Cognitive and Behavioral Understanding of Interaction with Multimedia in Exhibition Spaces

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PhD thesis

Cognitive and Behavioral Understanding of Interaction with Multimedia in Exhibition Spaces

展示空間に設置される
マルチメディアとのインタラクションの認知的、行動的な理解

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July 2017

Declaration

I hereby declare that this dissertation entitled "**Cognitive and Behavioral Understanding of Interaction with Multimedia in Exhibition Space**" is not substantially the same as any that I have submitted for a degree or diploma or other qualification at any other University.

Those parts of this thesis which have been published are as follows:

1. Chapter 2 is based on the paper "**Effect of the Hand-Omitted Tool Motion on mu Rhythm Suppression.** (Kazuo Isoda, Kana Sueyoshi, Yuki Ikeda, Yuki Nishimura, Ichiro Hisanaga, Stéphanie Orlic, Yeon-kyu Kim and Shigekazu Higuchi, Frontiers in Human Neuroscience 2016, Vol.10: 266), DOI:10.3389/fnhum.2016.00266".
2. Chapter 3 is based on the paper "**Tangible User Interface and Mu Rhythm Suppression: The Effect of User Interface on the Brain Activity in Its Operator and Observer.** (Kazuo Isoda, Kana Sueyoshi, Ryo Miyamoto, Yuki Nishimura, Yuki Ikeda, Ichiro Hisanaga, Stéphanie Orlic, Yeon-kyu Kim and Shigekazu Higuchi, Applied Sciences 2017, Vol.7, No.4: 347), DOI:10.3390/app7040347".
3. Chapter 4 is based on the paper "**Effects of the Display Angle in Museums on User's Cognition, Behavior, and Subjective Responses.** (Junko Ichino, Kazuo Isoda, Ayako Hanai and Tetsuya Ueda, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2013), DOI:10.1145/2470654.2481413".
4. Chapter 5 is based on the paper "**Effects of the Display Angle on Social Behaviors of the People around the Display: A Field Study at a Museum.** (Junko Ichino, Kazuo Isoda, Tetsuya Ueda and Reimi Satoh, Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing. 2016), DOI:10.1145/2818048.2819938".

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Chapter 1
Background

1.1 Introduction

· Advances in multimedia and the necessity of human understanding

In recent years, advances in information terminals known for displaying so-called multimedia are remarkable. For example, with respect to display performance, the resolution of a single unit has been increased from full HD (High Definition) to 4 K and 8 K, and the size has been miniaturized due to pixel integration, which is being in personal use. On the other hand, the size of the display is enlarging, not only as a single unit, but also as a combination of multiple units due to improvements in tiling technology. Furthermore, due to diversification in devices, such as organic EL (Electroluminescence) and LED (Light Emitting Diode) projections in addition to conventional panels, the range of use has expanded from personal devices, such as smartphones, tablet PCs and HMDs (Head Mounted Display), to signage installed in public spaces (Nakamura & Ishido, 2009; Digital Signage Consortium, 2016).

As a result, opportunities for coming into contact with multimedia in everyday life are expanding. Much of the information obtained from traditional media, such as printing media, has been digitized and is becoming available only via multimedia. Along with Internet connections and the development of various sensing technologies, opportunities will further expand, and not only the amount of information but also qualitative diversity will increase.

How will humans recognize, understand and act on the information obtained from multimedia? Understanding how humans interact with multimedia as information recipients is an indispensable factor in designing multimedia. As the information expands quantitatively and qualitatively, better ways of presenting information that understands human cognition and behavioral characteristics is required more than ever.

· Understanding the initiatives and layers of human computer interactions adopted up until now at the DNP Museum Lab

We have been searching for new forms of information communication using multimedia through such activities as the DNP Museum Lab (since 2006, http://www.museumlab.jp/). This project focused on museums as places to utilize multimedia, such as interactive systems. We have been working from various approaches on how multimedia can contribute to the viewing experience in appreciation of works represented by art works.

We held exhibitions that added various kinds of multimedia equipment to the exhibitions of art works held by museums, such as the Louvre Museum and the French National Library, in the past. In the exhibitions, which have been held a total of eleven times in the past, each theme was set as a thematic approaches, and various matters which had been participants in past artwork exhibitions were solved by using new technology and application methods (**Figure 1.1**).

Figure 1.1 Development examples at the DNP Museum Lab.

The efforts that have been proposed and developed until now are classified into three layers as the interaction between human beings and the technical elements constituting the multimedia (**Figure 1.2**).

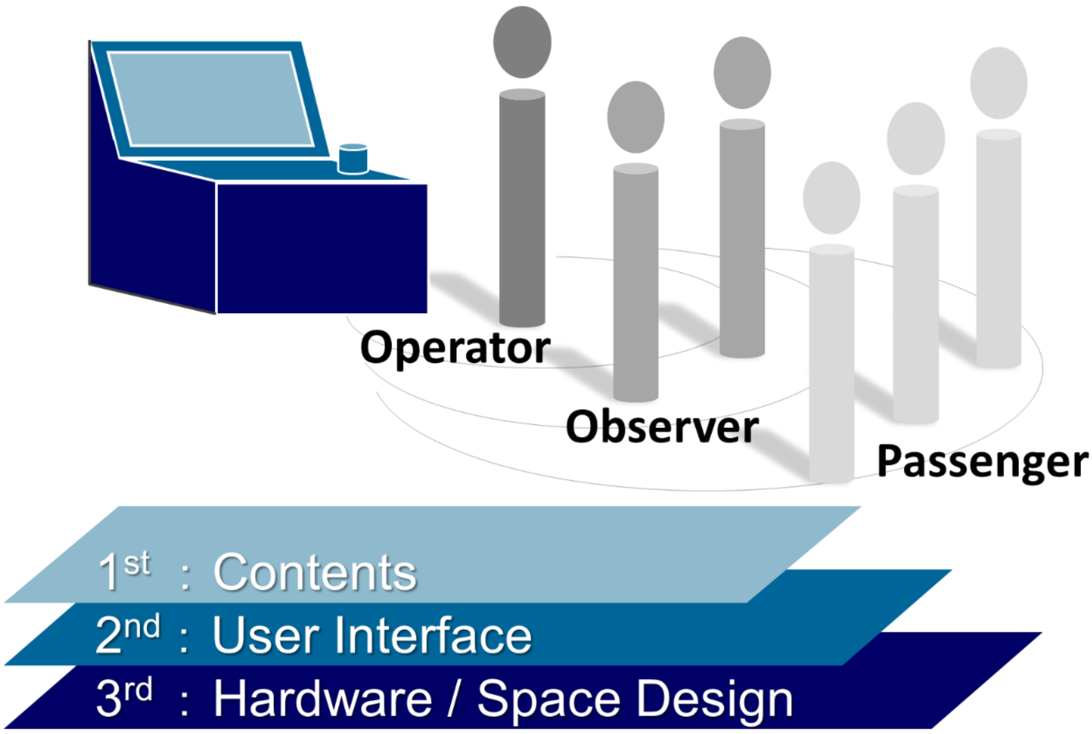


Figure 1.2 Factors related to equipment and humans.

The first layer is the technique of contents representation. We focused on how the information should be expressed so that it is easy for the viewers to understand it. This technology includes reproduction of artworks by digital representation, how to convey the background information of the work to help understand it, and so on.

The second layer is user interface technology. We focused on how to interact with the computer to acquire information. Initiatives to address issues that exist around the interface, including ease of operation, understanding operation methods, and so on.

The third layer is space design, including the design of hardware installed in the space. Issues such as the shape and arrangement of the equipment to be viewed or operated, and the design of the viewing route. Initiatives to address issues in spatial design, which is not limited to appreciating alone, but also assuming use by multiple people.

Although these layers are not completely independent, it is possible to cover many problems by paying attention to each layer and considering issues related to multimedia in exhibition spaces.

· Introduce scientific approach to development site
Even in the past proposals so far, human cognitive and behavioral characteristics, which are known from human research findings, were taken into consideration.

In the content representation technology, studies in human visual characteristics were used for information arrangement, color expression, character size, and the like. In the user interface technology, research knowledge on human information perception has been applied to the size and arrangement of operating systems. Even in the space and hardware design, research findings, such as ergonomics, have been used as guidelines for the height and size of the screen (Sato, Katsuura, Sato, Tochihara, & Yokoyama, 1992; Itoh, Kuwano, & Komatsubara, 2003; Oshima & Okubo, 2005). Materials serving as guides for incorporating those findings were also published (Weinschenk, 2011).

However, there are methods that are proposed and adopted on the basis of experience, even if there is no research backing on the development site. Methods proposed from such site problems and optimized for actual exhibitions, etc., were fed back to the research and their effects were not often verified from human characteristics.

In this research, we focused on linking academic research with on-site tasks and proposals. We will apply challenges / proposals born from actual development sites to hypotheses in the research field and try to verify them from a multifaceted aspect. We believe that not only scientifically supporting empirical know-how, which is only known from examples, but also scrutinizing issues / proposals by scientific approaches will lead to discovering a part of human characteristics.

1.2 Research areas of interest

In this paper, we focused on three research areas that are closely related to each layer (shown in **Figure 1.2**), and applied them to solving the problem in each layer.

· Mirror neuron system
Brain activity that works when seeing other people's behavior is already known (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Rizzolatti, Fadiga, Matelli, et al., 1996). It is known that brain activities that are activated by merely observing behavior performed by other people without them being executing themselves are related to understanding and predicting the intention of others to act (Iacoboni et al., 1999). From the work of the mirror neuron system (MNS), we set a hypothesis that we can explain the expression method and the effect of the user interface and verify the possibilities.

· Tangible user interface
As one of the ideas for interaction with computers, an interface has been proposed in which information processed digitally is represented in the real world and the physical behavior of real objects are reflected in computer operations (Ishii & Ullmer, 1997). In terms of performance and subjectivity, the simplicity of this is well known (Shaer & Hornecker, 2009), but we attempted to demonstrate it from the influence on brain activity.

· Social behavior around multimedia
Regarding behavioral characteristics to multimedia in public spaces, it is known that the honeypot effect (Brignull & Rogers, 2003) attracts the attention of users. In terms of communication, the space formed by a plurality of humans is defined as an instrumental F-formation (Kendon, 1990), and its social behavior is analyzed. Controlling the conditions for action in the actual exhibition environment and applying new approaches to social behavior analysis lead to acquiring new findings.

1.3 The purpose of this thesis

In the three layers related to exhibition technology, we focused on the empirical knowledge and tasks adopted for exhibitions as new experiments respectively. In order to explain this from the knowledge of human research and to discover new tasks, we will conduct a research approach and try to acquire knowledge newly supported by data by further examining new issues. Each related research area was set as follows, and approval verification approaches were made for each experiment.

· Effect of Hand-omitted Tool Motion on mu Rhythm Suppression (Chapter 2)
In this chapter, we investigated the effect of the image of hands on mu rhythm suppression invoked by the observation of a series of tool-based actions in a goal-directed activity. As a source of visual stimuli to be used in the test, a video animation of the porcelain making process for museums was used. In order to elucidate the effect of the hand imagery, the image of hands was omitted from the original ("hand image included") version of the animation to prepare another ("hand image omitted") version. The present study has demonstrated that in individuals watching an instructive animation on the porcelain making process, the image of the porcelain maker's hands can activate the MNS. In observations of “tool included” clips, even the "hand image omitted" clip induced significant mu rhythm suppression in the right central area. These results suggest that visual observation of a tool-based action may be able to activate the MNS even in the absence of hand imagery.

· Tangible User Interface and mu Rhythm Suppression: Effect of User Interfaces on Brain Activity in the Operator and Observer (Chapter 3)
The intuitiveness of tangible user interfaces (TUI) is not only for the operator. It is quite possible that this type of user interface (UI) can also have an effect on the experience and learning of observers who are just watching the operator using it. To understand the possible effect of TUI, the present study focused on mu rhythm suppression in the sensorimotor area reflecting execution and observation of action, and investigated brain activity both in the operator and observer. In the observer experiment, the effect of TUI on observers was demonstrated through brain activity. Although the effect of the grasping action itself was uncertain, the unpredictability of the result of the action seemed to have some effect on the MNS-related brain activity. In the operator experiment, in spite of the same grasping action, brain activity was activated in the sensorimotor area when UI functions were included (TUI). Such activation of the brain activity was not found with a graphical user interface (GUI) that has UI functions without the grasping action. These

results suggest that the MNS-related brain activity is involved in the effect of TUI, indicating the possibility of UI evaluation based on brain activity.

· Effects of the Display Angle in Museums on User's Cognition, Behavior, and Subjective Responses (Chapter 4)

In order to achieve the intended level of communication with visitors in museums where large displays are installed, it is essential to understand how various display factors affect visitors. We explored the effects of the display angle on individual users. In our experiment, we set up three types of flat displays -vertical, horizontal, and tilted- and comprehensively tested users' cognitive, behavioral, and subjective aspects. The results showed that significant differences could be discerned with regard to cognitive and subjective aspects. Test results for the cognitive aspect showed that the display angle on which the displayed content was easy to understand and remember differed depending on age. Test results for the subjective aspect showed that irrespective of age, users rated tilted displays as being quicker to attract attention and easier to peruse, to understand and remember the content, and to interact with, and such displays were the most preferred.

· Effects of the Display Angle on the Social Behavior of People around the Display: A Field Study at a Museum (Chapter 5)

In this chapter, we investigated through a field study how the angles (horizontal, tilted, and vertical angles) of displays deployed in a public space (at a museum) impact the social behavior of the people around the display. In the field study, we collected both quantitative and qualitative data of more than 700 museum visitors over a period of approximately three months. The findings of our study include the following: (1) the horizontal and vertical display angles have a higher honeypot effect, i.e., people interacting with a display attract other people, than the tilted display angle, (2) the vertical display angle, compared to the horizontal and tilted display angles, attracts several people to the display and encourages them to stay in the display space and share the space for a short period of time (88 seconds on average), and as a result, people frequently enter and leave the space with a display, and (3) display angles closer to the horizontal promotes the side-by-side arrangement, and display angles closer to the vertical promotes the L-shaped arrangement of an F-formation.

1.4 The structure of this thesis

In this paper, we focused on three layers related to exhibition technology (technology concerning content representation, interface technology, cabinet design and space design) in Chapter 2 to 5. Each research theme was set and tried by scientific examination using five experiments (**Table 1.1**).

In Chapter 2, we focused on the presence of human hand movement as one "technology on content expression" and measured human response to the movements of hands and tools expressed in the image. As a human response, we considered the influence on "brain activity" from the MNS activity using "mu rhythm suppression".

In Chapter 3, we focused on the "tangible user interface" as one of the "interface technologies" and focused on the movement of hands that actually manipulate existing objects. This study consisted of two experiments, the influence on the observer and the influence on the operator, and we examined the influence on the brain activity from the same "mu rhythm suppression" activity as in Chapter 2.

Next, we focused on "angle of display that can interact with large sizes" as one of the factors of "space and display devices design". In Chapter 4, a simulated exhibition space was constructed in the laboratory, and individual responses were acquired and the influence on behavior, cognition and subjective response was considered. Based on the results of Chapter 4, in Chapter 5 we observed the response of multiple users with a field study in the actual exhibition space. Then, we considered the influence on 'social behavior around multimedia' in a more natural environment.

Finally, we summarized my conclusions in Chapter 6.

Table 1.1 Experimental conditions.

Exp.	*Layer*	*Participants*			*Location*	*Survey items*	*Chapter*
1	Contents	Observer	without operation	alone	Laboratory Experiment 1	・Cognition <Brain Activity>	Chapter 2
2	User Interface	Observer behaind Operator	without operation	alone	Laboratory Experiment 2	・Cognition <Brain Activity>	Chapter 3
3	User Interface	Operator	with operation	alone	Laboratory Experiment 3	・Cognition <Brain Activity>	Chapter 3
4	Hardware and Space	Operator	with operation	alone	Laboratory Experiment 4	・Cognition ・Behavior ・Subjective Responses	Chapter 4
5	Hardware and Space	Operator Observer Passenger	with/without operation mixed	multiple	Field Study	・Behavior ・Subjective Responses	Chapter 5

Chapter 2
Effect of the Hand-omitted Tool Motion on mu Rhythm Suppression

2.1 Introduction

・Mirror neuron system

"Mirror neurons" that discharge during both action done and the same action observed were first identified in the F5 area (ventral premotor cortex) in macaque monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), and the neurons were subsequently found in the intraparietal sulcus, too (Fogassi et al., 2005). A number of experiments have suggested that this parieto-frontal cortical circuit in the observer of actions performed by other individuals encodes the goals and intentions of these actions (Rizzolatti & Craighero, 2004; Rizzolatti & Sinigaglia, 2010).

In humans, fMRI (functional magnetic resonance imaging) studies have revealed the presence of mirror-like brain regions similar to those in monkeys. It has been proposed that the MNS in humans (**Figure 2.1**) is involved not only in the recognition of the goals and intentions of actions (Iacoboni, 2005), but also in imitation (Iacoboni & Dapretto, 2006; Molenberghs, Cunnington, & Mattingley, 2009), empathy, facial expression recognition, and other social cognition functions (Preston & de Waal, 2002; Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Jabbi, Swart, & Keysers, 2007; Schraa-Tam et al., 2012). In the study using fMRI, disassociation of visual processing between ventral and dorsal pathways was revealed during object and action recognition (Shmuelof & Zohary, 2005).

・Mu rhythm suppression

In addition to fMRI, electroencephalography (EEG) has been used for the measurement of the activity of the MNS in humans (Pineda, 2005). Specific alpha ranges of EEG have long been known which are present over the central area, corresponding to the primary motor and other areas, in an individual physically at rest and suppressible by not only her/his performing an action but also just observing the same action performed by another individual (Gastaut & Bert, 1954; Chatrian, Petersen, & Lazarte, 1959) (**Figure 2.2**). Those EEG which have mirror-like characteristics and occur in the central area on the scalp of an individual physically at rest are also called "mu rhythm". Since the first discovery of mirror neurons in 1996, a number of studies have revealed that mu rhythm are related to the MNS (Pineda, 2005).

According to some of these studies, mu rhythm can be suppressed to a varying degree depending on the goal of an action to be observed (Muthukumaraswamy, Johnson, & McNair, 2004). Comparative EEG studies have also been reported using the test stimuli that are conventionally employed in fMRI studies (Perry & Bentin, 2009). Based on the study using both fMRI and EEG, mu rhythm are related to the activity of the primary motor cortex and the inferior parietal lobule that reflects the firing of the MNS (Arnstein, Cui, Keysers, Maurits, & Gazzola, 2011). These findings strongly suggest that, in humans, the level of mu rhythm suppression can be an index of the activity of the MNS.

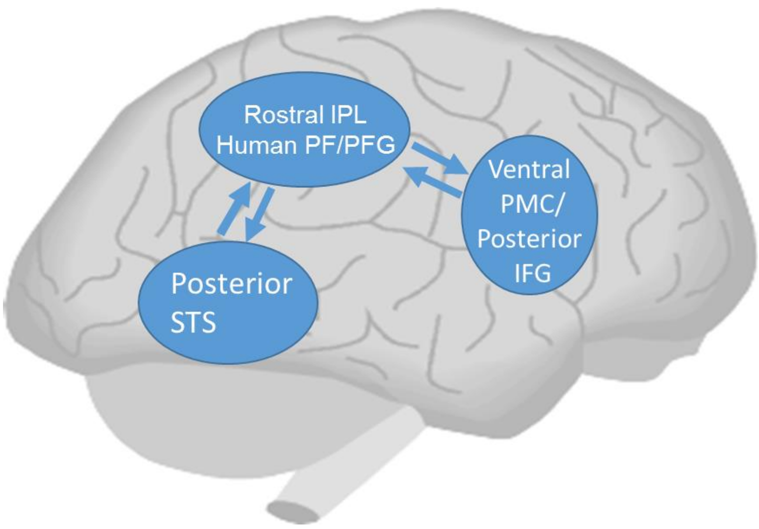


Figure 2.1 Human mirror neuron system: Neural circuitry for imitation (Modified from Iacoboni and Dapretto, 2006, Page 943, Figure 1).

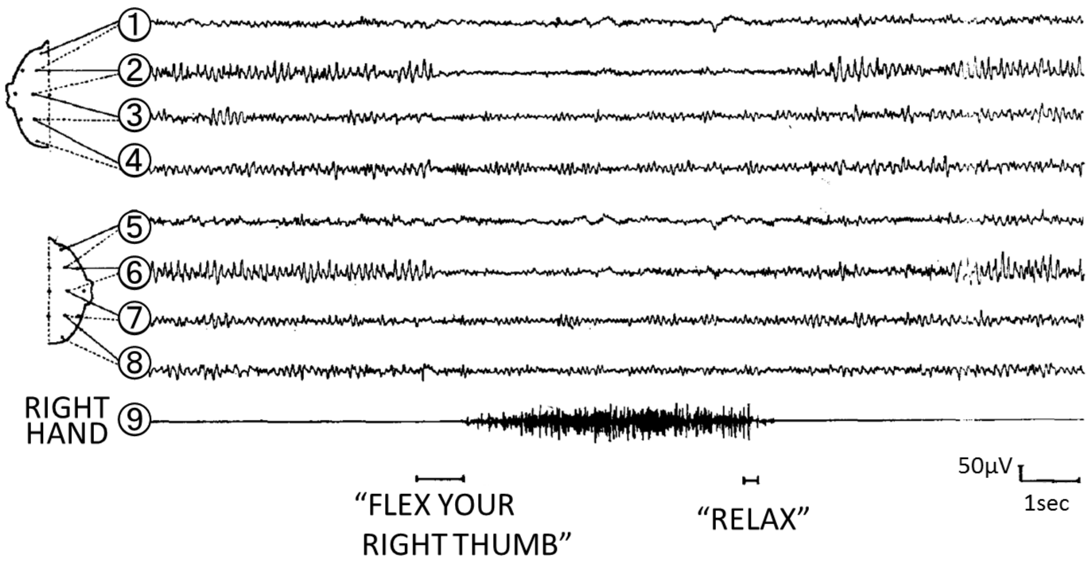


Figure 2.2 Example of mu rhythm suppression (Chatrian et al., 1959, Page 503, Figure 7).

・Tool-based action

The evolution of the brain has endowed humans with the ability of tool-based actions. Although non-human animals can also perform tool-based actions, they cannot handle tools in as complex a way as humans. In humans and monkeys, visuomotor neural mechanisms that are involved in the visual observation and the handling of tools has been extensively investigated (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Jarvelainen, Schurmann, & Hari, 2004; Maravita & Iriki, 2004; Peeters et al., 2009; Costantini, Ambrosini, Sinigaglia, & Gallese, 2011). However, the relation between the visual observation of the handling of tools and the activation of the MNS has been much less studied.

A magnetoencephalography (MEG) study has reported that the primary motor area in an individual can be activated by just watching the motion of hands of another individual in tool-based actions (Jarvelainen et al., 2004). fMRI studies in humans and monkeys also investigated the effect of watching a video featuring a tool-based action on the MNS (Peeters et al., 2009). As a result, a human-specific activity of the left inferior parietal lobule was identified, suggesting that this brain area is important in the tool-based actions in humans.

Similar mirror neurons are involved in brain activity induced by the visual observation of tools, which was first identified in monkeys (Murata et al., 1997). With the participant just focusing on the tool, these are neurons that respond, relying on the shape of the hand when it grabs the object and the pattern of movement. Rizzolatti et al. call them canonical neurons (Grezes, Armony, Rowe, & Passingham, 2003; Rizzolatti, Cattaneo, Fabbri-Destro, & Rozzi, 2014). According to a previous report in humans, the ventral premotor cortex, the posterior parietal lobe, and the precentral sulcus can be activated by the handling as well as the visual observation of a tool (Chao & Martin, 2000; Mecklinger, Gruenewald, Besson, Magnie, & Von Cramon, 2002; Grezes et al., 2003). These activities are regarded as important functions in the handling of tools. Furthermore, in tool action observations, mu rhythm is suppressed more according to participant's experience in the action (Cannon et al., 2014).

These previous reports are extremely intriguing as to the brain's response to tool-based actions, but there has been hardly any research that distinguishes between tool and the presence of hands. By controlling the task, Shmuelof et al. (2005) succeeded in distinguishing reaction to an object and reaction to an action; yet, this is purely the observation of a reaction to an object as a target matter. We will pay attention to the reaction to a tool that has been prepared as a medium to transmit the intended action to an object that is the participant. Research focusing on motion shows that mu rhythms are suppressed by biological motion but they will not be suppressed by random motion (Ulloa & Pineda, 2007). Indeed, there are reports that, even though mu rhythm suppression occurs when a person watches an image of a ball being thrown, just watching the ball in flight will not suppress the mu rhythm (Oberman et al., 2005). It is also unclear whether the MNS can be activated by watching the image of tools, hands, or both, because the test visual stimuli employed in previous studies included not only the image of a tool but also the image of hands that was handling the tool. If the MNS is activated by transmitting the intention of an action, even if the hand is omitted, it is probable that mu rhythm suppression will occur with just the movement of the tool.

In the present study, we investigated the effect of the image of hands on mu rhythm suppression invoked by the observation of a series of tool-based actions in a goal-directed activity.

