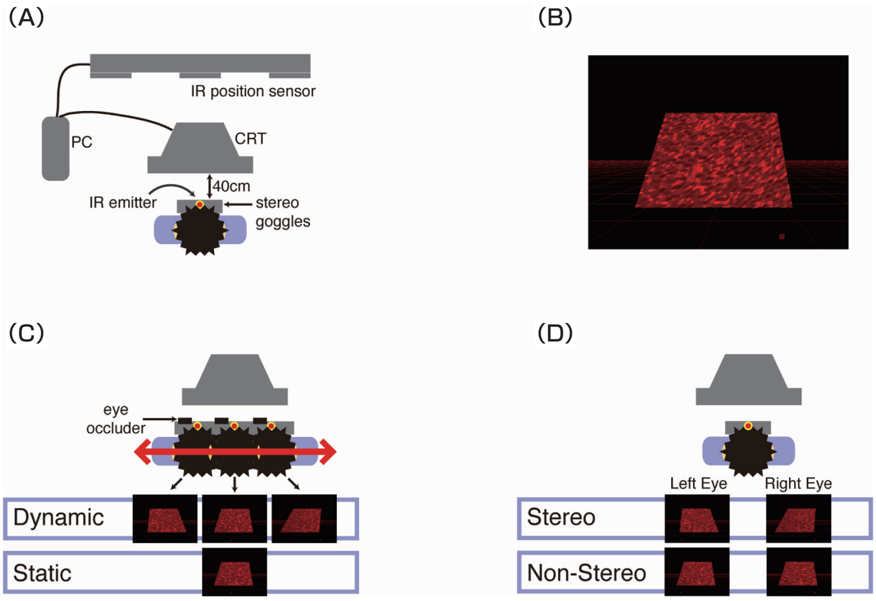

Fig.4 *Psychophysical experiments on glossiness perception: (a) Experimental apparatus, (B) Stimuli, (C) Experiment investigating dynamic effects (Experiment 1), (D) Experiment investigating 3D effects (Experiment 2) (Extracted from the reference[3])*

duced by ambient sound[5], brain activity imaging related to dynamic stereophonic sound[6], brain activity imaging related to naturalness and unnaturalness of images[7], psychophysical experiments[8] and brain activity imaging[9] on visual-haptic integration, and psychophysical research on the effects of contact sound and smell on haptics[10][11].

An overview of psychophysical experiments on perception of glossiness is given below as an example of presence evaluation.

In general, when a 3D image is viewed, people perceive not only the depth and shape as more realistic, but also the surface quality of objects. This can be because the images supplied to the right and left eyes are slightly different, and the perception of the glittering and roughness of the surface are improved. In addition the perceived surface quality of a 3D image using a multi-view method which allows viewing of 3D images with the naked eye by presenting large numbers of parallax images is different from a two-view method where specialized 3D glasses are used. This is because for the two-view method the viewer receives image information from only one viewpoint even if looking at the 3D image from different viewpoints and positions, whereas for the multi-view method the image can be viewed from different viewpoints by moving one's head (for example, an image looked at from the left of an object and an image looked at from the right). Actually when moving one's head and looking at an object's surface, the reflected light from the surface changes, and one may feel that the glossiness has increased.

The authors quantitatively measured in the psychophysical experiments to what degree the glossiness of an object's surface changed when an image of the object was dynamically changed and when different information was provided to both eyes[3]. In this experiment a two-view 3D display (time-division system using shutter glasses) was used, and a multi-view condition was imitated by having the subject move their heads with tracking their head movements in real-time (Fig. 4 (A)). As shown in Fig. 4 (B), a CG image of a textured flat object was used as visual stimuli. In experiment 1, the difference in glossiness for monocular vision was compared for dynamic conditions where the changes to the viewed image were

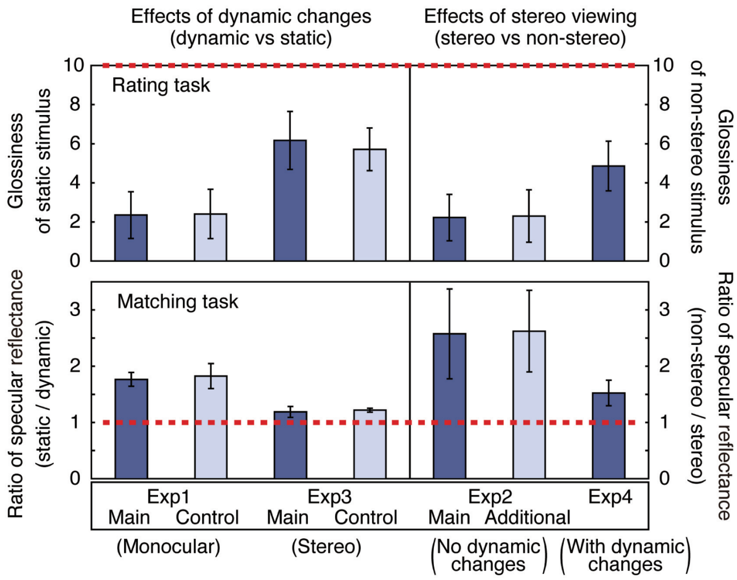

Fig.5 *Results of psychophysical experiment on glossiness perception (Extracted from the reference[3])*