2.2 Methods

[Experiment 1]

・Participants

The participants were 13 healthy, right-handed university students (7 females and 6 males, 22.2±1.3 years old) who normally do not engage in clay modeling work. The participants gave written informed consent to the present study only after they were provided with information on the test protocol. The study was approved by the Ethical Committee of Kyushu University (approval No. 84).

・Experimental conditions

As a source of visual stimuli to be used in the test, a video animation was chosen which a museum used to instruct its visitors on the porcelain making process (DNP Museum Lab). This imagery consisted of processes such as clay kneading and wheel rotation (processes where tools are not used) as well as clay modeling using a kidney shaped profile and decoration (processes where tools are used), all performed by the hands of a porcelain maker.

In this study, first we observed the MNS activity under circumstances not related to tools in order to confirm whether or not MNS activity via EEG can be observed in the animation used for trials. Next, in accordance with the focus of this study, we looked to confirm the effect of only tool motion by comparing the presence / non-presence of hands under circumstances mediated by a tool. Note that, to avoid the influence by the order of conditions appearances, we shuffled the order of these experiments.

In order to elucidate the effect of the image of these hands, the image of hands were omitted from the original ("hand image included") version of the animation to prepare another ("hand image omitted") version. From each of these two versions, chapters on tool-free actions (e.g. clay kneading and wheel rotation: **Figure 2.3**, left panel) and chapters on tool-based actions (e.g. clay shaping with a kidney: **Figure 2.3**, right panel) were separately extracted and edited to make two shorter clips ("tool-free" and "tool included"). Each of the four shorter clips was presented repeatedly to each participant (70 seconds / clip). The control stimulus employed in the test was a static frame with a cross-mark at its center.

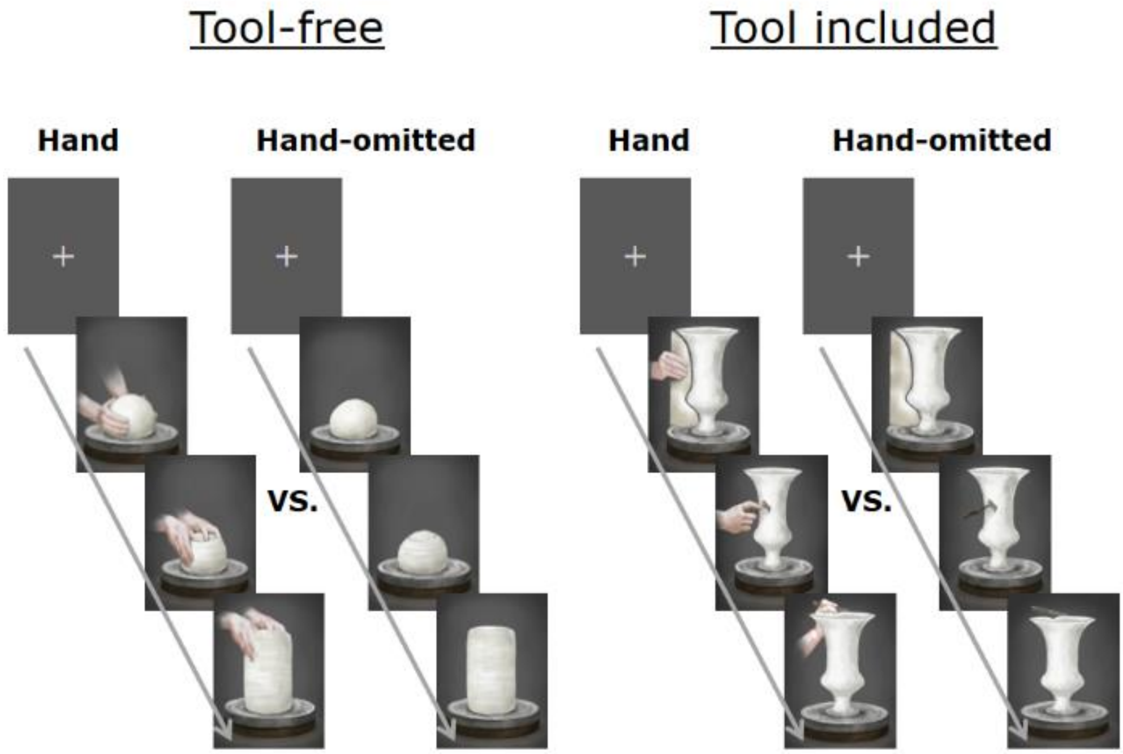


Figure 2.3 Chapters on "tool-free" actions (e.g. clay kneading and wheel rotation: left panel) and chapters on "tool included" actions (e.g. clay shaping with a kidney: right panel). The stimulus for baseline data was a still frame with a cross-hair at its center.

First, the participants were allowed to watch the whole movies (the "hand image included" version and the "hand image omitted" version). Then each of the four shorter clips was presented as a test stimulus. Before and after each shorter clip, the still frame control was presented (40 seconds). The "hand image included" stimulus and the "hand image omitted" stimulus were counterbalanced between the participants for both the "tool-free" stimuli and the "tool included" stimuli. While watching the video, the participants were instructed to move their eyes as little as possible from the center of the screen.

EEG were measured in an electromagnetically shielded room (illuminance = 200 lx, temperature = 25 degrees Celsius, moisture = 50 %). Each participant was seated on a chair and allowed to watch a series of the four clips and the still frame control on a liquid crystal display (19 in.), which was placed at 1.1 m from the chair. (**Figure 2.4**) EEG were detected using a 64-channel EEG cap (Hydrocel GSN 64 ver.1.0, Electrical Geodesics, Inc.), filtered with a low cut frequency of 0.3 Hz, a high cut frequency of 100 Hz, and a sampling rate of 250 Hz, which were A/D converted and recorded on a computer (PowerMac G5, Apple, Inc.) equipped with the Net Station 4.1.2 software (Electrical Geodesics, Inc.).

Figure 2.4 Settings of the Experiment.

The obtained data, except for those from the initial 10 seconds, were subjected to a frequency analysis (Fast Fourier Transform; FFT) at 1 epoch (4.091 seconds long) per 2 seconds. An average power value in the 10-12 Hz range, which was considered to well reflect the activity of the motor cortex (Pfurtscheller, Neuper, & Krausz, 2000), was used as the mu power value. The calculated power values were normalized after logarithmic transformation, which were then analyzed using the EMSE Suite Data Editor 5.3 Release Candidate 3 software (Source Signal Imaging, Inc.).
For each channel, we calculated mu rhythm suppression, i.e. the difference in the mu power value between each test stimulus and the control stimulus before/after the test stimulus. We set the motor area of the cerebral cortex region as the region of interest (ROI) to provide us with an indicator for confirming whether or not the MNS activity was increased by the movement of the tool with intention. The data from two of the participants contained missing values and outliers, and thus were excluded from the analysis.

In order to enhance the reliability of the data, Two regions of interest (ROI) were defined and respective electrode sites were pooled: left central (LC: electrodes 16, 20, 21, 22) and right central (RC: electrodes 41, 49, 50, 51; **Figure 2.5**). A paired t-test was performed to determine the significant mu suppression from the baseline data of the still frame. Next, a two-ways (hand image included/omitted x Left/Right hemisphere) repeated measurements of analysis of variance (rm-ANOVA) were conducted to determine the significance. Additionally, a paired t-test was used by using each individual electrode site of 64 channels and a three-dimensional topographic map (t-map) was generated.

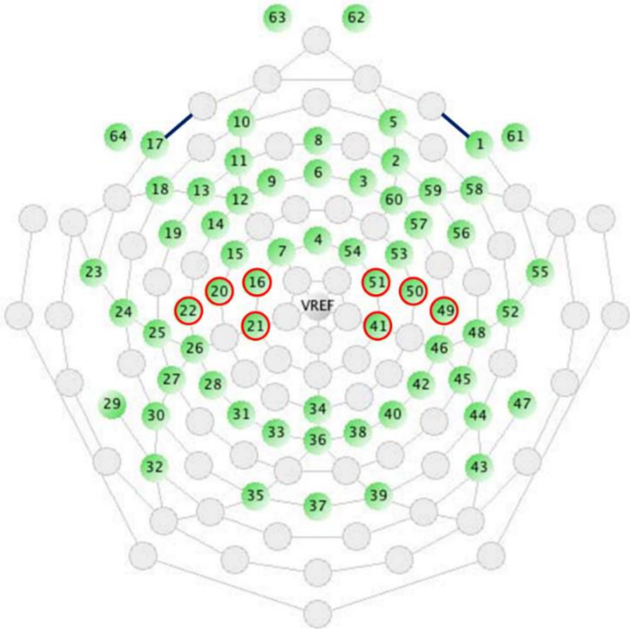


Figure 2.5 Two regions of interest (ROIs):
ROIs were defined and respective electrode sites were pooled: left central (16, 20, 21, 22) and right central (41, 49, 50, 51).

2.3 Results

Analysis 1: Changes in the mu power value induced by watching the "tool-free" clips are shown in **Figure 2.6**. Compared to the control stimulus by the still frame, a significant decrease in the mu power value was induced by the "hand image included" clip in the left central area (t (10) = -3.13; p = 0.011) and the right central area (t (10) = -3.05; p = 0.010). The "hand image omitted" clip did not induce any significant mu rhythm suppression.

We next compared the ability of the "hand image included" clip and that of the "hand image omitted" clip to induce mu rhythm suppression. As the results of two-way rm-ANOVA, although main effect of hand image was significant (F (1, 10) = 18.920; p = 0.001; η_p^2 = 0.654), main effect of hemisphere and interaction were not significant. It turned out that, compared to the "hand image omitted" clip, the "hand image included" clip induced a significant mu rhythm suppression in the right central area (t (10) = -4.01; p = 0.002) and the left central area (t (10) = -2.57; p = 0.028). We made a similar comparison for each electrode site, and plotted the results in a three-dimensional t-map (**Figure 2.7**), demonstrating the difference between the "hand image included" and "hand image omitted" clips specifically in the right and left central. No significant differences were found in other areas.

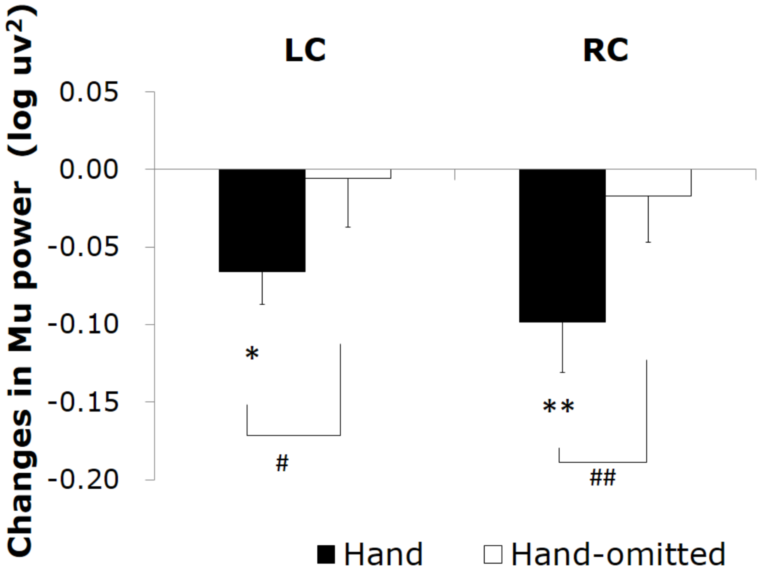


Figure 2.6 Changes in the mu power value induced by watching the "tool-free" clips: "hand image included" (■) and "hand image omitted" (□). Asterisks (*: $p < 0.05$, **: $p < 0.01$) mean the significant mu rhythm suppression from baseline to observation of video clips. Sharps (#: $p < 0.05$, ##: $p < 0.01$) mean the significant differences between mu rhythm suppression by watching video clips "hand image included" and "hand image omitted".

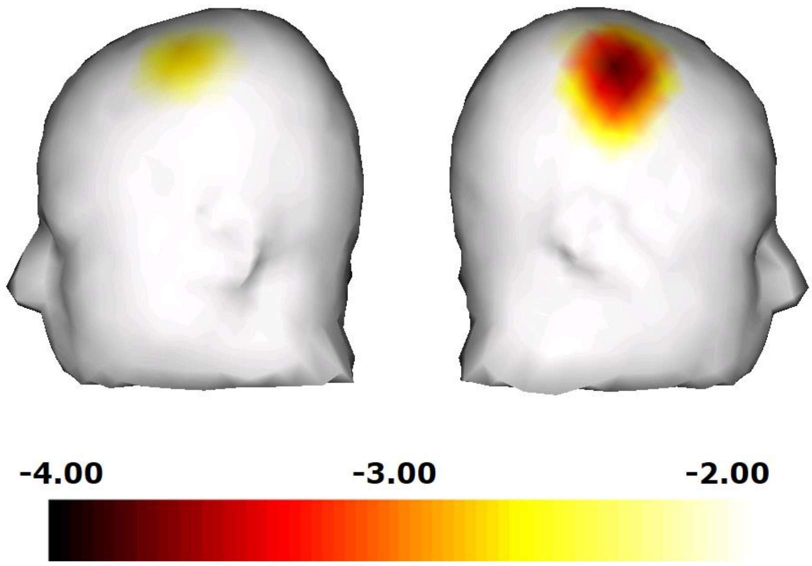


Figure 2.7 Three-dimensional t-map:
Comparison for each electrode site, and plotted the results in a three-dimensional t-map, demonstrating the difference between the "hand image included" and "hand image omitted" clips specifically in the right central.

Analysis 2: Changes in the mu power value induced by watching the "tool included" clips are shown in **Figure 2.8**. Compared to the still image control, a significant decrease in the mu power value was induced by the "hand image included" clip in the right central area (t (10) = -2.26; p = 0.035). In addition, the "hand image omitted" clip also induced a significant decrease in the mu power value in the right central area (t (10) = -2.10; p = 0.050). As the results of two-way rm-ANOVA, although main effect of hemisphere was significant (F (1, 10) = 7.299; p = 0.022; η_p^2 = 0.422), main effect of hand image and interaction were not significant. Mu suppression in right hemisphere was significant greater than that in left hemisphere. No significant differences were found for mu suppression between the "hand image included" and "hand image omitted" of the "tool included" clips. We made a comparison for each electrode site, and plotted the results by the corresponding three-dimensional t-map (**Figure 2.9**). In this analyze, we found also a significant difference from the left parietal region to the left temporal region (LP: electrodes 27, 30; **Figure 2.5**). No significant difference was found in other regions between these results.

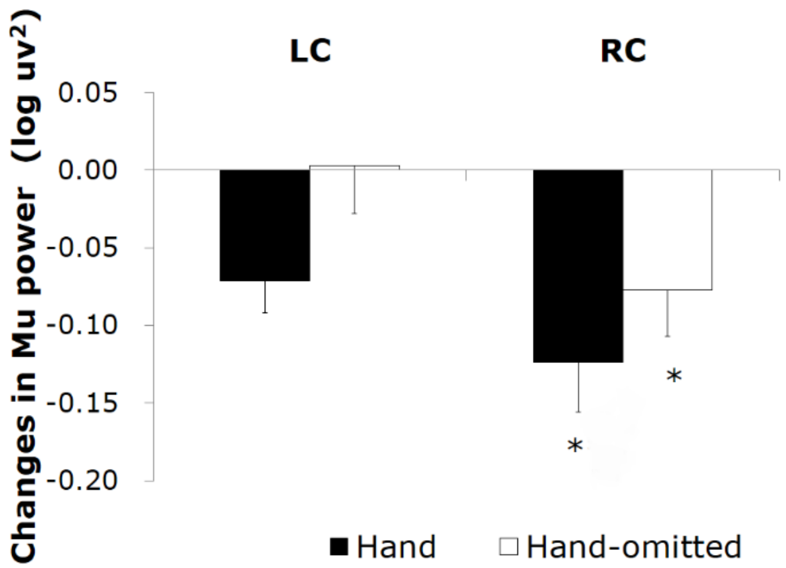


Figure 2.8 Changes in the mu power value induced by watching the "tool included" clips: "hand image included" (■) and "hand image omitted"(□).

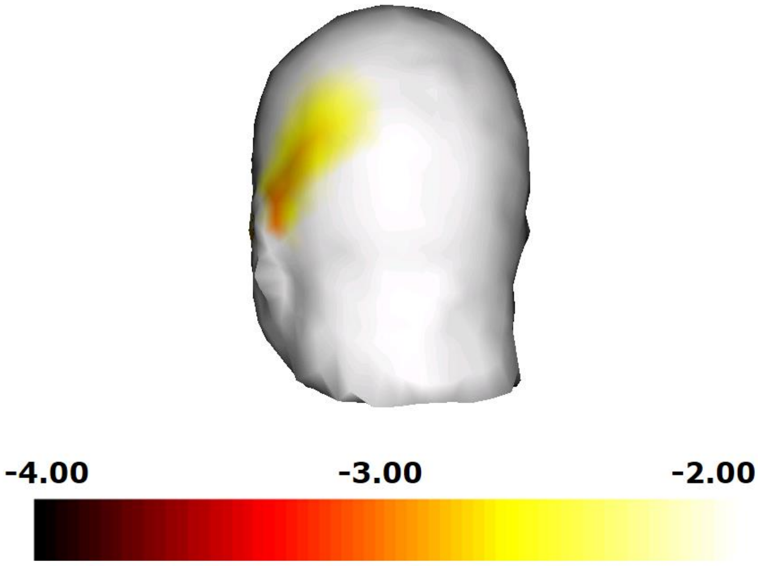


Figure 2.9 Three-dimensional t-map:
Comparison for each electrode site, and plotted the results in a three-dimensional t-map.
We found a significant difference from the left parietal region to the left temporal region.

2.4 Discussion

・"Tool-free" clips: comparison between "hand image included" and "hand image omitted"

In analysis 1, we confirmed mu rhythm suppression can be observed only when hands were present. As a result, we confirmed that MNS activity can be observed even with the animation video. In the observation of the "tool-free" clips by the participants, the "hand image included" clip induced a significant decrease in the mu power value in the central area (LC, RC), whereas the "hand image omitted" clip did not. These results are consistent with previous observation that the visual observation of the motion of hands induced mu rhythm suppression in the central area (Muthukumaraswamy et al., 2004; Oberman, McCleery, Ramachandran, & Pineda, 2007; Perry & Bentin, 2009), indicating that, in the animation of the porcelain making process used in the present study, the image of hands activated the MNS in the motor cortex. Moreover, activity was seen in both the LC and RC hemispheres. This is conjectured to be hand movement representation of a contralateral preference that appears in the dorsal stream (Shmuelof & Zohary, 2005) while, in this study, another factor is considered to be that both hands were active in the presented hand movement.

In the "tool-free" clips, the "hand image included" clip also induced a decrease in the power value in the 10-12 Hz range in some areas other than the central area (LC, RC). This is thought to have happened because of the visual stimuli due to the clay images in the activity shared by presentations. The effect of the image of hands was investigated by comparing the effect of the "hand image included" clip and that of the "hand image omitted" clip on the power value in the 10-12 Hz range. (**Figure 2.7**) A significant difference was only present in the right central area, where the "hand image included" clip induced a significantly greater suppression of mu rhythm than the "hand image omitted" clip, which results in reaction to object (clay images) in the activity shared by presentations being offset, indicating a motor cortex-specific effect of the image of hands.

・"Tool included" clips: comparison between "hand image included" and "hand image omitted"

In analysis 2, regardless of whether or not the hand was present, we confirmed mu rhythm suppression in just the RC, and, depending on the tool movement, we confirmed that MNS activity could be seen. In the observation of the "tool included" clips, even the "hand image omitted" clip induced a significant mu rhythm suppression in the right central area, resulting in activity being seen just in RC, which is thought to stem from the fact that the movement was nearly all presented on the left side of the screen. This too matches the contralateral tendency as described by Shmuelof et al. (2005), indicating that the motion of a tool can induce mu rhythm suppression in its observer even in the absence of the image of hands handling the tool. This is possibly because the motion of the tools (e.g. a kidney) may have compensated for the omitted image of the hands. According to previous studies in monkeys, as a result of watching a tool-based action, neurons in the parietal lobe can merge the tool into the hands handling the tool, leading to a cortical magnification (Hihara et al., 2006). In addition, it has been reported that the primary motor area can be activated not only by watching the motion of hands but also by just imagining the same motion (Pfurtscheller & Neuper, 1997; Pineda, Allison, & Vankov, 2000). Mu rhythm suppression induced by the "hand image omitted" clip in the central area might be attributable to an ability of the motion of a tool to evoke the image of the hands handling the tool in the brain.

Another possibility is the involvement of a brain activity that is induced by the visual observation of tools. It is known that the areas involved in the handling of tools can also be activated by just watching the tools (Chao & Martin, 2000; Grezes et al., 2003). This characteristic activation of brain is seen in monkeys (Murata et al., 1997). Mecklinger et al. (2002) reported that the visual observation of a graspable object induces a stronger activity in the ventral premotor cortex than that of a non-graspable object. We suppose that such an activity induced by the observation of the motion of a tool may have induced mu rhythm suppression in the present study.

Similar to the "tool-free" stimuli, the "hand image included" clip in the "tool included" stimuli also induced a decrease in the power value in the 10-12 Hz range in many areas over the scalp. Therefore we investigated the effect of the image of hands, by directly comparing the data from the "hand image included" and "hand image omitted" clips. As a result, the "hand image included" clip resulted in a significant mu rhythm suppression from the left parietal region to the left temporal region. From the two parameters compared, the only difference is the presence/non-presence of hands, so mu rhythm suppression in this case is considered to be dependent on caused by "hand movement". As the presented "hand movement" is a right-hand one for manipulating a tool, a contralateral action that corresponds to the participant's own hand movement is appearing. This matches the results showing a strong reaction to some of the images of a body shown in Downing et al. (2001). Yet again, viewed from a different perspective, according to a previous report based on both fMRI and EEG, the activity of the inferior parietal lobule is strongly related to mu rhythm suppression (Arnstein et al., 2011). In addition, it has been known that the observation of a tool-based action can activate the left inferior parietal lobule (IPL) in the observer (Peeters et al., 2009). This activation is human-specific and not found in monkeys. In this study, the use of a tool is strongly related to the recognition of the difference in mu rhythm suppression between the "hand image included" and "hand image omitted" clips in the area corresponding to the inferior parietal lobule.

The present study has demonstrated that the visual observation of a tool-based action may be able to activate the MNS even in the absence of such an image of hands. This phenomenon may involve brain activities, which are known to fire in response to the visual observation of a tool. In the observation of the tool-based process, the image of hands induced mu rhythm suppression in the observer in the area corresponding to the inferior parietal lobule.

· Limitation

In this study, we adopted the commentary video animation of art works as a stimulus to evaluate museum information interfacing from the aspect of cerebral function. However, it is assumed that visitors to actual museums vary in characteristics, such as age, gender and profession. In previous research, it has been reported that mu rhythm suppression is influenced by experiences (Cannon et al., 2014). Therefore, we need to take into consideration the experiences of participants when undertaking research. Indeed, although we validated the presence/non-presence of hands when presenting tool movement, we did not validate the presence/non-presence of a tool. To further stringently isolate influences, we should probably also carry out validation that can compare the presence/non-presence of the tool concerned.

Chapter 3
Tangible User Interface and mu Rhythm Suppression: Effect of User Interfaces on Brain Activity in the Operator and Observer

3.1 Introduction

・Tangible User Interface

Tangible User Interface (TUI) is a type of UI that allows a person to interact with digital information through the physical environment (Ishii & Ullmer, 1997). This type of UI involves the use of tangible objects that bridges the gap between digital information and physical space, and is characterized by its UI function based on the manipulation (e.g. grasping and moving) of that objects (Fitzmaurice, 1996). Because TUI accepts specific user actions on the objects as inputs, the result of each action can be easily predicted, implying that it is more harmonious with intuition in comparison with other UIs. As compared with physical and digital representations, TUI provides more fun as well as intuitiveness to its users. Its applications in the design community include those focusing on user experience (e.g., Baskinger & Gross, 2010; Van Den Hoven et al., 2007) and learning at museums (Wakkary, Muise, Tanenbaum, Hatala, & Kornfeld, 2008).

・The intuitiveness of TUI

The intuitiveness of various TUIs provided at museums is likely to have an effect on the experience and learning of not only those who are operating them, but also of those who are just watching it. TUI can make observers understand the purpose of each user action more easily, because the user action on the tangible object is visible.

Such characteristics have led to its applications to education (e.g., Stanton et al., 2001; Antle, 2007; O'Malley & Fraser, 2004), providing richer environment for education than conventional GUI (Shaer & Hornecker, 2009). For example, as proposed by Hornecker et al. (2006), TUI allows a variety of interaction styles and also has known social aspects. Its application to collaboration was proposed early on (e.g., Arias, Eden, & Fischer, 1997; Suzuki & Kato, 1995). TUI is also known to have an effect on its observers. When a person wants to use a UI for the first time, he/she often starts by watching someone actually operating it. Through such an observation to learn the operation, he/she can more easily find an interest in the operation and will become more motivated to operate the UI by himself/herself. Therefore, it is important to evaluate the intuitiveness of a UI for the observer.

There are a lot of UI evaluation methods, including those based on subjective, behavioral, and psychological approaches (e.g., Fitzmaurice & Buxton, 1997; Patten & Ishii, 2000; Zuckerman & Gal-Oz, 2013). However, most studies to date have focused on the effect on the user. The effect on observers has been studied about their behaviors or experiences, but their physiological effects are rarely investigated. (Reeves, Benford, O'Malley, & Fraser, 2005; Peltonen et al., 2008).

・Mirror neurons system

In the present study, we take a neuroscientific approach based on a brain function that is activated by observing the action of others. There are a set of neurons that fire both by performing and observing the same action. These are referred to as mirror neurons, first identified in specific areas in the brain of macaque monkey (Gallese et al., 1996).

It has been reported that mirror neurons play an important role in the understanding of the intention of an action of others (Rizzolatti, Fogassi, & Gallese, 2001). In humans, fMRI studies have shown that an MNS-like function involves a plurality of brain areas. MNS in human is far more complex than that in macaque monkey, and has been reported to be involved in imitation and empathy (Iacoboni, 2009) as well as understanding of the purpose of an action of others (Iacoboni, 2005).

・Mu rhythm suppression

EEG has been proposed as a convenient method to monitor the activity of MNS (Pineda, 2005). Performing and observing an action both suppress the alpha band rhythm in the central sulcus (Gastaut & Bert, 1954). The alpha band rhythm around the central sulcus is called mu rhythm. Mu rhythm suppression is enhanced by observing a goal-directed action or performing a social task (Muthukumaraswamy et al., 2004; Oberman, McCleery, et al., 2007). In particular, the band power in 10-12 Hz was previously reported as a relatively sensitive indicator of the motor cortex activity (Pfurtscheller et al., 2000; Muthukumaraswamy et al., 2004).

・Effect on the observer around the operator of UI

One characteristic of TUI is that it involves physical actions of the user to grasp a tangible object and the like, which are readily visible to its observers (e.g., Ishii, 2008; Shaer & Hornecker, 2009). On the other hand, it is known that MNS is activated by the observation of the action of others. In Chapter 2, we suggested that MNS also responds to the movement of hands and tools shown in an introductory video for museum. In particular, it shows a pronounced response to the action of grasping an object (Rizzolatti & Matelli, 2003). With regard to the action of the operator of UI, such a grasping action makes TUI different from GUI, which is a more common type of UI (Fitzmaurice, 1996). What kind of effect on MNS is caused by watching others operating TUI, in comparison with GUI? By monitoring the brain activity related to MNS during the operation of different UIs (i.e. different information acquisition processes), it will be possible to evaluate the effect of each UI in terms of understanding of intentions, and the like.

・Approach from both sides of observer and operator

Because UI is primarily designed for its users, there is a non-negligible effect on a person actually operating it, besides its observer. Therefore, in the present study, we conducted two types of experiment to understand the effect of TUI on both its operator and observer in terms of the MNS-related brain activity. First, we examined the effect of the observation of UI on the MNS-related brain activity in the observer (Experiment 2). Next, we investigated the same brain activity in the operator (Experiment 3). Based on the results of both experiments, the effect that was characteristic of TUI on the brain activity could be addressed.

3.2 Methods

[Experiment 2]

In Experiment 2, the brain activity in the observer watching the UI operation from behind was monitored to investigate the effect on the observer.

・Participants

The participants were 15 right-handed students (15 male, 21.9 ± 1.2 years old). All participants signed the informed consent form. The present study was approved by the Ethical Committee of Kyushu University (approval No. 84). No participant had a history of a psychiatric or neurological disorder.

・Experimental conditions

In the present study, each participant sat behind and watched an assistant (hereafter actor) operating a TUI. One of the art appreciation systems provided at the DNP Museum Lab was simplified into three different experimental TUIs composed of a screen and either tangible objects or a touch panel with object thumbnails. The effect of TUI was investigated in three conditions, i.e. using these different types of UI (two TUI and one GUI; **Figure 3.1**).

We adopted two TUI conditions to compare presence / absence of correspondence between the selected object and the displayed object. We also adopted third GUI condition to compare presence / absence of the grasping motion.

In the first condition, a set of small porcelain models (a total of eight different porcelains) was adopted as UI (TUI / OBJECT condition). In each task, the actor grasped one model and moved it onto a holder in front of the screen. As a result, the screen displayed a porcelain picture that corresponded to the model. Then the actor hid the porcelain picture from the screen by returning the model to the initial position. The actor conducted this task for all of the eight models (i.e. a total of eight tasks of displaying/hiding a porcelain picture).
In the second condition, eight identical can models were used as UI (TUI / CAN condition). The actor conducted a total of eight tasks of displaying / hiding a porcelain picture as in the first condition, except that the porcelain picture was not predicative from the appearance of the corresponding model.
In the third condition, thumbnails of eight different porcelains provided on the touch panel served as UI (GUI condition). In each task, the actor touched one thumbnail with a finger, as a result of which the screen displayed a porcelain picture that corresponded to the thumbnail. Then, the actor moved only a hand onto the holder in front of the screen. After that, the actor moved the hand and touched the same thumbnail to hide the porcelain

picture from the screen. Then the actor returned the hand to the holder. The actor conducted a total of eight tasks of displaying/hiding a porcelain picture as in the other conditions.

(a)

(b)

(c)

Figure 3.1 Settings of different conditions in Experiment 2:
(a) tangible user interface (TUI) / OBJECT condition; (b) TUI / CAN condition;
(c) graphical user interface (GUI) condition.

・Experimental procedure

Each participant put on an EEG electrode cap and sat 2 m behind the actor (**Figure 3.2**). During the first 70 seconds, the participants stayed at rest looking at a fixation point displayed on the screen. Then, the actor started to operate the UI. The operation time for each picture was about 8.7 seconds, and a total of eight operation tasks were conducted which included all the eight different pictures in a random order. This set of tasks (about 70 seconds) was repeated once again. EEG was recorded while the participant was at rest and watching the actor's manipulation, and data from the resting state and the second set were used for the subsequent analysis. We carried out the above process for each of the three conditions, wherein the order of these conditions was counter-balanced between the participants. Each participant was instructed to sit still throughout the EEG measurement watching the hand of the actor during the manipulation and the screen during each picture displayed on the screen.

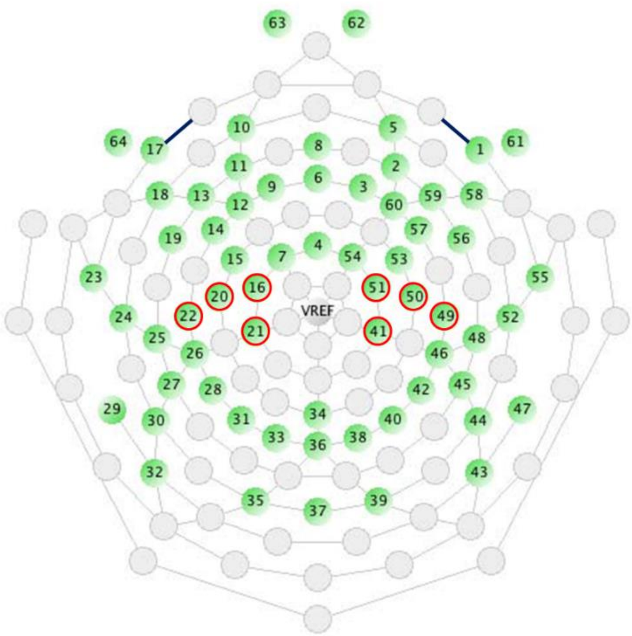


Figure 3.2 Two regions of interest (ROIs):
ROIs were defined and respective electrode sites were pooled: left central (16, 20, 21, 22) and right central (41, 49, 50, 51).

・EEG measurement and analysis

A 64-channel Ag-AgCl electrode cap, an EGI NetAmps 200 amplifier, and Netstation acquisition software (Electric Geodesics, Inc.) were used for the EEG measurement. The average of all channels was used as the reference, and sampling was done at 250 Hz, with a band-pass filter ranging from 0.3 to 100 Hz. FFT was applied to EEG segments (4.09-sec interval, 1024 points, Hanning window), which were overlapped by 50% (EMSE Data Editor 5.3, Source Signal Imaging, Inc.). Data from the first 10 seconds were excluded from the study for reason of transients in attention. The average power in 10-12 Hz was adopted as the mu rhythm power. Each power value obtained was converted into a logarithm to ensure the normality of the data. EMSE Suite Data Editor 5.3 Release

Candidate 3 (Source Signal Imaging, Inc.) was used for data analysis. Mu rhythm suppression in the observer watching the actor's action was adopted as the index of MNS. Mu rhythm suppression in each condition was calculated using data from the resting state as reference. Because the sensorimotor area showed mu rhythm suppression, EEG was analyzed in two ROIs: left central (LC: 4 electrodes around C3) and right central (RC: 4 electrodes around C4).

The main effects of conditions (the TUI / OBJECT condition, the TUI / CAN condition, and the GUI condition) and brain areas (LC and RC), and their interactions were tested by two-way rm-ANOVA. For multiple comparisons, we used modified sequentially rejective bonferroni procedure. Before significance testing, outliers in each participant were identified by Smirnov-Grubbs test ($p < 0.01$). All the outlier channels were excluded from the subsequent statistical analyses.

[Experiment 3]

In Experiment 3, the brain activity in the operator actually operating UI was monitored to study the effect on the operator.

・Participants

The participants were 18 right-handed students (18 male, 22.1 ± 1.57 years old). Other details were the same as described above for Experiment 2.

・Experimental conditions

An ACTION condition, which involved the user action but no visual information as a results of each actions, was included in addition to the three conditions in Experiment 2 (i.e. four conditions in total). The ACTION condition was adopted to compare presence / absence of visual feedback of the consequence of the operation. The eight identical can models in the TUI / CAN condition were also used in this condition (**Figure 3.3**). The operator conducted a total of eight tasks as in the TUI / CAN condition, except that no porcelain picture was displayed on the screen.

(a)

(b)

(c)

Figure 3.3 Settings of different conditions in Experiment 3:
(a) TUI / OBJECT condition; (b) TUI / CAN condition and ACTION condition (in the ACTION condition, no porcelain picture was displayed on the screen); (c) GUI condition.

・**Experimental procedure**
Each participant put on an EEG electrode cap and sat in front of the screen. The operator stayed at rest for the first 60 seconds and then started to operate the UI. The operation time for each picture was about 13 seconds, and a total of eight operation tasks were conducted which included all the eight different pictures in a random order. This set of tasks (about 104 seconds) was repeated once again. EEG of the operator at rest and during the two sets of tasks was recorded, and data from the resting state and the second set were used for the subsequent analysis. We carried out the above process for each of the four conditions, wherein the order of these conditions was counter-balanced across the participants.

The participant was instructed to operate to a sound stimulus presented at a constant rhythm, for the sake of the consistency of the movement. The participant was also instructed to sit as still as possible during the EEG measurement and to keep looking at the manipulating hand during the manipulation and at the screen during a picture was displayed, so that the eye movement would be in line with the operation process. The participant went through enough explanation and exercise before the experiment.

・**EEG measurement and analysis**
For comparison with Experiment 2, the 10-12 Hz component of EEG was analyzed as in Experiment 3. Mu rhythm suppression in the operator was adopted as the index of brain activities. The main effects of conditions (the TUI / OBJECT condition, the TUI / CAN condition, the GUI condition, the ACTION condition) and brain areas (LC and RC), and their interactions were tested by two-way rm-ANOVA. The other analysis procedure was the same as Experiment 2.

3.3 Results

[Experiment 2]
Mu rhythm suppression in each brain area due to UI was examined by comparing the power values in the mu band in the resting state and during the operation, by one sample t-test (**Figure 3.4**). As a result, RC in the TUI / CAN condition showed a significant difference (t (14) = -2.46; p = 0.028). In contrast, no brain area showed a significant difference in the TUI / OBJECT condition or the GUI condition. Based on the data from the resting state and the data from the operation, mu rhythm suppression was determined for LC and RC in different conditions (TUI / OBJECT condition, TUI / CAN condition, and GUI condition; **Figure 3.4**).

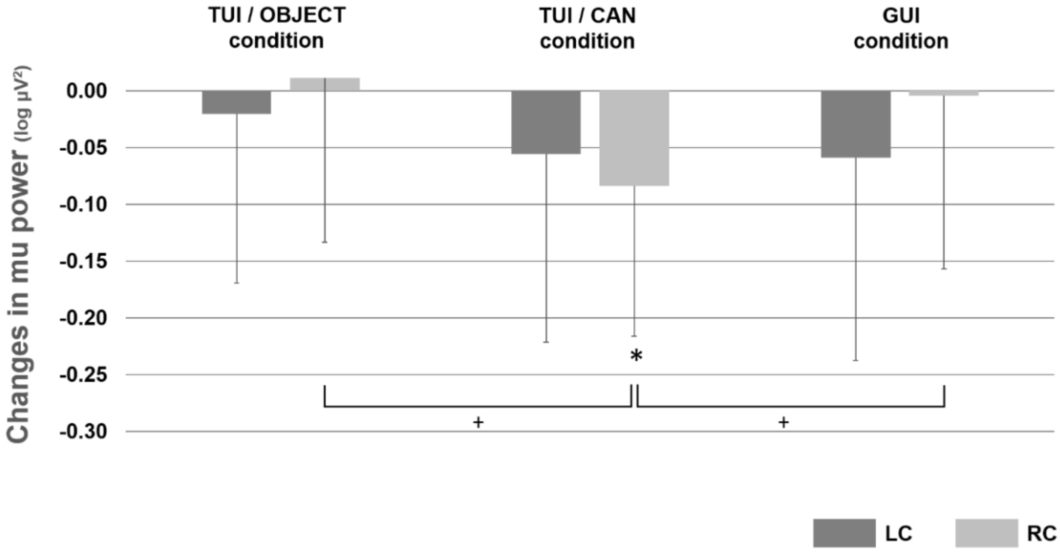


Figure 3.4 Changes in mu power:
Mu rhythm suppression (LC and RC) in different conditions in Experiment 2. Asterisk (*p < 0.05) means the significant mu rhythm suppression from baseline to observation of each actions. Daggers (^{+}p < 0.10) mean the tendency in comparison with other conditions at RC.

Next, the main effect of conditions (TUI / OBJECT condition, TUI / CAN condition, and GUI condition) and brain areas (LC and RC), and their interactions were tested by two-way rm-ANOVA. The ANOVA results confirmed an interaction between condition and brain area (F (2, 28) = 4.245; p = 0.025; η_p^2 = 0.233), and a main effect of condition in RC (F (2, 28) = 4.234; p = 0.025; η_p^2 = 0.232). By t-test, there was a tendency that the TUI / CAN condition resulted in a higher suppression in comparison with other two conditions (t (14) = 2.50; p = 0.077 in TUI / CAN vs TUI / OBJECT, t (14) = 2.02; p = 0.077 in TUI / CAN vs GUI).

[Experiment 3]

As in Experiment 2, mu rhythm suppression in each brain area due to UI was examined by comparing the power values in the mu band in the resting state and during the operation, by one sample t-test (**Figure 3.5**). As a result, there are significant differences (t (17) = -3.30; p = 0.004 in TUI / CAN at RC, t (17) = -2.50; p = 0.023 in TUI / CAN at LC, t (17) = -2.32; p = 0.033 in TUI / OBJECT at LC, t (17) = -2.79; p = 0.013 in TUI/OBJECT at RC). In contrast, in the GUI condition and the ACTION condition, no brain area showed a significant difference. Based on the data from the resting state and the data from the operation, mu rhythm suppression was determined for LC and RC in different conditions (TUI condition, CAN condition, GUI condition, and ACTION condition; **Figure 3.5**).

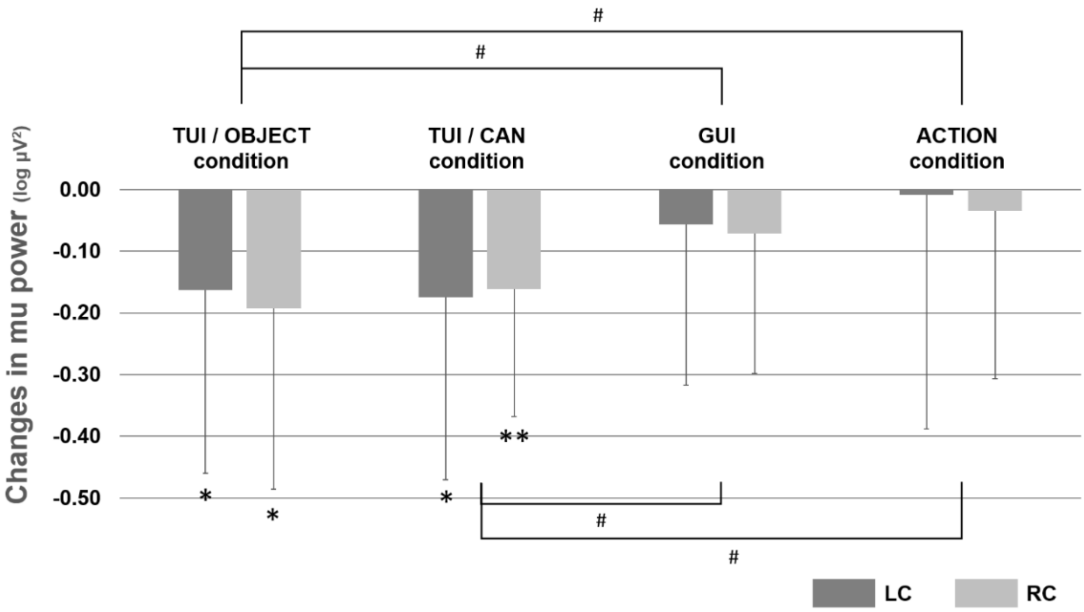


Figure 3.5 Changes in mu power:
Mu rhythm suppression (LC and RC) in different conditions in Experiment 3. Asterisks (**p* < 0.05, ***p* < 0.01) mean the significant mu rhythm suppression from baseline to observation of each actions. Sharps ($^{\#}p$ < 0.05) mean the significant difference between conditions.

Then, the main effect between conditions (the TUI / OBJECT condition, the TUI / CAN condition, the GUI condition, and the ACTION condition) and between brain areas (LC and RC) were tested by two-way rm-ANOVA. In rm-ANOVA, the sphericity assumption was violated; to account for this violation, degrees of freedom were Greenhouse - Geisser adjusted. The ANOVA revealed a main effect of condition (F (2.3, 39.12) = 6.572; p = 0.002; $\eta_p^2 = 0.279$). By t-test, it was shown that the TUI / OBJ condition and the TUI / CAN condition resulted in a significant suppression in comparison with the GUI condition and the ACTION condition (t (17) = 3.66; p = 0.012 in TUI / OBJECT vs GUI, t (17) = 3.65; p = 0.012 in TUI/OBJECT vs ACTION, t (17) = 3.12; p = 0.019 in TUI / CAN vs GUI, t (17) = 2.74; p = 0.042 in TUI / CAN vs ACTION).

3.4 Discussion

In Experiment 2, we found that the brain activity in the observer varied depending on the type of UI (**Figure 3.4**). In the TUI / CAN condition, watching the UI operation resulted in an elevated activity in RC in the observer in comparison with the resting state. This is consistent with the report that watching the action of others results in mu rhythm suppression in the somatosensory cortex, which roughly corresponds to RC (Pineda, 2005; Oberman, Pineda, & Ramachandran, 2007). Therefore, it is suggested that the brain activity was induced in this MNS-related brain area. Among brain areas, only RC showed the activity in this experiment. We suppose this was because the user action took place in the left hemifields of the observer (Shmuelof & Zohary, 2005) rather than the observer imagined imitating the right hand action of the operator as a result of watching it. This activity tended to be higher in the TUI / CAN condition in comparison with the TUI / OBJECT condition and the GUI condition, indicating that it was characteristic of the TUI / CAN condition. The MNS activity reflects the immediate goal of an action (Iacoboni, 2005). Thus we had expected mu rhythm to be suppressed in the TUI / OBJECT condition, but found the suppression only in the TUI / CAN condition. It has been reported that the observation of a highly unfamiliar action results in an elevated activity in the motor cortex (Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008; Van Elk, Van Schie, Zwaan, & Bekkering, 2010). In the TUI / CAN condition in the present study, the action results were not predictable from the appearance of the corresponding model, which is not seen in ordinary UIs. We suppose this caused the elevated activity in the sensorimotor area.

On the other hand, the response of the observer did not seem to differ between the TUI / OBJECT condition and the GUI condition, in spite of the presence / absence of the grasping. In this experiment, any of the two conditions did not even show activation in the same brain area, indicating that they did not activate the MNS. It has been reported that the observation of a familiar task results in a lower activity in the inferior frontal gyrus and the premotor cortex in comparison with an unfamiliar task (Vogt et al., 2007), and that repeated grasping of the same object leads to weaker mu rhythm suppression (Perry & Bentin, 2009). We suppose that the repeated monotonous stimulus presentation in the present study hindered the effect of the grasping action from being detected.

In Experiment 3, we found that the brain activity in the operator also varied depending on the type of UI (**Figure 3.5**). Areas around the somatosensory cortex were active in the TUI / OBJECT condition and the TUI / CAN condition, suggesting the possible induction of a brain activity related to the brain activity seen in Experiment 2 (Oberman, Pineda, et al., 2007; Pineda, 2005). The brain areas that were active in this experiment included not only LC, an area activated by performing a right hand action, but also RC. The visual information of each user action was presented primarily in the left hemifields, whereas the visual information of the output as the result of the action was presented primarily in the right hemifields. Processing of such visual information possibly had some effect (Shmuelof & Zohary, 2005). These activities tended to be higher in the TUI / OBJECT condition in comparison with the GUI condition and the ACTION condition. The TUI / OBJECT condition and the GUI condition differed in that only the former involved the grasping action. In an fMRI study, the action of reaching for an object and grasping it and the action of only reaching for that object differed in that the former resulted in an elevated activity in the anterior intraparietal sulcus (aIPS; (Frey, Vinton, Norlund, & Grafton, 2005)). In our experiment, the aIPS activity due to grasping probably had an effect on the sensorimotor area. The TUI / OBJECT condition and the ACTION condition involved the same user action, and only differed in that the former displayed a porcelain picture on the screen as the result of each action. The elevated activity in LC and RC in the TUI / OBJECT condition, in comparison with the ACTION condition, suggests that the visual output as the result of each action had some effect on the activity of sensorimotor area.

Similar results were also obtained in the TUI / CAN condition, except that RC showed a particularly pronounced activity in the TUI / CAN condition, as seen in Experiment 2. It is possible that the unpredictability of the result of each action enhanced the observer's attention (Beilock et al., 2008; Van Elk et al., 2010).

In the present study, we showed that MNS in the observer was more active in the TUI / CAN condition than in the GUI condition: i.e., the effect of TUI on its observers was demonstrated based on the brain activity.
We had also expected to detect the effect of the grasping action (Fitzmaurice, 1996) as an MNS activity in the TUI / OBJECT condition, in comparison with the GUI condition. However, we did not obtain such a result in the present study. One possibility is that the observer recognized the TUI as UI from the movement of the objects, but failed to pay attention to the action of "grasping" the objects. On the other hand, in the TUI / CAN condition, the unpredictability of the result of each action seemed to affect the MNS-related brain activity. We suppose that the factor of unfamiliarity attracted the attention and interest of the observer.
However, the brain activity in the operator did not show a difference between the TUI / CAN condition and the TUI / OBJECT condition. These conditions involved the same action as the ACTION condition, but activated the brain activity in the somatosensory cortex because they were provided with a screen to output the results. In comparison with the GUI condition, the TUI / CAN condition and the TUI / OBJECT condition resulted in an elevated activity in the same brain area because they involved the "grasping" action.
It is suggested that the same brain activity defined by mu rhythm suppression in this area is activated in the observer not only by a hand action but also by the addition of an unpredictable nature to UI, reflecting the degree of interest.
Altoghther, the brain activities observed as the mu rhythm suppression in the present study were activated by the combination of UI function, grasping action, and interest in UI. Therefore, it was suggested that the mu rhythm suppression in LC and RC could be used as an index in the evaluation of "grasping" action-based TUIs.

· Limitation

In this research, we focused on TUI, but the structure of UI has been simplified and limited to the elements of "grasp and move things" in order to verify relationships with MNS.
For this reason, it was an interface that almost never provided pleasure during operations, which is one of the advantages of the original tangible user interface.
It is not easy to control the pleasure offered to participants to the same extent, but devices to evaluate without losing important elements have become future tasks.
Also, as in this experiment, when conducting experiments involving oneself with others, it is conceivable to show different trends depending on personality characteristics (e.g. a desire for recognition from others, and so on). In the experiments under such circumstances, it is also necessary to consider the influence of personality characteristics.

Chapter 4
Effects of the Display Angle in Museums on User's Cognition, Behavior, and Subjective Responses

4.1 Introduction

There is a growing interest in setting up large interactive displays at public spaces such as museums and public institutions. In recent years, the design of such displays has not been limited to flat rectangular ones set up vertically, but now various types such as round and three-dimensional displays are being developed. Kuikkaniemi et al. (2011) state that in the present day, when the place for self-expression and interaction with others is shifting from the urban space to the digital space, display technology is a promising method to return the interactive and social experience back to the urban space.