simulated when viewpoint changes and static conditions where the object image doesn't change (Fig. 4 (C)). In experiment 2, glossiness differences were compared under binocular disparity conditions (stereo conditions) and conditions where the same image was shown to both eyes (flat surface conditions). In experiment 3, compared to the monocular view conditions in experiment 1,dynamic and static conditions in the case of binocular view were compared. (Results of the experiment 4 and other controlled conditions are omitted here.)

The glossiness perceived by the subjects was measured using two types of psychophysical methods, the magnitude estimation and adjustment methods. In the magnitude estimation method, we had subjects evaluate glossiness of the test condition with glossiness of the reference condition set at 10. In the adjustment method, we had the subjects adjust the glossiness parameter (the specular reflection rate) so that perceived glossiness of the reference condition and test condition were the same.

Results of the psychophysical experiments are shown in Fig. 5. The top row shows the results of the magnitude estimation method (the rating task) and the bottom row shows the results of the adjustment method (the matching task) . The results of experiment 1 show that compared to the conditions of looking at a dynamic image, in the conditions of looking at a static image the evaluation of glossiness was lower and the same glossiness could not be obtained without raising the specular reflection rate. The results of experiment 2 show that compared to the conditions of looking at an image with binocular disparity, in the conditions of looking at a flat image the rating value of glossiness was lower and the same perception of glossiness could not be obtained without raising the specular reflection rate. The results of experiment 3 show that even with the added binocular disparity, compared to the conditions of looking at a dynamic image, in the conditions for looking at a static image the rating value of glossiness was lower and the same perception of glossiness could not be obtained without raising the specular reflection rate.

To summarize these results, the movement of an object increases perception of glossiness (Experiment 1), the binocular disparity increases perception of glossiness (Experiment 2), and that if a object surface with binocular disparity moves, perception of glossiness increases even more (Experiment 3). This means that the perceived glossiness of an object surface on a two-view 3D display increases from the perceived glossiness on a flat display and that the perceived glossiness with changing the viewpoint on a multi-view increases even more. As shown above, the difference between perception of surface quality under different presentation methods can be quantitatively measured through psychophysical experiments.

5 Future issues

The following three items can be put forth as future issues on perceptual and cognitive mechanisms of presence and its evaluation techniques. First, we need to further clarify the meaning of brain activities by measuring brain activity and the psychophysical and behavioral responses when presented with given sensory information and analyzing the corresponding relationships. This process will lead to the establishment of methods that allow for evaluation of improved presence and increased discomfort through measurement of brain activity. Second, we need to find conditions for improving perception of presence through quantitative evaluation of presence using psychophysical experiments. It can be thought that these types of quantified technology requirement will be extremely significant for the future development of ultra-realistic communication systems. Finally, we need to seek to exceed the presence provided by physical information through utilizing human perceptual and cognitive mechanisms of presence. We believe this can be achieved by effectively using functions for generating, associating and predicting sensory information based on knowledge and memory. We plan to continue to pursue research from the above three viewpoints hereafter.

6 Conclusions

This paper first described the evaluation indexes, i.e., the components and factors, and the evaluation methods of presence. Second, as a presence-evaluation technique, we described the development of evaluation technology which can measure human brain activities when large-visual field 3D images are shown. We also describe the quantitative evaluation methods of human sense of surface quality, especially glossiness, and the results of experiments. Hereafter, we will continuously try to clarify human perceptual and cognitive mechanisms of presence, and both develop more objective and quantitative evaluation technologies as well as apply the obtained resultsto the development of ultra-realistic communication systems.

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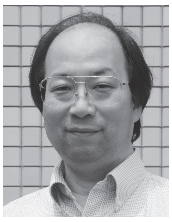

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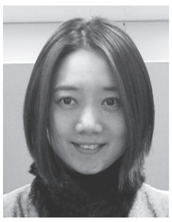

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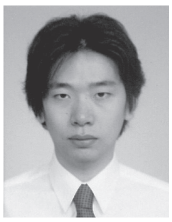

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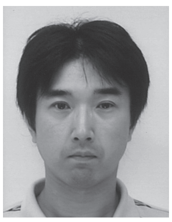

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