However, few researchers have devoted much attention to understanding how physical affordances of these displays affect human perception and thought. As such, design principles have been uniformly applied across a variety of display devices that offer different cognitive and social affordances. While spaces with interactive displays are expected to increase further in future, there is a need to define how these types of spaces appear to people and in what way they are used by people.

The main factors related to the display use are the physical display size, display shape, display angle, number of displays, number of users, and user position. It is important to clarify the impact of each of these individual factors. Especially in relation to the display angle, not only vertical but also horizontal or tilted displays are becoming common. Inkpen et al. (2005) propose several display factors and put them under scrutiny in an experiment with systematic variations. One of the display factors is the "display angle" which "has strong impact on user interaction" (Inkpen et al., 2005, page 2). A few researchers have studied vertical and horizontal displays and the impact of the display angle on the group's collaborative study (Forlines, Shen, Wigdor, & Balakrishnan, 2006; Inkpen et al., 2005; Rogers & Lindley, 2004); however, these studies did not statistically quantify effects of display angle in their users. In addition, there is almost no understanding of the effect of tilted displays—displays installed at angles other than vertical or horizontal.

In this study, we test the impact of the angle—vertical, horizontal, or tilted—of a large interactive display on the cognition, behavior, and subjective responses of a single user in the context of a museum, which is considered as a representative of a public space.

・Related work

The effects of display factors such as the physical display size, display shape, display angle, number of displays (Forlines et al., 2006; Inkpen et al., 2005), display arrangement (Inkpen et al., 2005; Wallace, Mandryk, & Inkpen, 2008; Wigdor, Shen, Forlines, & Balakrishnan, 2006), number of users (Ryall, Forlines, Shen, & Morris, 2004), and user position (Hawkey, Kellar, Reilly, Whalen, & Inkpen, 2005; Inkpen et al., 2005) have been investigated. These studies have tested the impact of these attributes on the user's cognition, behavior, and subjective responses. This section briefly describes three of these factors, physical display size, display shape, and display angle in the context of the related literature.

Physical display size

Most studies on the effects of display size have made comparisons focusing on individual users. Some prior work (e.g., Tan, Gergle, Scupelli, & Pausch, 2006; Shigemasu et al., 2006; Bao & Gergle, 2009) show that the recognition of picture or image media depends on the display size. On the other hand, Ichino et al. (2012) showed that for text media, the physical display size did not affect an individual's reading comprehension.

Few studies have made comparisons focusing on the collaborative study performed by multiple users (Inkpen et al., 2005; Ryall et al., 2004). Ryall et al. (2004), in the collaborative task, showed that the display size did not affect the time for task completion.

Display shape

The impact of the display shape has been investigated only in a few studies, which compared non-planar and flat displays. Beyer et al. (2011) compared the behavior of users using cylindrical and flat displays and concluded that cylindrical displays are more suitable for interaction through gestures for people in motion. Bolton et al. (2012) investigated the impact of differences in shape with displays on information sharing between people. Comparison of spherical and flat displays in their study suggested that while spherical displays navigate an individual's own workspace, flat displays have affordances in relation to other people's workspace.

Display angle

Furthermore, there is insufficient research on the impact of display angles. The published studies have mainly considered only two orientations, vertical and horizontal, and have tested only the impact of display angle on collaborative study by multiple users.

Rogers et al. (2004) conducted such a study and compared large vertical and horizontal displays to investigate the impact on collaborative study in groups. They found that horizontal screens contributed to role switching and idea generation more than vertical screens and that horizontal screens increased users' awareness of others. Inkpen et al. (2005) compared medium-sized (33 inch) vertical displays with horizontal displays and investigated their impact on collaborative study in groups. Based on observation and subjective evaluation, they speculated that vertical displays are more suited to brief focused tasks, whereas horizontal displays are better suited for tasks that require active discussion over extended periods of time. Forlines et al. (2006) conducted visual searches using small desktop displays. They found that differences in the angle (horizontal or vertical) did not affect task-completion time or error rates. Potvin et al. (2012)compared non-digital horizontal and vertical whiteboard orientations used by dyads performing a collaborative design task while standing. They investigated how the display orientation influences group participation and found that vertical surfaces better support face-to-face contact whereas display orientation has little impact on equality of verbal and physical participation.

It is evident from the above summary that no studies investigated the impact of the angles of large displays on the performance and behavior of individuals. Moreover, the only angles investigated so far are vertical and horizontal; tilted angles have not been well studied.

・Research questions

With an increasing number of exhibitions in the DNP Museum Lab, we arrived at a hypothesis on whether there were differences in approach rate, dwell time, and the amount of time spent on interaction depending on the way displays, especially their angles, were set up. A vertical display allows for a holistic view when the observer is distant to the screen. In contrast, in a horizontal display an observer faces problems viewing content from the distance due to an increased acute-angled viewing perspective. Tilted displays could be providing better visibility to distant observers than fully horizontal displays.

Image exhibits in museums can be broadly divided into primary image material such as "video recordings" and "stored images" and secondary image material such as "explanatory images" and "guidance images" (National Council of University Museology Course of Japan, 2008). When planning the manner in which these image materials should be displayed, we must consider not only the content of the material but also the format of the material in order to realize the most appropriate way for communicating with exhibition visitors (The Japan Society for Exhibition Studies, 2010). When studying the form of image material, it is important to establish the desired effect in the communication with visitors without getting distracted by bewildering changes in imaging technology. Do we want people passing through to stop? Do we want people to wait and look closely? Do we want to explain this only to people who want to know about it in detail? By studying these kinds of approaches toward visitors, the criterion becomes clear for deciding the technical requirements for the parameters, such as visitor flow, dwell time, and visitor's viewing angle range. With this in mind, in this study, we posed the following five research questions regarding the effect of the display angle when exhibiting image material in a museum.

RQ1: *At what angle do displays easily attract attention (have a high visual attraction / visibility)?*
RQ2: *At what angle are displays easy to peruse?*
RQ3: *At what angle is it easy to understand / remember a display's content?*
RQ4: *At what angle is interaction (touching) with displays easy?*

RQ5: *How do visitors experience displays at different angles?*

Many visitors visit a museum with friends or family, but as people's individual pace and objectives vary, they often naturally disperse individually while viewing an exhibition and stand face to face with artificial objects. Therefore, we will leave the study of multiple users as an issue for the future, and concentrate on single users for this article.

4.2 Methods

[Experiment 4]

・User study design

To set up a situation in which museum visitors' viewing behavior is approximated as closely as possible, and to have participants conduct themselves as naturally as possible, we made the following four arrangements for this study. (1) We used roughly the same content on the displays as that in the above-mentioned DNP Museum Lab. (2) To divert participants' attention, we also provided benches and related books in addition to the exhibits using displays. (3) Before the start of the experiment, we stressed the following to the participants:" You do not need to look at all the materials in the room impartially, but please look at the things you like, as you would normally do when in an art gallery." (4) We did not inform the participants, until just before the questionnaires, that we would conduct tests relating to the exhibition contents at the end of the experiment.

Under these arrangements, and to test the five research questions, we conducted a laboratory experiment to compare user cognition, behavior, and subjective response using three types of interactive (single-touch enabled) displays, namely vertical, horizontal, and tilted displays.

Setup

We set up three displays under varying angle conditions in the center of a room (**Figure 4.1**). There were three angle conditions: vertical, horizontal, and tilted. We used the same model 40 LCD (SAMSUNG 400TS-3) for all three displays. The displays had a resolution of 1920 x 1080, a refresh rate of 60 Hz, and were set to have identical luminance and contrast.

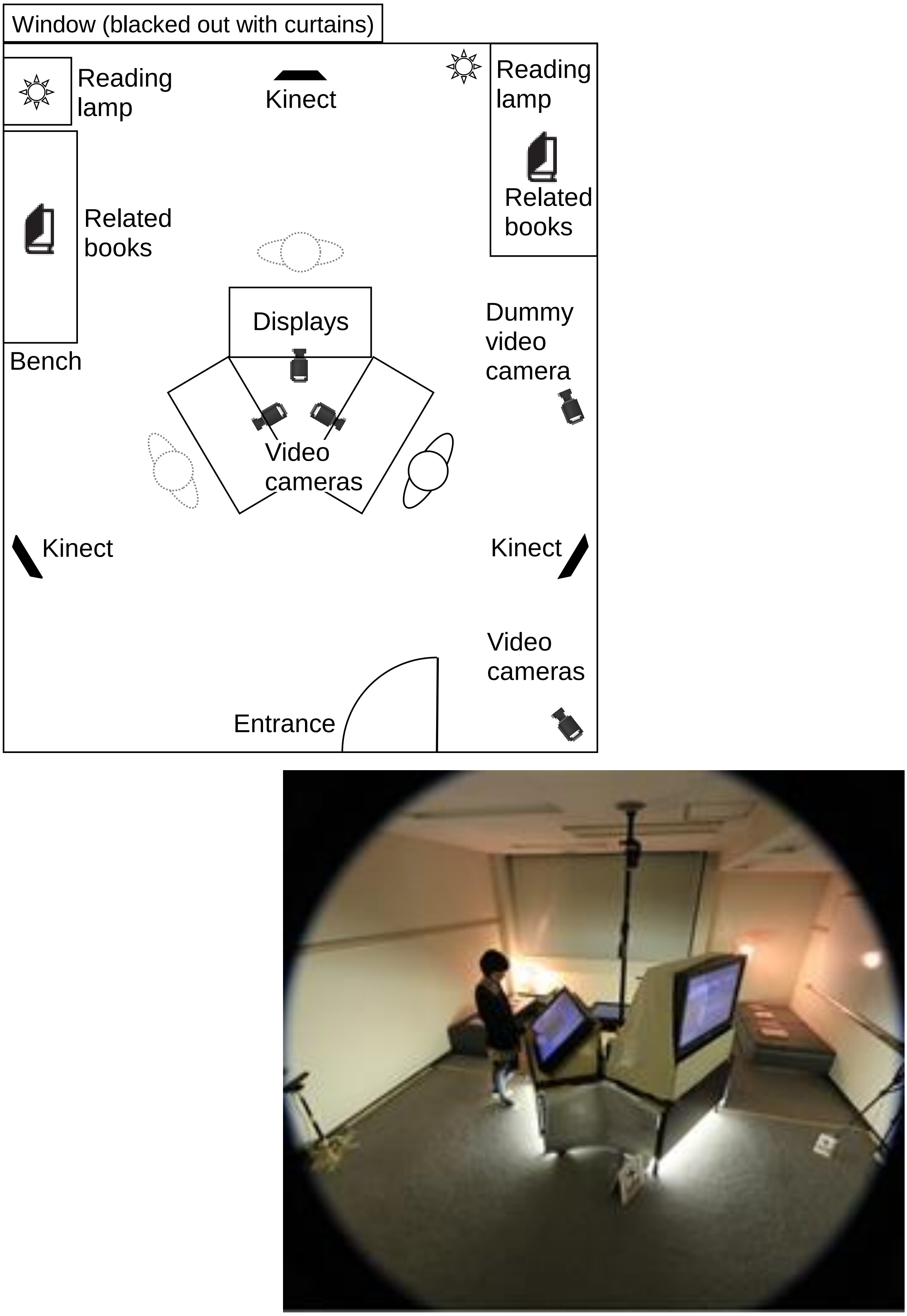
The tilted display was set at 45-degree angle to the ground. Tilted displays on display in general museums were set up at various angles, e.g. 15 or 60 degrees. We therefore considered identifying the angle most commonly used and employing that. However, for the first experiment, to examine tilted displays, we decided the use of the median value of 45 degrees to be rational.

The displays' height was set at the standardized height used for the display exhibits in the DNP Museum Lab (vertical display: 1050 mm, from floor to bottom of the display; horizontal display: 800 mm; tilted display: 800 mm). As we considered the possibility of the participant's height having an effect, we carefully discussed questions regarding the adjustment of display height for each participant. Because of the weight (33.6 kg) of the displays used in the experiment, they would, if their height was going to be adjusted for each participant, need to be installed in a reliably stable manner in consideration of the safety of each participant. When attempted, we found it both time consuming and labor intensive to do that. As we aimed for a laboratory experiment that resembled reality as closely as possible, we wanted to increase the number of participants as much as possible, and cover a wide variety of ages and occupations. Consequently, we chose to use the cost for adjusting display heights for each participant instead, in the form of participant remuneration, on increasing the number of participants. When we performed a statistical analysis of the data, we also performed an ANOVA analysis adding the height group of participants as a factor. However, the primary effect of the height factor was not significant. Generally, having too many factors in an ANOVA analysis is undesirable, so we decided not to include height factor in the final analysis.

We placed a bench in two corners of the room, and placed on both benches a number of books related to the content shown on the displays. This is, as previously mentioned, to avoid users' attention being focused solely on the displays. Even though it is a laboratory experiment, an environment that is as realistic as possible is created.

To track user behavior, we installed three Kinects and five video cameras. The three Kinects and three of the video cameras were placed so that user behavior around each display could be tracked. One of the remaining two video cameras was used to film the entire room, and the dummy camera was used to capture user behavior around the benches. The purpose of capturing behavior around the benches was to show to users that the acts of taking a break or browsing through books on the bench held equivalent value to that when looking at the displays.

To avoid difficulties in viewing the screens due to the reflection of the sun or room lighting, or reflection of the display of the user themselves, we hung blackout curtains in front of the windows and turned overhead lighting off. As that resulted in a very dark situation, we installed fluorescent tubes beneath the tables on which the displays were placed to provide indirect lighting and reading lamps next to the benches for the browsing of books.



Video camera filming the entire room

Figure 4.1 Experimental setup.

Participants

The ages, gender, occupations, etc. of people visiting galleries are diverse. Therefore, to approximate this as closely as possible, we recruited the participants from the general public for this experiment. A total of 42 members of the general public (20 female, 22 male) took part in the experiment. Unaided vision or corrected eyesight of 1.0 or above was a condition for participation. The average age was 34.0 years (the youngest and oldest was 18 and 57, respectively). The occupations of the participants varied, e.g., student, office worker, engineer, designer, musician, lawyer, translator, and architect. Participants were paid a fee for participation. They were divided into three age groups (young: 15–29, young middle age: 30–44, old middle age: 45–60). The number of participants in each group was 19 (9 female, 10 male), 12 (5 female, 7 male), and 11 (6 female, 5 male), respectively.

Materials

The materials for the study were two types of content shown on large displays, developed by the DNP Museum Lab. Both of these have been actually displayed in the Eighth Presentation by the project, "Offerings for Eternity in Ancient Egypt: a Question of Survival" (see http://www.museumlab.eu/exhibition/08/).

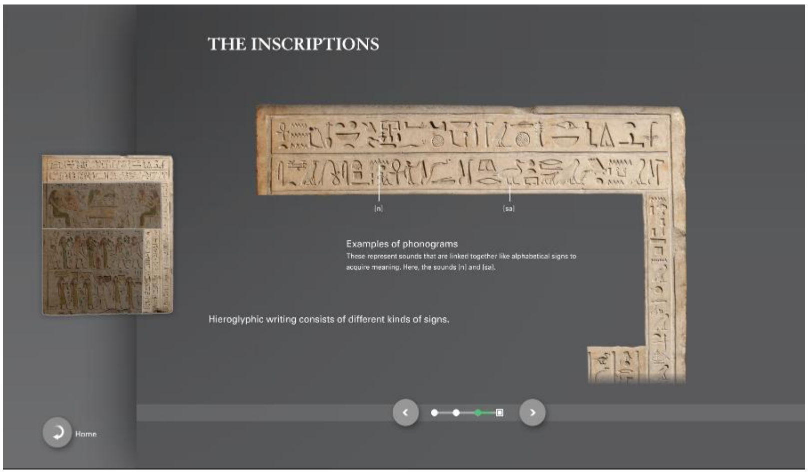
The first content, Stele, was developed to explain what was written on the stela (stone monument) for an individual known as Sakherty, who was a dignitary in the Egyptian royal family (**Figure 4.2**, left). The second one, Convention, was developed as introductory content, providing a key to the appreciation of Egyptian art (**Figure 4.2**, right). It describes in detail how Egyptian art was produced according to a number of rules, e.g., multi-aspect drawing, body-expression ratio, left–right symmetry.

We used these two sets of content for the experiment with a few revisions. As they were made up from multiple menus, we divided them into three content subsets and allocated the subsets to the three differently angled displays. The content was divided in such a way that the number of screens, images, characters in the explanatory texts, links, and animations were roughly the same for each subset.

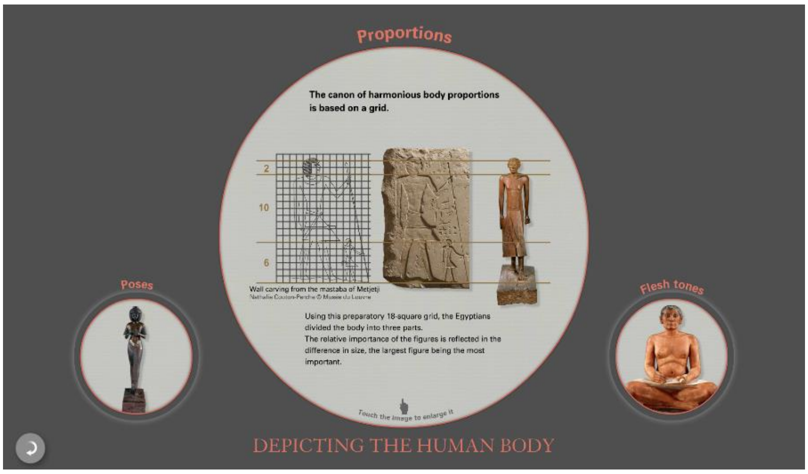
Procedure

We asked the participants to take part in two sessions, with a break in between the sessions. First, we explained the outline of the experiment. We told the participants that there was an exhibition space with several types of material relating to ancient Egyptian art. We asked them to walk around the exhibition space and, in the same way as they would normally do when visiting a gallery, go as they like and let themselves be guided by their interest. We did not tell participants about the concrete contents shown on the screens or the fact that they were touch enabled. We did tell them that nobody else would enter the space during the experiment, and that they were free to take a break and sit on a bench in the exhibition space if they got tired. We set one session spent in the exhibition space at 20 min. We used the Stele for one session and the Convention for another. After finishing the two sessions, we conducted a subjective evaluation questionnaire. Finally, we performed a recall test related to the contents shown on the displays. As a whole the experiment, it took up approximately 90 min.

Because the experiment was performed according to a within-participant design (all participants viewed displays under all angle conditions), we counterbalanced the set-up positions of displays under all angle conditions (on the right hand side on coming in through the entrance, on the left hand side, and on the back side) across participants. We also counterbalanced the contents/sessions combinations and content subsets/display angle condition combinations across participants.



Stele



Convention

Figure 4.2 Examples of content screens used in the two sessions.

・Data collection

Table 4.1 shows the collected data for this experiment for a comprehensive study of the five research questions given in the previous section on cognitive, behavioral, and subjective aspects.

Table 4.1 Data collected for this experiment.

	Cognition	Behavior	Subjective responses
RQ1		- Approach rate	- Subjective ratings (paired comparison method)
RQ2		- Total dwell time - Total walk time - Page arrival rate	- Subjective ratings (paired comparison method)
RQ3	- Recognition performance		- Subjective ratings (paired comparison method)
RQ4		- Touch frequency - Page arrival rate - Touch rate	- Subjective ratings (paired comparison method)
RQ5			- Subjective ratings (SD method, AttrakDiff) - Subjective ratings (Likert method, NASA-TLX)

Recognition performance

To test users' cognitive aspect regarding RQ3, we asked the users to indicate how much of the displayed content could they recollect. We created a recognition task that asked users to answer true or false questions related to the content shown on the displays. We compiled a total of 51 questions, of which 24 were related to the Stele content and 27 were related to the Convention content. All questions were set on full pages. Because we used multimedia content, we prepared two types of questionnaires: 1) questions that can be answered provided the respondent has read the content explanation (textual questions), and 2) questions that can be answered provided the respondent has looked at the images (graphical questions). We tested them in the laboratory beforehand and ensured that the overall ratio of correct answers was approximately 60%–70%.

Approach rate and touch rate

As one of the indices to test RQ1 on the user's behavioral aspect, we examined users' approach behavior immediately after entering the room in relation to the display closest to the exhibition space entrance (**Figure 4.1**, display on the front, right-hand side). Because we counterbalanced the set-up positions of displays under all angle conditions between participants, the display nearest the entrance varied depending on the user. When checking the video footage we rated cases where, immediately after entering the room, users stopped and looked at the nearest display, even for a few seconds, or stood and looked at it for a long time with a 1, and cases where they walked straight past while hardly looking with a 0.

To test RQ4 we examined touching behavior immediately after entering the room in relation to the display nearest the exhibition space entrance. In the same way, when checking the video footage, we gave a rating of 1 for the cases where, immediately after entering the room, the user stopped in front of the nearest display and interacted with it by touching the screen, and for the other cases we gave a rating of 0.

Total dwell time and total walk time

As one of the indices to test RQ2 on the user's behavioral aspect, we examined the user's total dwell (stoppage) time around the display and the total walking time around the display. We used RGB-D sensors (Kinect) for these measurements. The sensors were set up approximately 200 cm from each display (see **Figure 4.1**) and tracked users' behavior from the back. Using the sensor data , we obtained coordinate values for the user's center of gravity, and considered the cases where movements between frames exceeded a fixed value to be 'walk' time, while the cases where they were below a fixed value to be 'dwell' time.

Touch frequency and page arrival rate

As another index to test RQ4 on the user's behavioral aspect, we used the amount of content manipulation. We measured touch frequency and page arrival rate using an operation log acquisition program embedded in each content set.

Subjective ratings

To test users' subjective aspects for all research questions, we introduced three types of subjective evaluation questionnaires, namely, the paired comparison method, AttrakDiff, see http://www.attrakdiff.de/ (see **Appendix A**), and NASA-TLX.

We prepared a total of 22 questions related to RQ1–RQ4 (see **Figure 4.7**), and evaluated them using Thurstone's method of paired comparison. In the paired comparison method, multiple comparison participants are rated in pairs (two by two), and are assessed on the basis of their characteristics, i.e., superior/inferior, like/dislike, and large/small. Because these are simple judgments, its advantages are that 1) they are easy as well as highly reproducible and 2) they can discern subtle differences. The paired comparison combinations for the three display angle conditions are ${}_3C_2=3$ varieties. The participants carried out three types of comparisons for each question.

RQ5 is evaluated from the perspectives of both the attractiveness (AttrakDiff, Hassenzahl, Burmester, & Koller) and mental workload (NASA-TLX) of the objects available for the user. We asked participants to evaluate the respective three Display Angle conditions using both criteria. AttrakDiff questionnaire consists of 28 items with bipolar adjective pairs (7-point semantic differential). AttrakDiff has four dimensions for evaluating the system. The dimensions are the pragmatic quality (PQ), the hedonic quality - identity (HQ-I) and stimulation (HQ-S) as well as the attractiveness (ATT). Each of four dimensions has seven items. The evaluation results were automatically generated after entering the results on the AttrakDiff website. The NASA-TLX questions consist of six items, and they were rated using the 10-point Likert scale.

4.3 Results

Recognition performance

To analyze the two types of content used in this experiment (Stele and Convention), we converted the raw scores for the 51 true or false questions into standard scores (Average value is 0, standard deviation is 1. In other words, when the score is higher than the average value, it is marked with a plus, and if it is lower, it is marked with a minus). The recognition performance for each Display Angle condition was set as the combined standard scores for all questions divided by the number of questions. We analyzed the recognition performance using a 3 × 2 × 2 × 3 four-way ANOVA: 3 (Display Angle: Vertical · Horizontal · Tilted) × 2 (Content: Stele · Convention) × 2 (Question Type: Textual · Graphical) × 3 (Age Group: Young · Young-middle-age · Old-middle-age). The Display Angle, Content, and Question Type are within-subject factors, and the Age Group is a between-subject factor.

The result showed that the main effect of the Display Angle was not significant (F (2, 78) = 0.048, p = 0.953). However, the main effect of the Age Group was significant (F (2, 39) = 3.917, p = 0.028). Because the Age Group × Display Angle interaction was significant (F (4, 78) = 3.026, p = 0.023), we carried out a post-hoc test (Tukey's HSD) between the three Display Angle conditions for each Age Group. This showed that for the Young age group, significant differences were observed for Vertical > Horizontal (p = 0.002), and Vertical > Tilted (p = 0.007). For the Young-middle-age group, significant differences could be seen for Tilted > Vertical (p = 0.003), and Tilted > Horizontal (p = 0.014). For the Old-middle-age group, a significant difference could be seen for Horizontal > Tilted (p = 0.016).

No interaction was also observed for the Display Angle × Question Type. Therefore, this suggests that for either text or image content shown on the displays, the angle of the display does not affect content recognition.

Other main effects or interactions were not significant as well. **Figure 4.3** shows the total averages and the Age Group averages for the Display Angle condition.

Approach rate and touch rate

In order to analyze these across the two content sets used in the experiment, similarly to the recognition performance analysis, we converted all users' raw scores (0 or 1) for the Display Angle condition nearest the entrance into standard scores for each content set. We set these standard scores as the approach rate and touch rate, and analyzed them using a 3 (Display Angle) x 2 (Content) x 3 (Age Group) three-way ANOVA. The result showed that, for both approach probability and touch probability, none of the main effects or the interactions for Display Angle, Content and Age Group were significant. **Figure 4.4** shows the averages for all participants and the averages by Age Group.

Total dwell time and total walk time

We obtained the standard scores for the overall dwell time and the overall walk time for all participants for each subset in a similar way. We analyzed these standard scores using a 3 (Display Angle) x 2 (Content) x 3 (Age Group) three-way ANOVA. The result showed that, for both dwell time and walk time, none of the main effects or the interactions for Display Angle, Content, and Age Group were significant. **Figure 4.5** shows the averages for all participants and the averages by Age Group.

Touch frequency and page arrival rate

For the touch frequency and the page arrival rate we also obtained the standard scores for all participants' raw scores for each content subset by using a three-way ANOVA. The result showed that, for both touch frequency and page arrival rate, none of the main effects or the interactions for Display Angle, Content, and Age Group were significant. **Figure 4.6** shows the averages for all participants and the averages by Age Group.

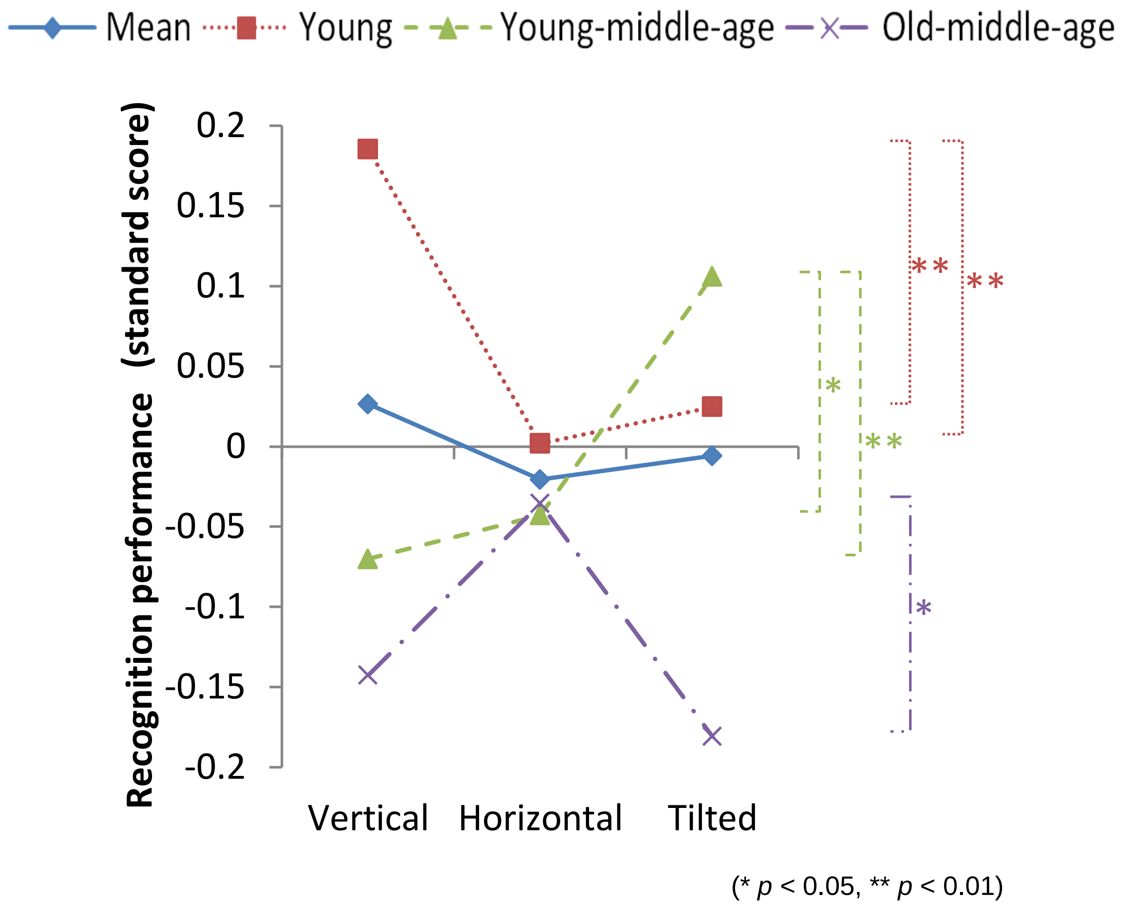


Figure 4.3 Recognition performance.

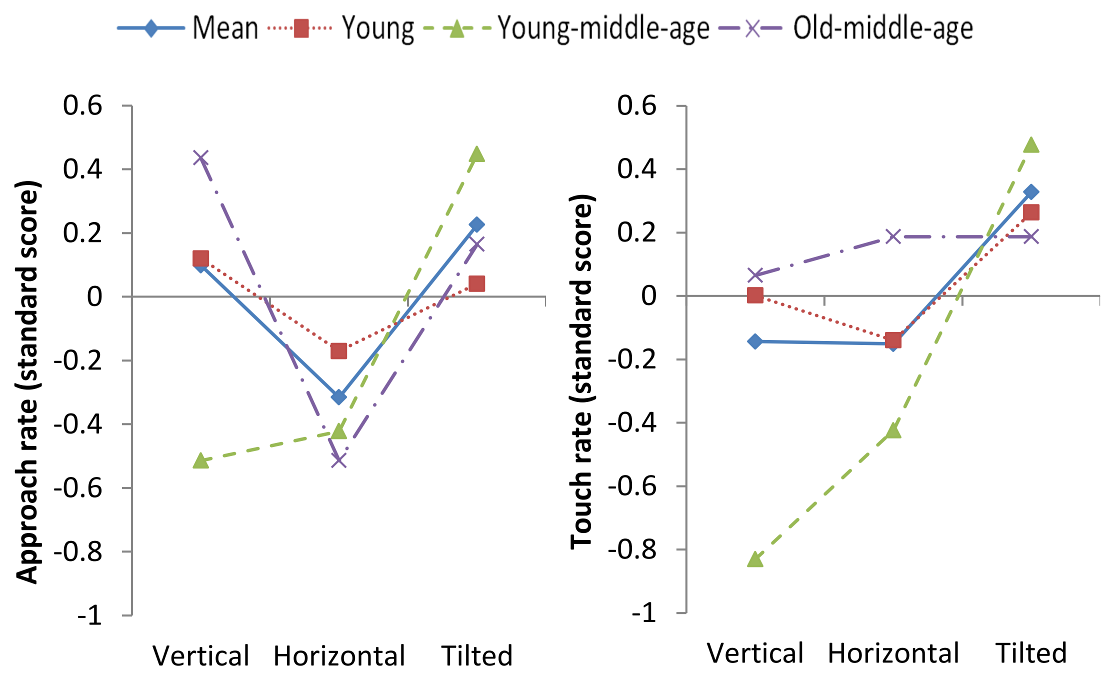


Figure 4.4 Approach rate and touch rate immediately after entering the room.

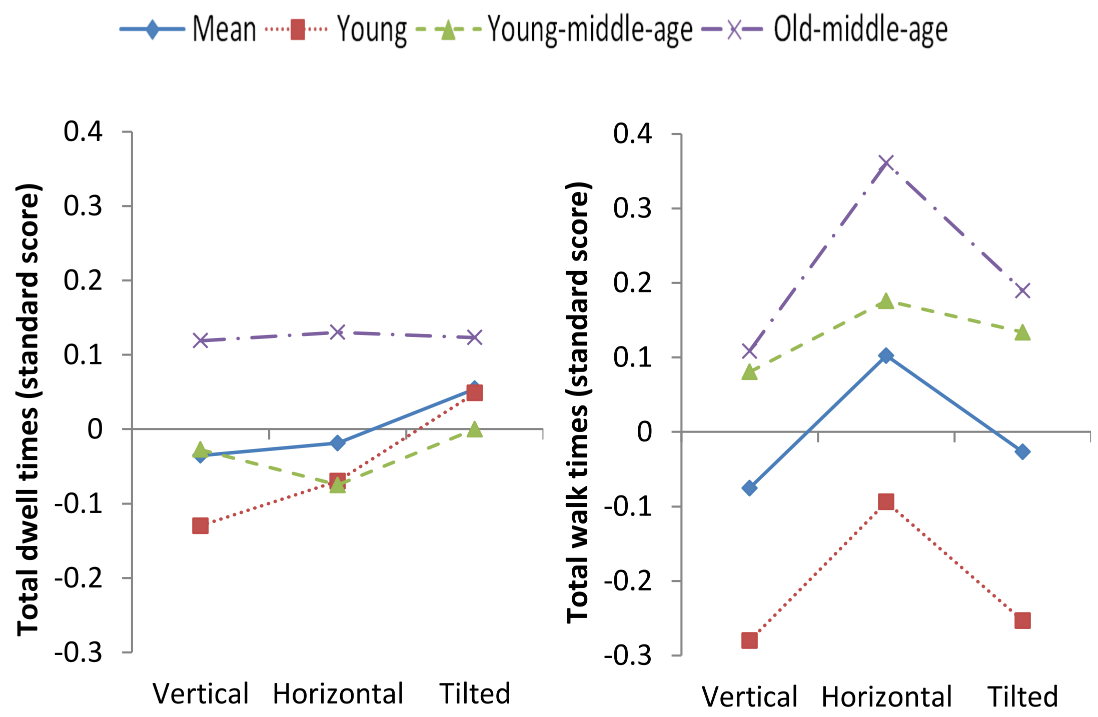


Figure 4.5 Total dwell times and total walk times.

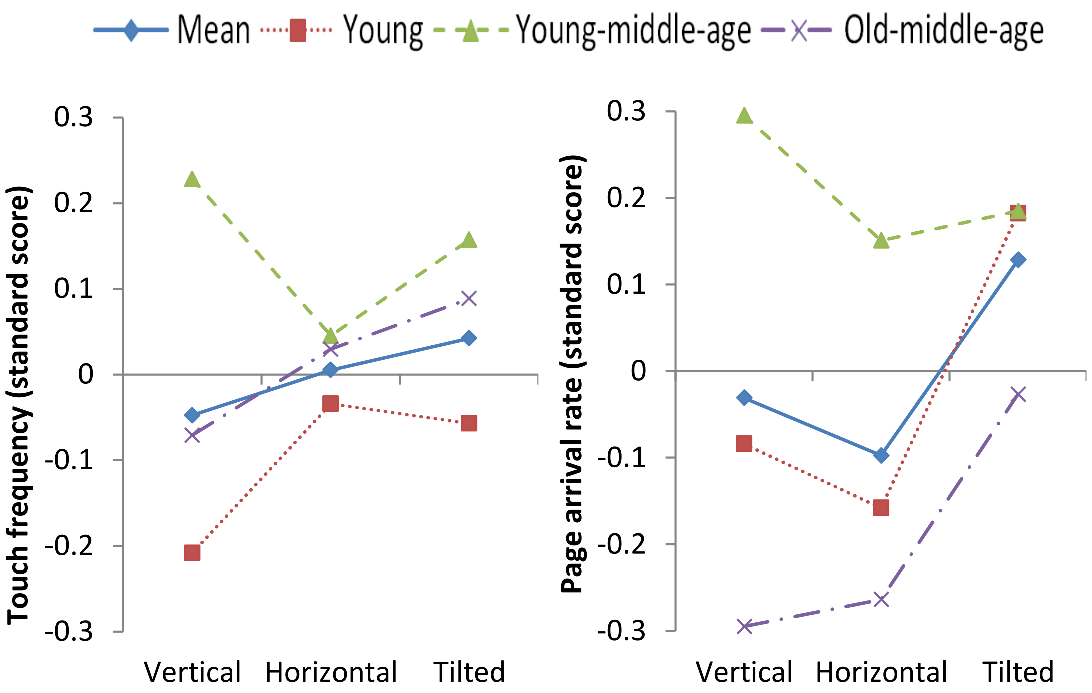
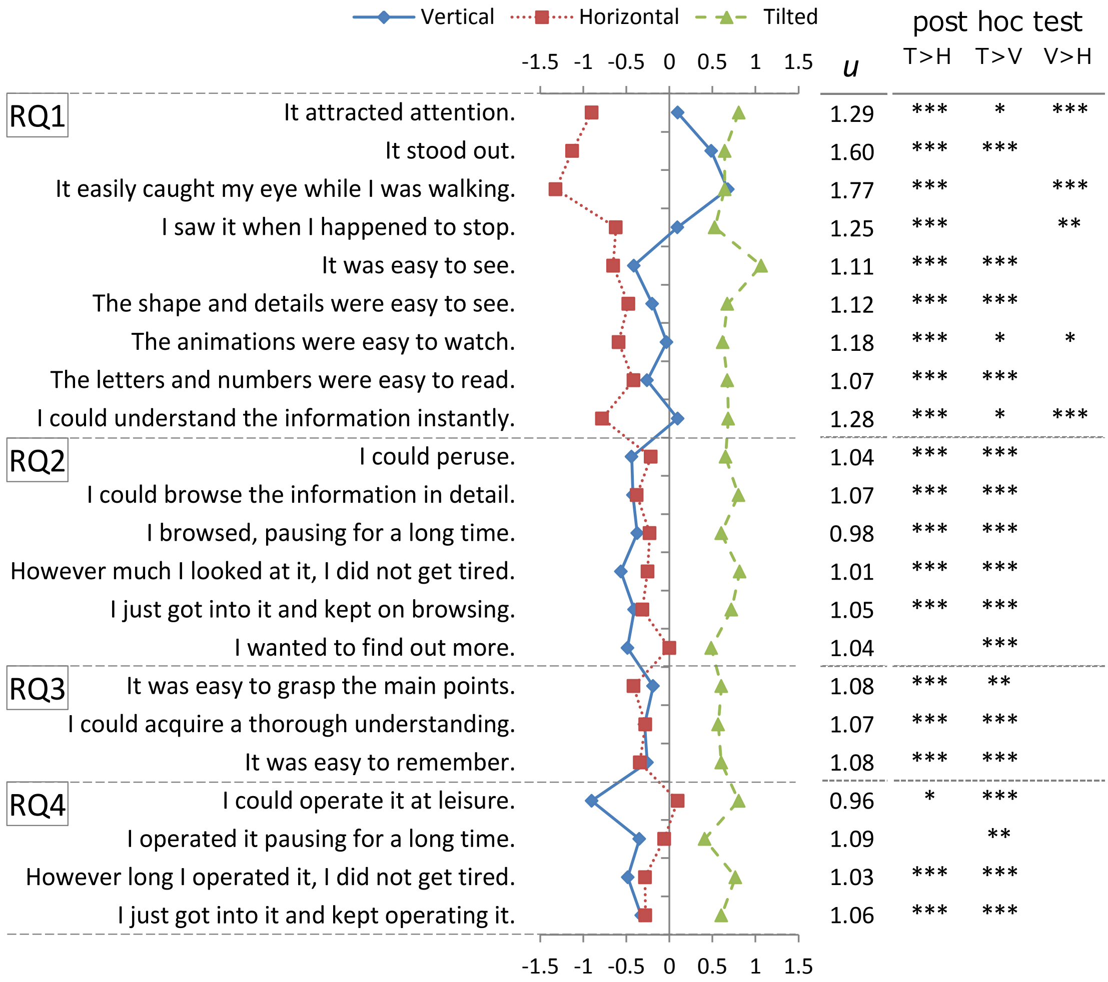


Figure 4.6 Touch frequency and page arrival rate.

Paired comparison
As mentioned previously, participants were asked to compare two display angle conditions three times for each questions related to RQ1-RQ4. The judgments made using Thurstone's method of paired comparison are evaluated according to the following procedure: (a) Kendall's (1975) coefficient of agreement u is obtained. When the judgments for n persons completely match each other, u is 1, when they are completely apart, u is almost 0. With (b) using (a), determine whether or not there is consistency in the judgment of respondents (chi-square test). (c) When consistency is observed in (b), the paired comparison ratio is converted into the standard score, and dimension values are obtained. (d) Test (chi-square test) whether or not the frequency for each Display Angle condition (the number of respondents that selected those conditions) varies. (e) Carry out a post hoc test (Ryan's method) between the three Display Angle conditions for which the frequency in (d) was judged to have been significantly different.

The analysis results indicated that consistency among respondents was obtained statistically for all 22 questions, (b). We performed a post hoc test (Ryan's method), (e), because for all questions, the Chi-square test showed statistically significant difference in the frequency among the three Display Angle conditions, (d). **Figure 4.7** shows the dimension values for each Display Angle condition, (c), Kendall's coefficient agreement u, (a), and the results of the post hoc test, (e).

We found that for majority of items, there were significant differences for Tilted > Horizontal and Tilted > Vertical. With regards to questions for R2 and R3, the values for Horizontal and Vertical were approximately the same.



(V: Vertical, H: Horizontal, T: Tilted, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

Figure 4.7 Dimension values for the 22 questions used for Thurstone's method (the higher the value, the higher the rating).

AttrakDiff

Figure 4.8 shows some of the evaluation results that were generated automatically on the AttrakDiff website. This graph shows the average values for the PQ and HQ dimensions together with their certainty factors. From the graph, it is clear that although Vertical, Horizontal, and Tilted are all evaluated as 'neutral,' the evaluation values for Tilted are high when compared to the others.

Figure 4.8 Portfolio generated on the AttrakDiff website.

We further analyzed the values obtained in the questionnaires using a one-way ANOVA with the Display Angle as a factor. The result showed that out of the four AttrakDiff dimensions, the display angle had the main effect on HQ-I, HQ-S, and ATT dimensions, i.e., HQ-I: F (2, 82) = 12.655, $p < 0.001$; HQ-S: F (2, 82) = 7.541, $p = 0.001$; ATT: F (2, 82) = 18.068, $p < 0.001$. We carried out a post hoc test (Tukey's HSD) for the three dimensions for which the main effect was significant. The result showed that for all three dimensions, the participants rated Tilted significantly higher than Vertical (HQ-I: $p < 0.001$; HQ-S: $p < 0.001$; ATT: $p < 0.001$); furthermore, that for HQ-I and ATT, the participants also rated Tilted significantly higher than Horizontal (HQ-I: $p < 0.001$; ATT: $p < 0.001$). **Figure 4.9** shows the average values for AttrakDiff for the four dimensions.

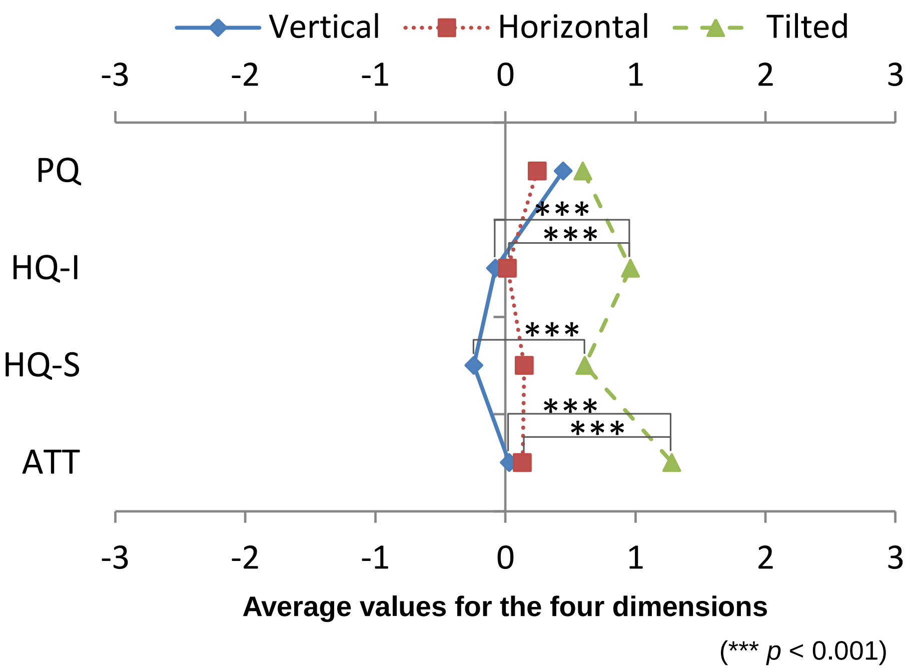


Figure 4.9 Average values for the four dimensions obtained from the AttrakDiff questionnaires (the higher the value, the higher the rating). The dimensions are the pragmatic quality (PQ), the hedonic quality - identity (HQ-I), the hedonic quality - stimulation (HQ-S) and the attractiveness (ATT).

NASA-TLX

We analyzed the values obtained in the questionnaire using a one-way ANOVA with the display angle as a factor. The result showed that with the exception of 'effort,' for five out of six NASA-TLX items, the display angle had the main effect (mental demand: F (2, 82) = 3.490, $p = 0.035$; physical demand: F (2, 82) = 14.860, $p < 0.001$; temporal demand: F (2, 82) = 9.229, $p = 0.0002$; performance: F (2, 82) = 6.110, $p = 0.003$; frustration: F (2, 82) = 14.087, $p < 0.001$). The result of the post hoc test (Tukey's HSD) for the five items for which the main effect was significant showed that for four items, the participants' mental workload was significantly higher for Vertical than for Tilted (physical demand: $p < 0.001$, temporal demand: $p = 0.007$, performance: $p = 0.018$, frustration: $p < 0.001$), for two items, the mental workload was significantly higher for Horizontal than for Tilted (physical demand: p = 0.004; frustration: p = 0.027), and for one item, the mental workload was significantly higher for Vertical than for Horizontal (temporal demand: p = 0.023). **Figure 4.10** shows the ratings for each item.

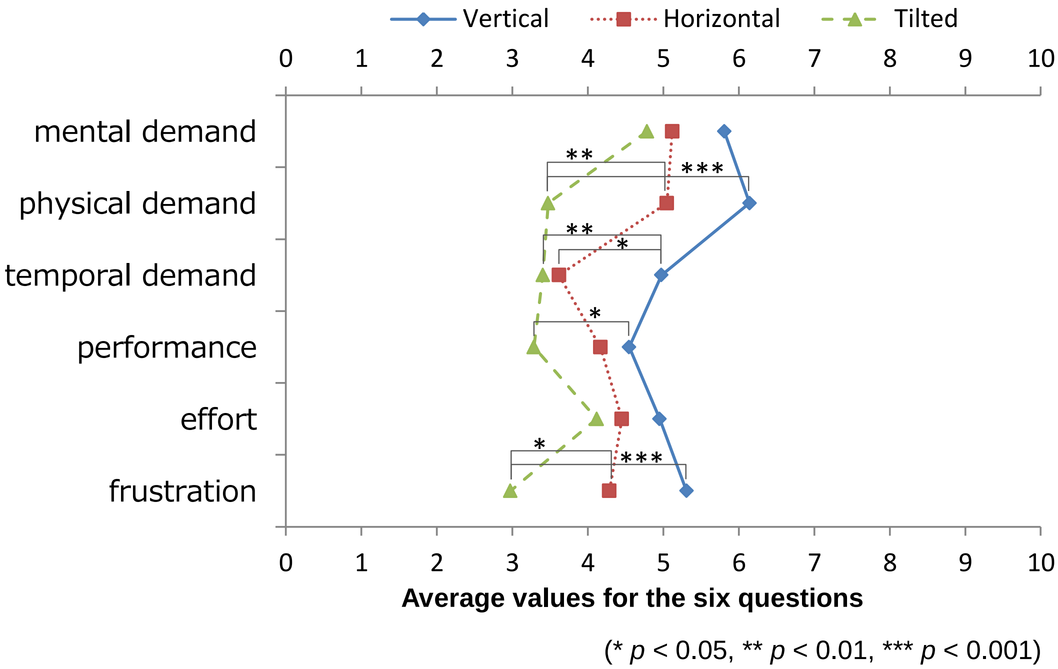


Figure 4.10 Average values for the six questions obtained with the NASA-TLX questionnaire (the higher the score, the higher the mental workload).

4.4 Discussion

The results of this experiment are summarized in **Table 4.2**. These are based on the average values for all participants represented by the blue line in **Figure 4.3-Figure 4.6**, and **Figure 4.7-Figure 4.10**. Because **Figure 4.10** is for a negative questionnaire, evaluation results and inequalities are reversed.

Table 4.2 Summary of study results.

	Cognition		Behavior		Subjective responses	
RQ1			Approach rate	n.s. (T＞V＞H)	Subjective ratings	T＞V＞H
RQ2			Total dwell time Total walk time Page arrival rate	n.s. (T＞V≧ H) n.s. (H＞T＞V) n.s. (T＞V＞H)	Subjective ratings	T＞H ≧ V
RQ3	Recognition performance Overall: Young: Young-middle: Old-middle:	 n.s. (V＞T ≧ H) V＞T ≧H T＞H ≧V H＞V＞T			Subjective ratings	T＞V ≧ H
RQ4			Touch frequency Page arrival rate Touch rate	n.s. (T＞H＞V) n.s. (T＞V＞H) n.s. (T＞V ≧H)	Subjective ratings	T＞H＞V
RQ5					Subjective ratings Attractiveness Mental workload	 T＞H ≧ V T＞H＞V

V: Vertical, H: Horizontal, T: Tilted

Underlined inequalities contain pairs for which significant differences were seen in the post-hoc tests.

Angles at which displays easily attract attention

For RQ1 it was clear from the subjective ratings that tilted displays attracted users' attention most easily and that horizontal displays were the least likely to attract attention. A similar tendency was observed in the approach rate immediately after entering the room as well, although there was no significant difference. These results suggest that, for example, when showing the overall concept of a specific part of the exhibition story, it is appropriate to set up tilted displays for showing information that one wants most visitors to stop at and look over. It can further be assumed that by placing tilted displays at key points it becomes easier to guide the flow of visitors.

Additionally, it can be seen that not only tilted displays but vertical displays also easily attracted attention. For the third statement from the top in **Figure 4.7**, 'it easily caught my eye while I was walking', vertical displays were rated more highly than tilted ones. In addition, for Young and Old-middle-age users, approach rates immediately after entering the room were higher, even if only a little, for vertical than for tilted displays. Because visitors who are walking while looking in the direction they are going can spot them without looking down, we can assume that vertical screens are effective in spaces where one does not want visitors to dwell a long time.

Angles at which displays are easy to peruse

For RQ2 it became clear, based on the subjective ratings that tilted displays were the easiest for users to peruse. The ratings for horizontal and vertical displays were not much different from each other. The dwell time and page arrival rate would seem to have similar patterns, though no significant difference was found. These results suggested that it is appropriate to set up tilted displays when presenting information that one wants those people who have an interest to spend time and peruse. In other words, when setting up tilted displays one can expect visitors to dwell there for a long time. Because tilted displays have the effect of easily attracting most people's attention and making them stay for a long time, this needs to be given sufficient consideration when designing for the flow of visitors.

However, in the informal interviews that we held after the experiment we recorded the following comments in relation to RQ2, suggesting that horizontal displays have a special quality that is different from tilted displays: 'I could look at the tilted display without any hurry, but I felt like the content of the horizontal display penetrated more deeply', 'The tilted display was the easiest to look at, but once I started looking at it the easiest to concentrate on was the horizontal display', 'When looking at the horizontal screen I felt like actively investigating something.'. From them we can assume that there is a possibility that horizontal displays encourage users to select egocentric navigation strategies (Hart & Moore, 1973). This needs to be investigated separately.

For walk time results differed from subjective ratings, dwell time and page arrival rate, and walk times around the horizontal display were the longest. It can be supposed that the main cause for this is that with horizontal displays the screen can be seen and touched from the side. Based on this, it is desirable to leave plenty of space around horizontal displays.

Angle at which is it easy to understand/remember a display's content

In regards to RQ3, results for user cognition and subjective responses did not match. When testing the subjective aspect, tilted displays were, similarly to the other research questions, judged to be the easiest to understand/remember the content of. However, when testing the cognitive aspect, tendencies differed according to age, and it was found that results were different among the age group – information shown on displays was most easily understood / remembered by the Young on vertical displays, by the Young-middle-age group on tilted displays and by the Old-middle age on horizontal displays. If it is possible to limit, to a certain extent, the targeted age group for a planned exhibition space, a space can be designed with these results as a reference. For example, when planning an exhibition that targets high school students for educational purposes, the use of vertical displays would be effective.

Moreover, the difference of media between text and image composing the content had no affect recognition performance. This suggests that, when designing for content aimed at user's comprehension, there is no need consideration with separate media for text and image.

Angle at which touch interaction with displays is easy

For RQ4 it became clear from subjective ratings that tilted displays were the easiest for users to interact with. Similar results were obtained for touch frequency and page arrival rate, although there was no significant difference. Ratings for horizontal and vertical displays differed depending on the evaluation item. These results suggest that when showing image material with a high degree of interaction, tilted displays are appropriate.

Comments recorded in the informal interviews also supported the effectiveness of tilted displays: 'I had to keep my arm up the whole time when operating the vertical display, which was tiring,' 'Because I had to lean over the horizontal display to be able to operate it, my back started hurting.' It can be inferred that when vertical and horizontal displays are touch-enabled, they are not ideal from an ergonomic point of view.

Angles that impart a favorable impression

For RQ5 it was clear from the two types of subjective ratings that users' preferred Display Angle was tilted, horizontal, and vertical, in that order. This is consistent with earlier results (Müller-Tomfelde, Wessels, & Schremmer, 2008). In the results for the evaluation items that queried the degree of the object's attractiveness, tilted displays were much more attractive for the user than horizontal or vertical displays, while horizontal and vertical displays were rated roughly the same. Results for the evaluation items that queried the degree of mental workload showed that the mental workload on the user was lowest for tilted displays and highest for vertical displays. Based on these results we can consider tilted displays to be the most appropriate when the objective is to offer an experience that is highly entertaining to visitors.

Relation between touch interaction and learning effect

We will now analyze the results of recognition performance and operation. It was clear that, despite low touch frequency and page arrival rate values in the Young age group for the Vertical condition, recognition performance was significantly higher than for Horizontal and Tilted. For the Young-middle-age group recognition performance was significantly low for Vertical, in spite of the fact that touch frequency and page arrival rate values were highest for Vertical. For the Old-middle-age group recognition performance was lowest for Tilted in spite of the fact that that touch frequency and page arrival rate values were highest for Tilted. These results suggest the possibility that recognition performance, in other words learning effect, drops when the degree of interaction is high. As this is an important implication with regard to interactive display characteristics further investigation is needed in the future.

The results showed that a significant difference could be discerned in regards to cognitive and subjective aspects.

Test results for the cognitive aspect showed that the display angle on which the displayed content was easy to understand and remember differed depending on age. Although we have not confirmed from this survey, one of the possible causes may depend on previous experiences in their lives. By surveying the usage frequency of the smartphone and experience of the large touch panel, it may show different trends by age in the present study.

Test results for the subjective responses showed that users gave high evaluation to the tilted display irrespective of age in almost all aspects. One of the reasons for this results may be that the impression of a physical load may also affect other evaluations as the informal interview response (see previous section for RQ4) or the physical demand by NASA-TLX show (**Figure 4.10**). The degrees of the influence among each factors should be investigated in the future.

The findings acquired in this study is not limited to museum exhibitions, but can also be used when setting up large displays and showing multimedia content in public spaces such as educational or public institutions.

· Limitation

The three future issues for this study are as follows. The first issue involves improving the number and quality of the samples. There were many items in this experiment where cognition and behavior showed different results according to age group. In order to develop more comprehensive guidelines that can deal with the real world, investigations are needed that look at large numbers of users of a wide variety.

The second issue involves the investigation of the effect the display angle has on cognition, behavior and subjective responses when multiple users are targeted. Situations where displays set up in public spaces are experienced with friends or family are expected to increase in the future. Some papers (Inkpen et al., 2005; Rogers & Lindley, 2004) have shown that horizontal displays encourage cooperation more than vertical displays in situations where multiple users use a display collaboratively. Quantitative investigations are needed that also include tilted displays.

The third issue involves fieldwork. This experiment was a laboratory experiment testing users under controlled conditions, but there is a possibility that users' behavior in an actual gallery will differ from these experiment results (Hornecker & Nicol, 2012).

Chapter 5
Effects of the Display Angle on Social Behaviors of the People around the Display: A Field Study at a Museum

5.1 Introduction

Displays deployed in public spaces such as museums, train stations, airports and shopping malls have not only increased in number at an accelerated pace, but have also become significantly diversified in their styles, (e.g., Beyer et al., 2011; Bolton et al., 2012; Ten Koppel, Bailly, Müller, & Walter, 2012). In the present day, when the place for self-expression and interaction with others is shifting from the urban space to the digital space (e.g., Facebook, Twitter), display technology is a promising method to return the interactive and social experience back to the urban space (Kuikkaniemi et al., 2011) When designing a public display, it is necessary to understand the cognitive and social affordances of the display, i.e., to understand how people around a display may interpret content on the display, behave in front of the display, and change their behavior when other people are around.

Researchers in human-computer interaction have been actively pursuing issues related to the cognitive and social affordances of the display in recent years, (e.g., Ten Koppel et al., 2012; Müller, Walter, Bailly, Nischt, & Alt, 2012; Akpan, Marshall, Bird, & Harrison, 2013; Schmidt, Müller, & Bailly, 2013). The main factors related to the display use are the physical display size, display shape, display angle, number of displays, display configuration, number of users, user arrangements, and so on. Among these factors, we focus on the angle of the flat and touch type display. Although we regularly see different types of displays in our daily life, the type of display most widely deployed in public spaces is the flat and touch type display of a rectangular shape. Besides, as it is easy to adjust the display angle by moving the display mount and as there are no standards for the display angle, flat displays are installed in public spaces with different angles without any considerations as to whether they are installed with appropriate display angles or by simply applying the display installer’s own standards.

In our past DNP Museum Lab, we have often chosen a tilted display due to reasons such as avoiding reflections (reflection of the ceiling light on the horizontal displays, and reflections of the face of a display user on the vertical display) and expressing respect for artworks (avoiding using a vertical display angle that competes against the artwork, which is usually displayed vertically). Some researchers (e.g., Rogers & Lindley, 2004; Inkpen et al., 2005; Forlines et al., 2006) compared the vertical and the horizontal display and investigated how the display angle impacted group collaboration.

In the previous chapter, we compared three display angles of 0°, 45°, and 90° and showed that the display angle influenced how well a single user remembered the display contents and how much he/she preferred the display he/she used. However, there exists no study that systematically addresses in detail how vertical, horizontal, and tilted display angles impact the social behaviors of multiple users. Social behavior (Rummel, 1975) refers to actions and conducts that one takes towards the other individual (s). He/she and other individual (s) may be aware of each other or sometimes only one party may be aware of the other.

In this chapter, we investigate the impact of the angle—vertical, horizontal, or tilted—of a display on the social behaviors of the people around the display in the context of a museum. In order to compare these three display angles, we conducted a field study using displays commonly used for interactive exhibits held at a museum. These displays were deployed at a special exhibit and set up with each of the three angles for a period of two to three weeks. We analyze the quantitative data (RFID access logs, videos from depth camera, and answers to questionnaires) and qualitative data (data obtained through observing the visitors to the museum) collected from a total of more than 700 visitors to the special exhibit between the ages of 10 and 70, and examine how the three display angles impact visitors' attention, sharing of space, and communication.
The findings of our study help to design a public display of the flat and touch type, i.e., the type of display most widely deployed in museums and other public spaces. They also help further study into the public display.

・Related work

Impact of display angle

Most of the existing studies only use two angles (vertical and horizontal) to investigate the impact of the display angle. Many such studies evaluate the impact that the display has on the collaborative work of a small group of people (Rogers & Lindley, 2004; Inkpen et al., 2005; Forlines et al., 2006; Potvin et al., 2012); a group performs a collaborative task, and vertical and horizontal display angles are compared and evaluated with respect to the level of activities such as conversations, gestures, and eye directions, within the group. In Rogers et al. (Rogers & Lindley, 2004), a group of three individuals performed a task of developing an itinerary for a day trip to London for a group of tourists with a specified budget. Rogers et al. observed that group members switched their roles more frequently, generated more ideas and had a better grasp of other group members' activities when they used the horizontal display rather than the vertical display. Based on these observations, they concluded that the horizontal display is suitable for group collaborations. In Inkpen et al. (2005), the study of two individuals used a subway map and planned a sightseeing route to visit as many sites as possible, including the required sites. Inkpen et al. observed that, with the horizontal display, group members exhibited more pointing gestures, made more comments to support the task of planning a sightseeing route and were fairly stationary making only torso movements. They also observed that, with the vertical display, group members exhibited fewer pointing gestures and a higher degree of full body movement. In Potvin et al. (2012), a group of two individuals collaboratively designed two software systems using UML class diagrams. They found significant differences between the horizontal and vertical displays; the vertical display better supported face-to-face contact, whereas the horizontal display promoted more discussion.

Unlike the previous studies described above, Pedersen et al. (2012) compared impact of horizontal and vertical multi-touch displays on a single-user, rather than on a group of multiple users who collaboratively perform a task. As a result, they found that users were quicker in tapping with the vertical display, quicker in dragging with the horizontal display, and users preferred the horizontal display because it placed a less physical burden on users. In the previous chapter, we conducted a laboratory-based user study for single users and verified the cognitive, behavioral, and emotional influences that the 0°, 45°, and 90°display angles have on the users. We found that the display angle influenced users' cognition (with different angles best suited for different ages to help memorize display contents) and subjective responses (with the tilted angle being most preferred).

Interactive display in museums

In recent years, a number of art, archaeology and science museums around the world have significantly increased interactive exhibits and interactive installations. A vast body of research exists exploring the potential of interactive displays in museums (Kortbek & Grønbæk, 2008; Hornecker, 2008; Hornecker & Nicol, 2012; Horn et al., 2012). Kortbek et al. (2008) developed a new installation using a floor as an interactive display and showed that new technologies could support the holistic and social experience of visitors, without interfering with the work of art. Hornecker et al. (2008) installed an interactive exhibit using a multi-touch table in a museum and conducted a field study. They observed that, although a multi-touch table looked aesthetic and appeared easy to use at first, in reality, visitors struggled when operating the interface and were distracted from the actual content due to short wait times experienced while operating the interface. As these studies show, interactive displays in museums differ from those deployed in stations and shopping malls in that they not only provide entertainment but also facilitate a deeper understanding of and insight into the artwork.

Public display

Researchers have proposed a variety of innovative displays such as a water display (Matoba et al., 2013) and a furry touch display (Nakajima et al., 2011), although some are not designed for use in a public space with other users. With respect to displays for use in a public space where a number of passers-by exist, researchers have examined panel displays and rear projection screens considering their high durability, low cost, and ability to display a significant amount of information. These studies include creating a new public display through manipulating the shape (Beyer et al., 2011; Bolton et al., 2012; Beyer, Köttner, Schiewe, Haulsen, & Butz, 2013) and size (Schmidt et al., 2013) of the display screen, as well as through combining multiple screens to create a new public display surface of various shapes and sizes (Ten Koppel et al., 2012) for use in a public space. In addition, existing studies have also actively explored interaction techniques suitable for the public display (e.g., Müller et al., 2012; Schmidt et al., 2013; Müller, Eberle, & Tollmar, 2014).

When evaluating the public display, it has become more prevalent to assess it in the field (Rogers, 2011), rather than in the laboratory, namely, assess the public display while being used in a daily life over a period of time (e.g., Marshall, Morris, Rogers, Kreitmayer, & Davies, 2011; Johnson, Rogers, Van der Linden, & Bianchi-Berthouze, 2012; Beyer et al., 2013). This is because of the following two reasons. First, in a public space with a display, people tend to come and go (Rogers, 2011; Marshall, Morris, et al., 2011; Hornecker & Nicol, 2012). In a laboratory, it is difficult to recreate such a dynamic and unpredictable environment that involves a number of people. Second, in laboratory experiments, participants typically try to become 'good participant' and tend to adjust their behavior and their questionnaire answers in ways that fit with their perception of researchers' expectations (Brown, Reeves, & Sherwood, 2011; Hornecker & Nicol, 2012). Hornecker et al. (2012) pointed out that it was difficult to replicate social behavior particularly in the presence of strangers. These findings suggest that the public display should be evaluated in the field.

In summary, there exist few studies that investigate the angle of the display, including the tilted as well as horizontal and vertical angles in public display, and there exists no field study that compares these angles. Although some impacts of the display angles are observed in laboratory-based user studies, it remains unclear how the display angles impact people with diverse backgrounds in a public space. For these reasons, we conducted a field study to compare display angles. The next section discusses social behaviors of the people in a public space where a display is deployed.

・Social behaviors of the people around a public display

As with research of any HCI technique, it is not sufficient to simply consider utility, usability, and likeability when designing and evaluating a public display through which display user's interaction with others. Based on a number of existing studies, we address three aspects of people's social behaviors around a public display: (1) attention, (2) sharing of space, (3) communication.

Attention: honeypot effect

In general, since the information processing capacity of the human brain is limited, the human brain decides where to direct visual attention. A public display competes for the attention of passers-by against all other stimuli (like other signs, traffic, or people) (Müller, Alt, Michelis, & Schmidt, 2010). Some studies (Michelis & Müller, 2011; Ten Koppel et al., 2012; Müller et al., 2012) have shown that people who are already at the display and interacting with the display are strong stimuli in drawing the attention of passers-by. This is referred to as the honeypot effect (Brignull & Rogers, 2003), i.e., a social effect where people who are already near the display attract other people to the display. In our study, we consider the honeypot effect and examine the impact of the angle of a public display on attention among people.

Sharing of Space

It is generally desirable that a display deployed in a public space is shared by general public instead of being occupied by particular people. However, it is also known that individuals often feel annoyed by the presence of a display or other people and avoid such circumstances (Müller et al., 2010). For instance, Marshall et al. (2011) and Ten Koppel et al. (2012) observed the influence of a public display on sharing of space and explained the observation using the concept of personal space (Sommer, 1969), i.e., space that creates psychological strain when encroached upon by other people.

Communication: F-formation

Artificial objects that constitute the field of communication, including those that directly aid communication (such as a telephone and a memo) and those that do not directly aid communication, have been found to have a significant impact on the communication of the people in the communication field (Suchman, 1987). For example, certain arrangements of desks and passages within an office inhibit the smooth flow of business-related information in an office (Suchman, 1987). An 'instrumental' F-formation (McNeill, 2005) is a concept to analyze spatial and orientational behavior of a small group of people (2-5 people) who communicate through an artificial. Marshall et al. (2011) and Koppel et al. (2012) applied the concept of F-formation and analyzed the spatial arrangement of users in front of the public display (i.e., an artificial object). Typical arrangements in F-formation are 'vis-a-vis' (face-to-face placement), L-shaped, and side-by-side (Kendon, 1990). Different F-formation arrangements afford different types of tasks to perform; 'vis-a-vis' for competitive tasks, L-shaped for communicative tasks, and side-by-side for collaborative tasks (Sommer, 1969). In our study, we apply the concept of F-formation and examine the impact of the angle of a public display on communication among users.

5.2 Methods

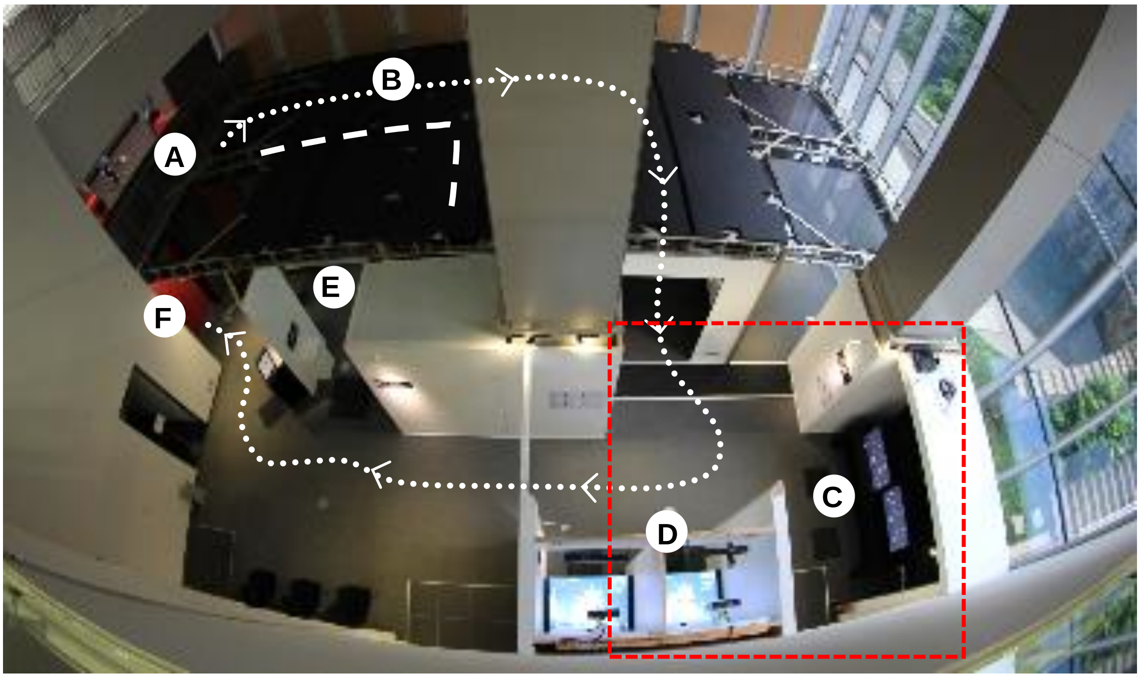
[Experiment 5]

・Field study

The goals of the field study are (1) to quantitatively and qualitatively investigate how museum visitors behave to three different display angles (horizontal, tilted, and vertical) in-the-wild and (2) to understand, in particular, the impact of the display angles on three primary factors of our analysis, i.e., attention, sharing of space, and communication. We conducted the field study in cooperation with "A Masterpiece of Ancient Greece: a world of Men, Gods, and Heroes" (http://www.museumlab.eu/exhibition/10/), the 10th exhibition of the Louvre - DNP Museum Lab (http://www.museumlab.eu/), a joint project between the Paris Louvre Museum and Dai Nippon Printing. The exhibition was held for approximately seven months, during which the exhibition was only open on weekends, i.e., Friday evenings, Saturdays, and Sundays. We used three months of the seven month duration to conduct the field study.

Experiment environment

The field study was conducted using one of the interactive exhibits at the 10th exhibition. The 10th exhibition was held at a part of the entrance hall of an office building and comprised of three spaces, i.e., an exhibition room (a space to view artwork of the Louvre Museum), a theater (a space to watch videos regarding artwork), and a participation space (a space to experience interaction systems regarding artwork). The participation space consists of four interactive exhibits (**Figure 5.1**). Visitors enter into the participation space from the entrance (A), pass the first interactive exhibit (B), move to the space with the remaining three interactive exhibits (C, D, and E), and exit the participation space from the exit (F). Since the 10th exhibition was open to anyone with an advance reservation, people with diverse backgrounds visited the exhibition. Basic attributes of the 730 visitors were as shown in **Table 5.1**. When visitors entered into the participation space, they reported their attributes using a touch panel display at the entrance (A), and the reported attributes were linked to their active RFID tags.



Participation space

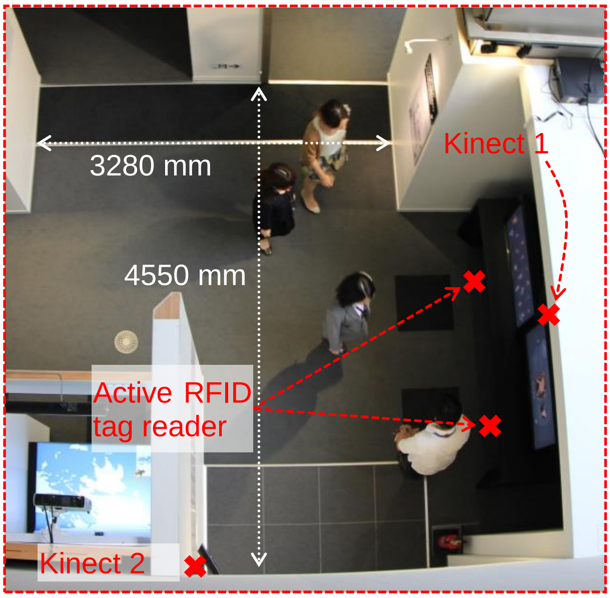


Exhibit Gods and Heroes

Figure 5.1 Overview of the participation space.

Table 5.1 Characteristic of the visitors.

	n	%
Age (years)		
10 to 19	100	13.7
20 to 29	137	18.8
30 to 39	103	14.1
40 to 49	161	22.1
50 to 59	90	12.3
60 to 69	85	11.6
70+	54	7.4
Gender		
Male	306	41.9
Female	424	58.1
Occupation		
Art related	56	7.7
Office worker	191	26.2
Student	137	18.8
Homemaker	93	12.7
Teachter	19	2.6
Public official	27	3.7
Self-employed	25	3.4
Retired	38	5.2
Others	144	19.7

We used the display of one of the four interactive exhibits, "Recognising Greek Gods and Heroes (hereinafter referred to as Gods and Heroes)" (**Figure 5.1**, C), in the field study. We set up the display with one of the three angles of our interest and maintained the angle for a period of two to three weeks before changing to another angle. The exhibit Gods and Heroes has been now installed in an alcove (i.e., a small section of the room that is set back from the rest of the room, creating a cave-like hollow environment) in the Louvre Museum. We chose the field study environment shown in **Figure 5.1** because of its close structural proximity to the alcove in the Louvre Museum. The exhibit Gods and Heroes used two displays placed side by side on a table (**Figure 5.2**). Both displays are a 40 inch liquid crystal display with built-in single-touch panel functionality (SAMSUNG 400TS-3). The displays had a resolution of 1920 x 1080.

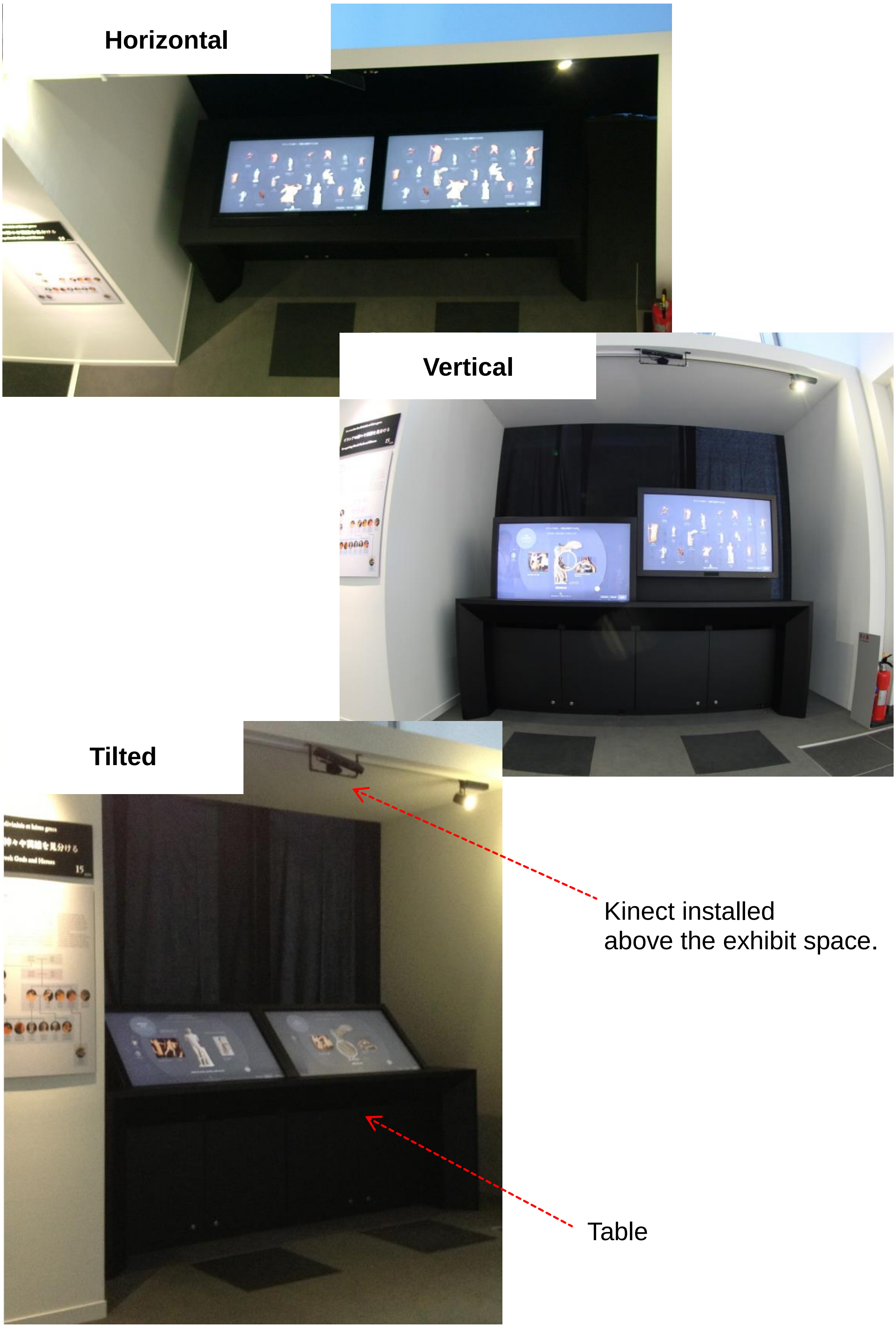


Figure 5.2 Displays with 0°, 45°, 90° angles.

In order to monitor the behavior of visitors, we installed two antennas for active RFID tags (Matrix Powertag, http://www.matrix-inc.co.jp/) and two cameras (Microsoft Kinect) around the exhibit Gods and Heroes. An RFID tag antenna was placed in front of each of the two displays (**Figure 5.1**). Each visitor received a card with a RFID tag attached at the entrance (**Figure 5.1**, A) and wore the card hanging from their neck while in the participation space. Of the two cameras, one was placed on the ceiling above the two displays to monitor the behavior of visitors approaching, passing and leaving the displays, and the other was placed on the wall in front of the two displays to monitor the behavior of the visitors who stood before the displays (**Figure 5.1**, **Figure 5.2**, **Figure 5.5**). In order to protect privacy of the visitors, we only recorded the depth images and did not record the actual RGB image. We neither recorded voice for the same reason.

Displayed content

We used the contents used in the exhibit Gods and Heroes in the field study. The contents explained features of gods and heroes in ancient Greece and how to recognize them (**Figure 5.3**). A user touched a screen and pulls out the information, a typical type of interactive exhibit in a museum. When a user touched an image of artwork on a detailed content page, a magnifying glass appeared, allowing a user to view details of the artwork image. Two displays, one on the right and the other on the left, provided completely identical content.

Figure 5.3 Examples of a content screen.

Conditions

In our examination, only one parameter was varied; the display angle (Horizontal (0°) vs. Tilted (45°) vs. Vertical (90°)). The content displayed on the displays remained the same for different display angles.

Two displays on the exhibit Gods and Heroes table were placed at the same height of 800 mm from the floor to the lower edge of the display panel for the Horizontal and Tilted conditions. For the Vertical condition, one display was placed at a height of 800 mm, and the other was placed at a height of 1050 mm (**Figure 5.2**). These heights allow both a physically unimpaired person and a wheelchair user to operate the display. These heights have been adopted as a guideline by a number of museums in Japan as well as the DNP

Museum Lab. We adopted the guideline and installed two displays accordingly. After carefully considering the impact of having displays at different heights on the behavior of the visitors, we decided to place displays at different heights only for the Vertical condition for the following two reasons. First, it is not our intention to artificially place two displays at the same height in order to make the field study environment simple and easy to handle, ignoring the actual needs of display users, for instance, the needs of users who use wheel chairs and require a display at a lower height. Second, as the contents on the two displays are completely identical, a visitor would likely access only one display, not both, making little difference from the other angles (i.e., the horizontal and tilted) when having two vertical displays at different heights.

Data collection and analysis

We collected both quantitative and qualitative data and analyzed the social behavior of the people around public displays (i.e., in front of the displays and near the displays) with respect to the three aspects (attention, sharing of space, communication) described earlier. As for the quantitative data, we collected RFID access logs, depth videos, and answers to the questionnaires distributed to the visitors. As there were variations in visitors to the exhibit in the time of the day and the day of the week, our analysis used a subset of the collected data such that the distributions of data become similar between the different display angles with respect to the number of visitors, the time of the day, and the day of the week. In order to do so, we first obtained the exact number of visitors to the exhibit for each and every 30 minute interval, using the RFID access logs, and removed the values that significantly deviated from the rest of the values. From the remaining values, we then selected values such that the distributions of values became similar between the different display angles with respect to the number of visitors for different times of the day (morning, afternoon, evening) and different days of the week. The data for our analysis consisted of a total of RFID access logs of 122 hours and 730 visitors, depth videos of 102 hours and 714 visitors, and answers to the questionnaires from 472 visitors. As for the qualitative data, we observed the visitors and collected data for approximately 9 hours through direct observation in the field and for approximately 15 hours through indirect observation with the recorded depth videos (see “Observation notes” section).

RFID access logs

We collected the following RFID access log data: date, time, visitor ID, RFID tag in, and RFID tag out. When a visitor wearing an active RFID tag either enters or exits the RFID detection area of approximately 750 mm radius with the center of the detection area located on the floor in front of the displays (**Figure 5.1**), the active RFID tag transmits a signal to the receiver. The receiver then transmits the tag information on a real time basis to the data storage PC. The PC stores RFID tag in and out logs along with the visitor ID.

Depth videos

We collected the following data from the depth videos (i.e., videos obtained through depth cameras): transitions of a visitor between three types of activity spaces (Brignull & Rogers, 2003) for each and every visitor as well as social communication among two individuals for each and every two individual pairs. The following two paragraphs explain activity space and social communication.

Activity space is a concept introduced by Brignull et al. (2003). They identified three distinct types of activity spaces based on the activities that take place around the display; peripheral awareness activities, focal awareness activities, and direct interaction activities. We classified the state of the individuals who passed by the exhibit Gods and Heroes into three types of activity spaces (**Figure 5.5**). From several models proposed to represent a life cycle of interactions between a passer-by and a display (e.g., Brignull & Rogers, 2003; Vogel & Balakrishnan, 2004; Michelis & Müller, 2011), we chose the model by Brignull et al. (2003).

When there are multiple individuals in front of the display, their social communication is defined by a set of the following communication indicators; the type of F-formation arrangement (i.e., ‘vis-a-vis', L-shaped, or side-by-side), the presence (or absence) of physical contact, and the presence (or absence) of visual contact (i.e., eye contact). From all cases that we observed in our field study, we extracted cases only when there are two individuals in direct interaction activity space at the same time and examined their social communication. This is because of the following two reasons. First, for 79% of the cases obtained from the depth videos, we observed only two individuals in direct interaction activity space. Second, it is easy to evaluate social communication within only two individuals, compared to three or more individuals, and thus, it is less likely to result in evaluation variations due to personal differences among evaluators.

The data described above were collected in the following manner. First, we developed the analysis software that synchronizes recorded depth (still) images from the two Kinect cameras and replayed the synchronized images consecutively (to show them as a moving video) (**Figure 5.4**). Two different evaluators used the software and manually coded the data. In coding the data, each visitor was first coded with the space in and space out events for each activity space model. Codes were assigned based on the criteria by Brignull et al. (**Figure 5.5**) Based on these events, each two individual pair was then coded with the action they took in response to their social communication. We calculated inter-evaluator reliability between the two evaluators for each and every code. Cohen’s Kappa coefficient was between 0.73 and 0.93, and two evaluators were considered to be sufficiently in agreement (Landis & Koch, 1977).

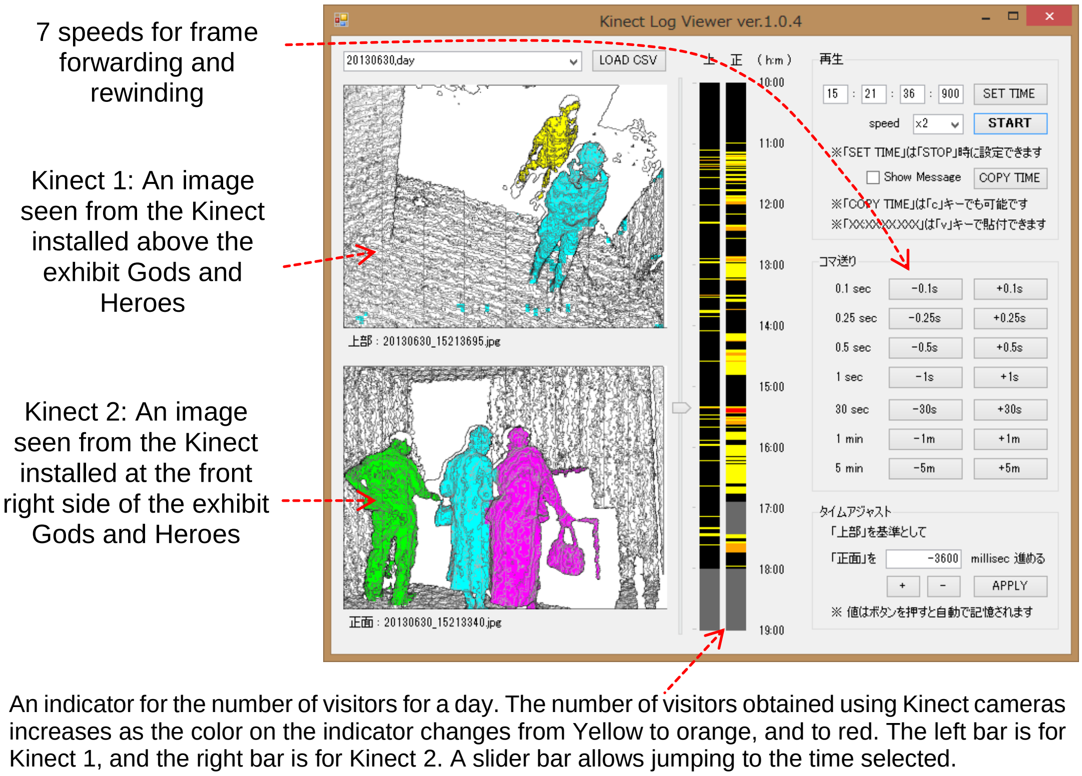
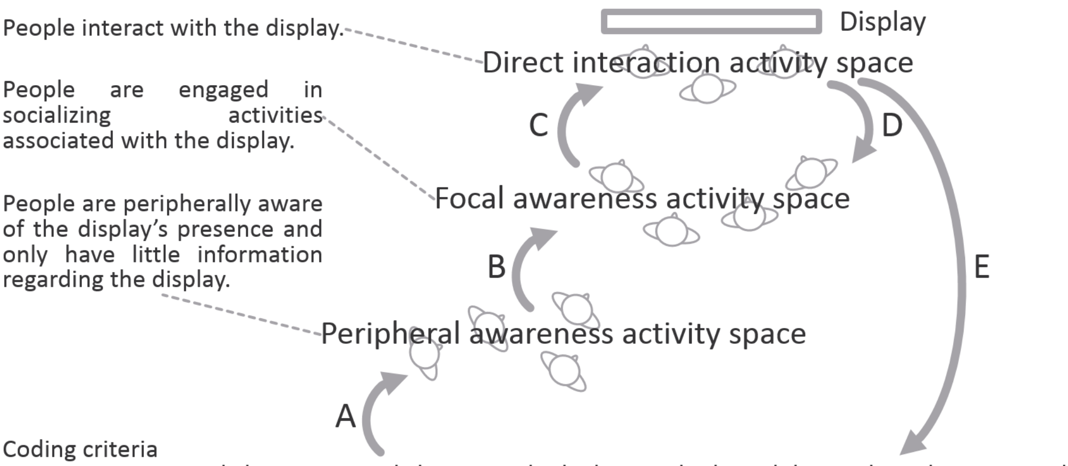


Figure 5.4 Kinect video analysis software developed.



Coding criteria
A: Kinect 1 captured the visitor, and the visitor looked towards the exhibit Gods and Heroes and either stopped walking or slowed down.
B: The visitor became aware of and moved towards the display
C: The visitor placed himself/herself in front of the display within his/her arms reach to the display.
D: The visitor left from the front of the display but is still near the display and looking at the display.
E: The visitor left the exhibit Gods and Heroes, namely, the visitor left the Kinect 1 range.

Figure 5.5 Three types of activity space (Brignull & Rogers, 2003) and our coding criteria for visitor's transitions between activity space types.

Questionnaires to visitors
Questionnaires distributed to visitors asked about their experience in the exhibit Gods and Heroes.

Observation notes
We employed two non-participant observation methods; non-participant direct observation and non-participant indirect observation. Non-participant observation involves no manipulation of the field study targets by the observer and simply studies behaviors that occur naturally in natural environments. In non-participant direct observation, two researchers observed visitors from the upper floor in an atrium structure and recorded their observations in the field observation note. In non-participant indirect observation, one researcher examined depth videos at a later time and recorded his/her observation in the video observation note.

5.3 Results

General Findings from Observation Notes, Questionnaires and RFID Access Logs
We observed that almost all museum visitors who entered into the participation space showed sufficient interest in the exhibit Gods and Heroes and actually experienced the interactive exhibit. The results of the questionnaire showed that 100.0% (Horizontal), 93.1% (Tilted) and 97.7% (Vertical) of the visitors who responded to the questionnaire answered “they experienced the exhibit Gods and Heroes”, Fisher’s exact $p = 0.0028$. Ryan’s multiple comparison test showed that the ratio was significantly higher for Horizontal than for Tilted. The results of the RFID access logs showed that visitors spent on the average 3.7 (Horizontal), 2.8 (Tilted), and 4.2 (Vertical) minutes experiencing the exhibit (ANOVA: F (2, 640) = 2.342, $p = 0.097$). We also observed that most of the visitors who experienced the exhibit Gods and Heroes were drawn into the content and enjoyed the exhibit. The results of the questionnaire showed that, of those who answered “they experienced the exhibit Gods and Heroes,” 92.9% (Horizontal), 92.6% (Tilted) and 85.9% (Vertical) also answered “they were drawn into the content and enjoyed the exhibit.” (χ^2 (2) = 5.661, $p = 0.06$)

Findings from observation notes: Honeypot effect
In the Horizontal condition, when there were a small number of existing visitors (i.e., visitors who were already in focal awareness or direct interaction activity space), we observed that a new visitor (i.e., a passer-by who came to the exhibit Gods and Heroes later) moved to focal awareness or direct interaction activity space, and looked at the display content that the existing visitors were accessing (**Figure 5.6** left). When there were a large number of existing visitors, however, we frequently observed that a new visitor paid very little attention to the display and behaviors and interactions of the existing visitors.
In the Tilted condition, we observed that a new visitor stayed away from focal awareness or direct interaction activity space, when there were existing visitors, regardless of the number of existing visitors. We further observed that, even when a new visitor moved to focal awareness activity space and when there were already some existing visitors, he/she

did not stand to the side of or behind any existing visitor, kept their distance from the existing visitors, and observed them from far (**Figure 5.6**, middle).

In the Vertical condition, we observed that a new visitor either stayed in peripheral awareness activity space to look at existing visitors or moved to focal awareness activity space, when there were existing visitors (**Figure 5.6**, right). A new visitor who moved to focal awareness activity space formed a line behind, rather than next to, the existing visitor, standing apart with room for roughly one person from the existing visitor. In these cases, the line that new visitors formed started at a slightly slanted angle from directly behind the existing visitor, rather than directly behind.

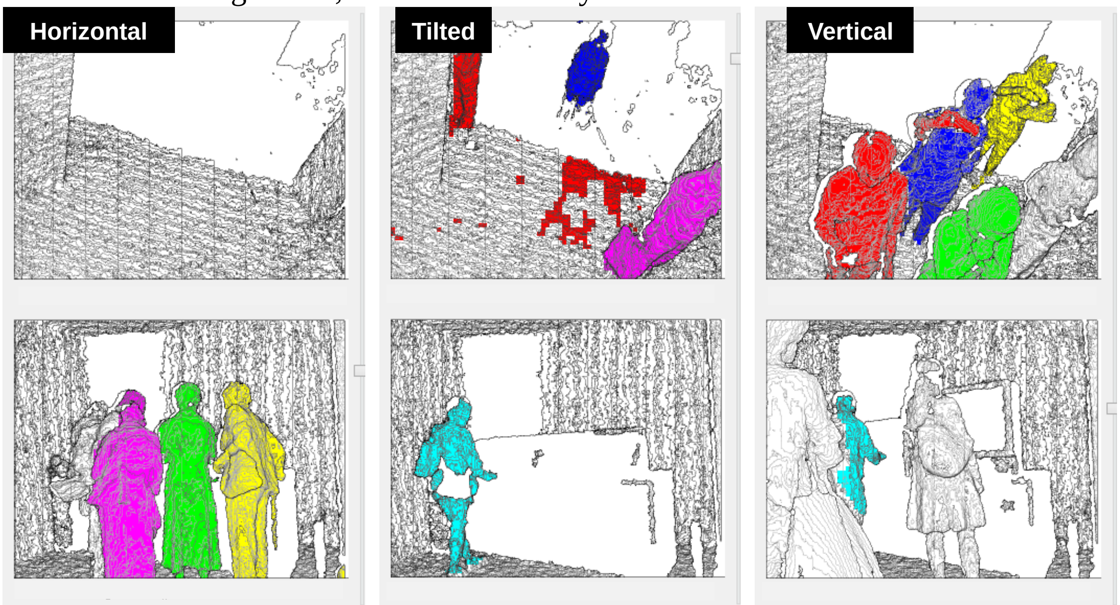
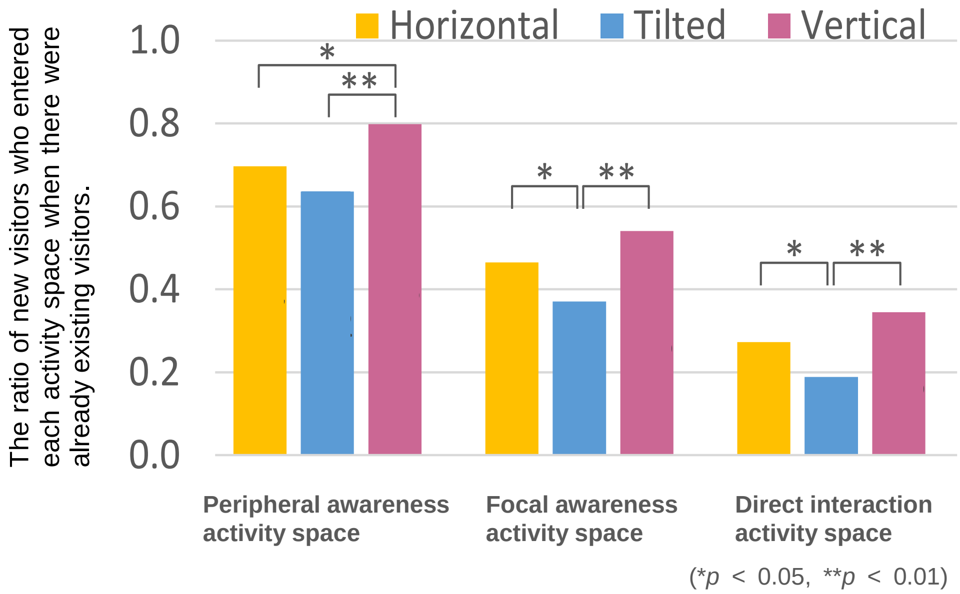


Figure 5.6 Example of observation images: Honeypot effect.

Statistical results from the depth video analysis: Honeypot effect

The analysis of the depth videos showed that, when there were already existing visitors, 46.5% (Horizontal), 37.1% (Tilted) and 54.1% (Vertical) of all new visitors entered focal awareness activity space (**Figure 5.7**, center). A chi-square test showed that the display angle had a significant effect on the frequency of occurrence (χ^2 (2) = 17.741, $p < 0.001$). Ryan's multiple comparison test showed that the ratio was significantly higher for Vertical and Horizontal than for Tilted. When there were existing visitors, the ratio of new visitors showed a similar distribution among different display angle conditions before and after their entering focal awareness activity space. Here, the ratio of new visitors who entered peripheral awareness activity space (**Figure 5.7**, left), and the ratio of new visitors who entered direct interaction activity space (**Figure 5.7**, right).



Note:
Passer-by who came to the exhibit Gods and Heroes later, when there were existing visitor (Horizontal: 297, Tilted: 302, Vertical: 307).

The total number of passers-by is 906, larger than 714. This is because the visitors who visited the exhibit Gods and Heroes multiple times are counted separately and included in this figure.

Figure 5.7 Behaviors of new visitors with existing visitors.

Findings from observation notes: Sharing of space

In the Horizontal condition, we observed that, when a small group of acquaintances were together in focal awareness or direct interaction activity space, they stayed together in the space and left the space together. When the existing visitor interacting with the display became aware of a stranger (a new visitor) approaching focal awareness or direct interaction activity space, the existing visitor often left the exhibit Gods and Heroes as if to give the display to the new visitor. These observations gave us the impression that the horizontal display angle promotes the formation of a private space for a small group of acquaintances.

In the Tilted condition, we made similar observations to those in the Horizontal condition.

In the Vertical condition, we observed that, even when a group of acquaintances were in focal awareness or direct interaction activity space together, they do not necessary leave together. When the existing visitor interacting with the display became aware of a new visitor approaching focal awareness or direct interaction activity space, the existing visitor sometimes left the display to give the display to the new visitor, sometimes stayed and continued interacting with the display, and sometimes adjusted his/her standing position such that the new visitor can easily see the display. These observations gave us the impression that the vertical display angle promotes the formation of a public space where people, acquaintances and strangers alike, frequently enter and leave.

Statistical results from the RFID access log analysis: Sharing of space

The analysis of the RFID access logs showed that, out of the time when there were one or more visitors in the RFID tag space (i.e., when one or more visitors were logged as RFID tag in), two or more visitors co-existed in the RFID tag space for 19.5% (Horizontal), 19.8% (Tilted) and 23.7% (Vertical) of the time (**Figure 5.8**, left). This time interval of two or more visitors sharing the space around the display is referred to as the space sharing time interval. A chi-square test showed that the display angle had a significant effect on the ratio of the space sharing time interval (χ^2 (2) = 320.041, p < 0.001). Ryan's multiple comparison test showed that the ratio was significantly higher for Vertical than for Horizontal and Tilted.

After completing the analysis described in the above paragraph, we then calculated the average space sharing time interval of two visitors who entered the RFID tag space successively and shared the space for a certain time period. It was 127 (Horizontal), 103 (Tilted) and 88 (Vertical) seconds (**Figure 5.8**, right). A one-way ANOVA revealed no significant main effect of the display angle (F (3, 227) = 0.819, p = 0.484). Although there was no significant difference between display angles, the space sharing time interval of exactly two visitors is longer for Horizontal, Tilted, and Vertical in this order, on the contrary to the results of the ratio described in the above paragraph.

The analyses described in the above two paragraphs collectively reveal the following. Although the ratio of the space sharing time interval of two or more visitors was significantly higher for Vertical than for Horizontal and Tilted, there was no significant difference in the average space sharing time interval of exactly two visitors away different display angles. Note that, although there was no significant difference, the average space sharing time interval of exactly two visitors was shorter for Vertical than for Horizontal and Tilted. In other words, in the Vertical condition, visitors share the space more frequently but for a shorter period of time in each sharing of the space.

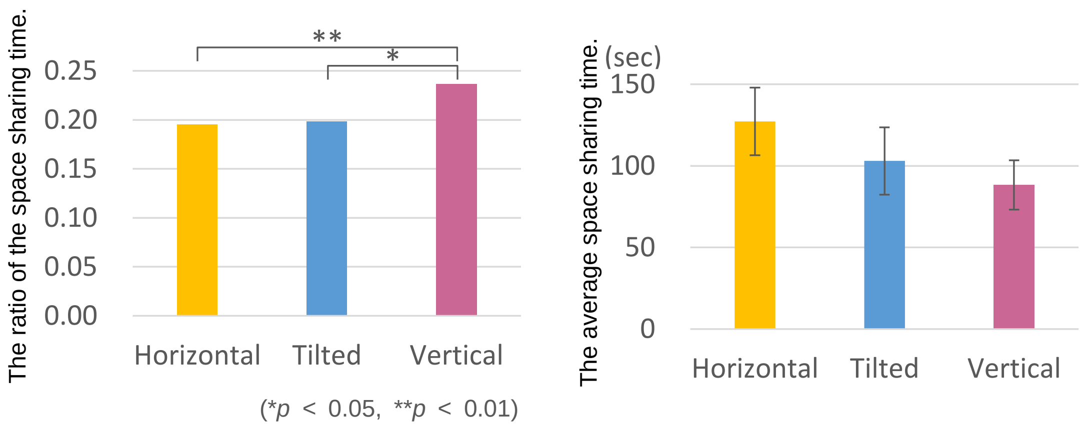


Figure 5.8 Left: the ratio of the space sharing time interval of two or more visitors. Right: the average space sharing time interval of two successive visitors, with standard error bars.

Findings from observation notes: F-formation

In the Horizontal condition, we observed that display users usually stood perpendicularly to the display and stood side by side next to each other. We also observed that almost all users stood very close to the display with their bodies contacting and leaning against the display. Users also stood very close to each other with their shoulders almost touching each other (**Figure 5.9**, left). It appeared that users, while interacting with the display, explored the contents together.

In the Tilted condition, we observed some users stood in a spatial arrangement similar to that seen in the Horizontal condition explained in the paragraph above and that some users stood in a spatial arrangement similar to that seen in the Vertical condition to be explained in the paragraph below. We also observed intermediate spatial arrangements between these two patterns (**Figure 5.9**, center). In the former case (where users stood similarly to the Horizontal condition), users stood relatively close to each other, and in the latter case (where users stood similarly to the Vertical condition), users stood relatively far from each other.

In the Vertical condition, we frequently observed that users stood diagonally to the display and orthogonally to each other. We also observed that users stood somewhat far from the display, approximately at an arm's length to the display surface, and also from other users, approximately with room for one person from other users (**Figure 5.9**, right). It appeared that users looked at each other occasionally and interacted with each other through discussing the content presented on the display. It was as if the display is another member of the group carrying on a conversation.

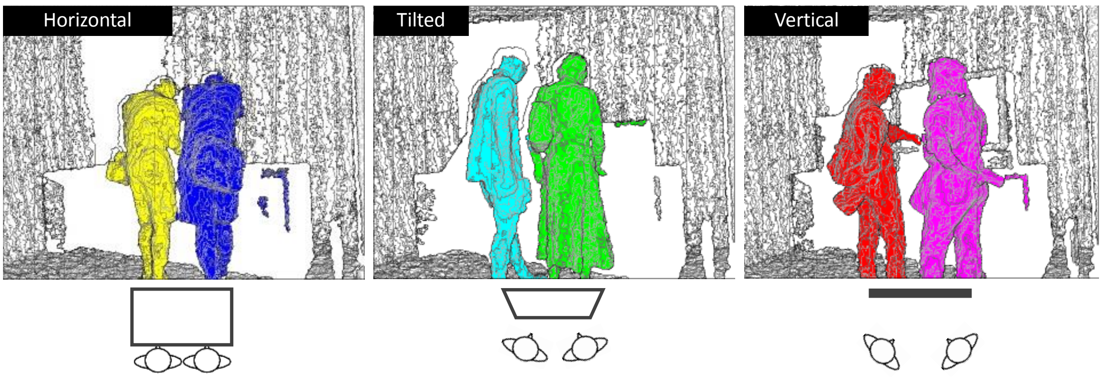


Figure 5.9 Social communication through an artificial object (a display).

Statistical Results from the Depth Video Analysis: F-formation

We analyzed spatial and orientational behavior of two individuals. With respect to the F-formation that two individuals formed with each display angle, we observed both L-shaped and side-by-side arrangements (**Figure 5.10**). We did not, however, observe any instances of the 'vis-a-vis' arrangement. The analysis showed that 14.3% (Horizontal), 55.3% (Tilted) and 82.3% (Vertical) of the two individual pairs we observed formed the L-shaped arrangement. A chi-square test showed that the display angle had a significant effect on the frequency of the L-shaped arrangement (χ^2 (2) = 54.809, p < 0.001). Ryan's multiple comparison test showed that the differences were significant among all pairs of the display angles. Namely, the ratio of the L-shaped arrangement was higher for Vertical, Tilted, and Horizontal in this order (i.e., the ratio of the side-by-side arrangement was higher for Horizontal, Tilted, Vertical in this order).

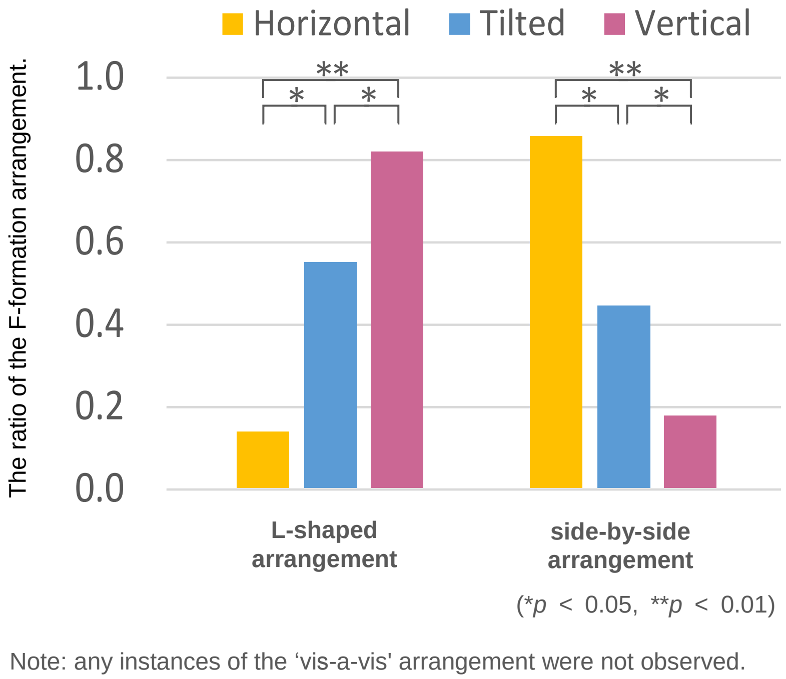


Figure 5.10 F-formation arrangement: L-shaped arrangement (left) and side-by-side arrangement (right) of two individuals in front of an artificial object (a display).

We examined the presence (or absence) of physical and visual contact. The analysis showed that 47.8% (Horizontal), 30.4% (Tilted) and 3.5% (Vertical) of all two individual pairs we observed had physical contact at least once (**Figure 5.11**, left). A chi-square test showed that the display angle had a significant effect on the frequency of the physical contact (χ^2 (2) = 41.125, $p < 0.001$). Ryan's multiple comparison test showed significant differences both between Horizontal and Vertical and between Tilted and Vertical, namely a higher chance of physical contact with the smaller display angle (i.e., a display angle closer to the horizontal). With respect to visual contact, 1.4% (Horizontal), 5.4% (Tilted) and 18.6% (Vertical) of the two individual pairs we observed had visual contact at least once between the two individuals; the order was reversed from the physical contact case (**Figure 5.11**, right). A chi-square test showed that the display angle had a significant effect on the frequency of the visual contact (χ^2 (2) = 14.641, $p < 0.001$). Ryan's multiple comparison test showed significant differences both between Horizontal and Vertical and between Tilted and Vertical, namely, a higher chance of visual contact with the larger display angle (i.e., a display angle closer to the vertical).

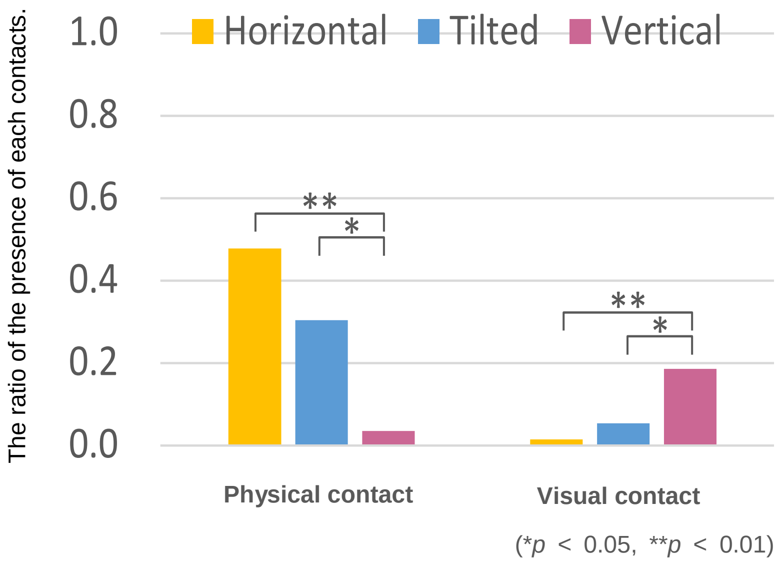


Figure 5.11 Physical contact (left) and visual contact (right) of two individuals in front of an artificial object (a display).

5.4 Discussion

· Summary of findings

This section summarizes the findings from the analyses described in the previous section and describes how they are interrelated with each other.

Display angles change the honeypot effect

The results from the statistical analysis of the depth videos are consistent with our observations that the display angle changed the honeypot effect. When there were already existing visitors, the display in the Vertical and Horizontal conditions attracted more new visitors, namely, new visitors moved to peripheral awareness, focal awareness, and direct interaction activity space more often, than in the Tilted conditions. We expected a high honeypot effect in the Vertical condition, as the display had a larger area that allowed visitors to see the content from the front of the display compared to Tilted (or Horizontal) one. We did not anticipate, however, that it was as high as in the Horizontal condition. In the Horizontal condition, a new visitor sees the display content only when he/she comes near the display, and as such, we conjecture that existing visitors enhanced new visitor's motivation to approach the display and see its content.

Display angles affect sharing of the space

The results from the analysis of the RFID access logs support our observations that the display angle affected how long visitors share the space with a display. The display in the Vertical condition promoted more continuous sharing of space than in the Horizontal and Tilted conditions, namely, a new visitor moved to the space around the display to share the space with an existing visitor, the existing visitor left the space, and another new visitor moved towards the display to share the space, and so on. With respect to the relationship between the visitors sharing the space around the display, we observed that, in the Horizontal and Tilted conditions, they were normally acquaintances, and that, in the Vertical condition, they were occasionally strangers. These findings suggest that the Vertical condition promotes formation of a highly public space with several strangers sharing the space and that Horizontal and Tilted conditions promote formation of a highly private space with people who are close to each other sharing the space.

Display angles impact F-formation

The results from the statistical analysis of the depth videos are consistent with our observations that different display angles resulted in different spatial and orientational behavior of users who are communicating. In the Horizontal condition, users stood side by side next to each other in front of the display and very close to each other with their bodies almost touching, while experiencing the display. In the Vertical condition, users stood in front of the display in the L-shaped arrangement and looked at each other, while experiencing the display. In the Tilted condition, users stood side-by-side for a half of the cases and in the L-shaped arrangement for the other half of the cases.

· Inadequate suitability of tilted display for public spaces

In this subsection, we discuss results of the previous chapter that investigated three display angles similarly to this study and compare their results against results in this chapter. In the previous chapter, we conducted a study in a laboratory for single users using the display. Each user experienced the space with a display alone and subjectively evaluated his/her experience for various evaluation criteria. We found that the tilted display received a significantly high evaluation in almost all evaluation criteria, namely, users strongly preferred the tilted display. Given the findings in the previous chapter, the results from this chapter were contrary to our expectations. We conducted the field study for multiple users sharing the space with a display in public and found that the tilted display had no positive impact on the honeypot effect and sharing of the space. Results from the previous chapter and from this chapter collectively suggest that the tilted display is suitable for a single user, but is not effective for promoting social interactions among its users. Therefore, careful considerations must be given when installing a public display with a tilted angle.

· Impact of the display angle on social communication

In this subsection, we discuss findings from the past studies that investigated the impact of the display angle on the collaborative work that group members perform (Rogers & Lindley, 2004; Inkpen et al., 2005; Potvin et al., 2012), as well as findings of our study on the impact that the display angle has on the users in a public space. We then apply these findings, as well as theories of social psychology, and consider in a systematic manner the impact that the display angles (primarily the vertical and horizontal angles) have on communication among users.

Our study found that the vertical display angle better supported face-to-face contact, and this is consistent with the results obtained by Potvin et al. (2012). With the vertical display angle, our study found that users formed an L-shaped arrangement for more than 80% of the cases and that users made visual contact more often than with other display angles. This supports Sommer's (1969) finding that users made more visual contact in an L-shaped arrangement than in a side-by-side arrangement.

Table 5.2 summarizes the results from our study and from the existing studies. From this table, one may derive the impact that the display angles have on user communication, as well as patterns of communication suitable for different display angles. When a user interacts with the horizontal display, he/she tends to pay attention to the following, rather than other nearby users who stand side-by-side to him/her: changes taking place to the contents on the display, and his/her own or other user's interactions with the display. Thus, the horizontal display angle may be suitable for supporting communication to perform tasks (task-oriented communication). On the other hand, when a user interacts with the vertical display, he/she tends to pay attention not only to changes to the display contents and his/her or other user's interactions with the display, but also to the face of a nearby user located at a close height of the display surface. Thus, the vertical display angle may be suitable for task irrelevant communication (non-task-oriented communication). As discussed in the previous subsection, the tilted display is not effective for promoting social interactions among its users. However, once users start socially interacting through the tilted display, their behaviors appear to lie between those of users interacting through the horizontal and vertical displays.

Table 5.2 Summary of studies on the display angle impact on social communication among display users.

Communication channels			Horizontal	Tilted	Vertical	Study
Verbal	Talk	Discussion	More	(Unkown)	Less	(Rogers & Lindley, 2004) (Potvin et al., 2012) (Inkpen et al., 2005)
Non-verbal	Gaze	Face-to-face contact	Lesser	Lesser	Greater	(Potvin et al., 2012) our study
		Awareness of what each other was doing (on the display)	Greater	(Unkown)	Lesser	(Rogers & Lindley, 2004)
	Hand	Pointing gestures	More	(Unkown)	Less	(Inkpen et al., 2005)
	Body	Physical movement	Stationary, only torso movement	(Unkown)	Full body movement	(Inkpen et al., 2005)
		Interpersonal distance	Closer	Average	Farther	Our study
		Interpersonal orientation (F-formation arrangement)	Side-by-side (afford collaborative task (Sommer, 1969))	Side-by-side and L-shape half-and-half	L-shape (afford communicative task (Sommer, 1969))	Our study

· Ethical issues of observing social communication
In the 10th Exhibit, we used commercially available devices and collected anonymized data. Through disclosing our privacy policy at the time of their making a reservation to visit the exhibit, visitors are made aware of and consented to statistically processing data and making such data publicly available. We summarizes our insights into the possibility and difficulty of how these devices and data may be used in observing social communication (see **Appendix B**).

In the public space where people dynamically move, depth videos are effective in ethically observing their behaviors. However, it requires considerable man power to manually code the depth videos. In an environment where the movement of people is limited, if multiple Kinect video cameras are strategically placed in front of people's bodies, automatic coding may be feasible using the skeleton data. On the contrary, RFIDs are effective in observing social communication at a coarse granularity such as flows of people movement and gatherings of people, as RFIDs can automatically detect entering and leaving of people into and from a given space.

· Public display as a means of urban space design
In this subsection, we reflect upon how a variety of factors, beyond the display angle, of the public displays proposed in the past impact the behavior of their users. Müller et al. (2010) stated that, in designing a public display, it is important to consider, not only the contents to display, but also how to attract the attention of passers-by to the display, motivate them to use the display, and have them actually use and interact with the display in public. Many studies, including our study, have revealed that users of a public display change their behavior differently in response to different factors of the display. For example, a flat display attracts more attention of passers-by to the display than a hexagonal or a concave display (Ten Koppel et al., 2012), displaying user's silhouette or his/her mirror image on a public display motivates a user stronger to interact with the display than displaying a text "Step Close to Play" (Müller et al., 2012), a public display with a frame placed on the display increases the space between users(Beyer et al., 2013), a horizontal or tilted display promotes the formation of a private space for communication within a group of acquaintances and a vertical display promotes the formation of a public space for communication between strangers.

Reflecting upon the findings described above, we conclude that the public display, not only provides contents (to connect users of the public display and information that the contents provide), but also gather people around the display and facilitate communication among them (to connect people around the public display), and creates flows of people (to connect buildings and objects to other buildings and objects); the public display ultimately becomes an affordable artificial object. In other words, the public display presents not only a promising means to return the interactive and social experience back to the urban space (Kuikkaniemi et al., 2011) but also an effective means to design the urban space itself. By strategically placing public displays, we may control flows of people at museums and at train stations. We may also turn a quiet and calm space into am noisy space where people are always on a move. A designer of a public display must be aware that he/she is designing, not only a public display, but also an urban space.

· Limitation

First, our findings may not apply to public spaces where most people rush with a clear and specific intention such as train stations and airports. Next, we focused on the angle of a display in space where interactions are through touching the display. Thus, our findings may not apply to a display where interactions are through gestures. A type of display with which users interact through gestures is expected to become more popular, and future study is necessary to address how the angle of such a display impacts user behaviors.

It is important to apply our findings in a systematic manner in designing public displays that meet given objectives. It may become possible in the future to automatically adjust the display angle on a real time basis to the optimal angle, considering both the dynamically changing characteristics of the users and the space where the display is deployed.

Chapter 6
Conclusion

6.1 Summary

In this research, we focused on three layers related to exhibition technology (such as technique of content representation, user interface technology, design of equipment and space), set their research topics, and tried a scientific verification approach.

In Chapter 2, we demonstrated that the presence of hands in a video animation can activate the MNS. Furthermore, the present study has suggested that the visual observation of a tool-based action may be able to activate the MNS even in the absence of such an image of hands. This phenomenon may involve brain activity, which is known to fire in response to the visual observation of a tool. In the observation of the tool-based process, the image of hands induced mu rhythm suppression in the observer in the area corresponding to the inferior parietal lobule. From the measurement of brain activity, we explained one of the significant elements of using the image of human movement in video expression, and showed that the effect can be obtained only by expressing the movement of the tool.

In Chapter 3, we adopted the following approaches for TUI, which have been hardly studied so far. One is the approach from brain activity and the other is the approach from the focus on the influence on surrounding observers. In order to clarify the influence of TUI, we focused on suppression of mu rhythm in the sensory motor cortex reflecting exercise behavior and exercise observation. Investigating the influence on brain activity due to differences in UI, TUI with object-oriented operation showed the possibility to strengthen the activity of the sensory motor field reflecting MNS in the operator and observer. This result seems to have indicated part of the effectiveness of TUI from the influence on brain activity. It is one of the significant elements of positively adopting TUI. In addition, we showed that the measurement of brain activity related to observer's MNS could be a new method of UI evaluation.

In Chapter 4, we focused on the display angle among various display factors. In a laboratory experiment we set up a tilted, a horizontal and a vertical flat screen in one exhibition space, and comprehensively tested users' cognitive, behavioral and subjective aspects. The experiment results showed that display angle affects user cognition and subjective responses. On the contrary, because user behavior tendencies differ for different age groups, no statistically significant effect was obtained. We obtained useful knowledge when installing and displaying purpose-oriented multimedia. Factors of equipment shape in information acquisition, that is, the attitude facing information, are likely to affect cognition.

In Chapter 5, we installed a flat touch-type display in a public space (at a museum) and investigated, through observations in the field study and analyses of the collected data, the impact of three display angles on people's social behavior in a natural setting. We confirmed that different display angles have significantly different impacts on the honeypot effect, sharing of space and F-formation arrangements. We also found that, through collectively considering our results in this chapter and results in a previous chapter that conducted a laboratory experiment for single users, users do not actively interact with the tilted display when they are in a public space with others. We showed that the shape of the equipment and the existence of people may influence space recognition, such as personal space formation.

While science and technological advances and information equipment functions are improving, it is considered one of social tasks that the existence of human beings interacting with equipment is not left behind. We positioned this research as a case study. The scientific verification approach was attempted with the theme of multimedia equipment in exhibition spaces. In the three layers constituting the multimedia devices (**Figure 1.2**), setting and verifying the problem in each layer promoted an understanding of human characteristics. While it was an issue under certain circumstances, it also led to the discovery of common problems by digging deep on each issue.

Through experiments on multimedia in exhibition spaces, we showed the significance of the approach to deepen human understanding by the multifaceted application of human research knowledge to the verification of problems generated from the development site.

6.2 Future work

We believe not only problem verification with the research approach but also the approach to reflect the findings from the verification on the actual display device and evaluate it in a more natural state is also important. I would like to pursue the ideal image of interaction between human and digital information through research on both sides.

Also, not only expression by the flat panel display device discussed in this research, but also the OLED (Organic Light Emitting Diode) display realizing new display shapes, the HMD, which almost covers the entire field of view and provides immersive space, the optically see-through type HMD capable of expressing almost the limit of visible resolution, and devices capable of presenting information to the senses other than the visual and auditory senses, etc., further accelerates the diversification of the expression method.

In addition, technologies related to digital archiving, which digitize and record the real world, are progressing. Due to social demands, such as the protection of cultural properties lost due to time lapses and natural disasters, unprecedented data has been acquired by technologies, such as ultrahigh-definition 3D measurement technology and technology to measure internal structures, etc., and new content expression is also required.

Also, not only human motion, but also sensing technology to capture facial expressions and biological signals remotely in a noncontact manner is evolving. Human cognitive technology with computers that realize nonverbal communication is developing with them. Combined with multimodal feedback presentation with nonvisual devices, human - computer interactions that are not only conventional gesture interfaces but also unprecedented have been proposed.

In order to adapt advanced expression technologies to such societal demands, an understanding of human cognitive characteristics, which will play a role in connecting these, is required more than ever. We would like to make use of the approach we attempted in this research and contribute to the realization of a society where human beings coexist with technology.

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Reference

Akpan, I., Marshall, P., Bird, J., & Harrison, D. (2013). *Exploring the effects of space and place on engagement with an interactive installation*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Paris, France.

Antle, A. N. (2007). *The CTI framework: Informing the design of tangible systems for children.* Paper presented at the TEI'07: First International Conference on Tangible and Embedded Interaction.

Arias, E., Eden, H., & Fischer, G. (1997). *Enhancing communication, facilitating shared understanding, and creating better artifacts by integrating physical and computational media for design.* Paper presented at the Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, DIS.

Arnstein, D., Cui, F., Keysers, C., Maurits, N. M., & Gazzola, V. (2011). mu-suppression during action observation and execution correlates with BOLD in dorsal premotor, inferior parietal, and SI cortices. *J Neurosci, 31*(40), 14243-14249. doi:10.1523/JNEUROSCI.0963-11.2011

Bao, P., & Gergle, D. (2009). *What's "this" you say?: the use of local references on distant displays*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA.

Baskinger, M., & Gross, M. (2010). Tangible interaction = form + computing. *Interactions, 17*(1), 6-11. doi:10.1145/1649475.1649477

Beilock, S. L., Lyons, I. M., Mattarella-Micke, A., Nusbaum, H. C., & Small, S. L. (2008). Sports experience changes the neural processing of action language. *Proceedings of the National Academy of Sciences of the United States of America, 105*(36), 13269-13273. doi:10.1073/pnas.0803424105

Beyer, G., Alt, F., Müller, J., Schmidt, A., Isakovic, K., Klose, S., Schiewe, M., & Haulsen, I. (2011). *Audience behavior around large interactive cylindrical screens*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, BC, Canada.

Beyer, G., Köttner, F., Schiewe, M., Haulsen, I., & Butz, A. (2013). *Squaring the circle: how framing influences user behavior around a seamless cylindrical display*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Paris, France.

Bolton, J., Kim, K., & Vertegaal, R. (2012). *A comparison of competitive and cooperative task performance using spherical and flat displays*. Paper presented at the Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work, Seattle, Washington, USA.

Brignull, H., & Rogers, Y. (2003). *Enticing people to interact with large public displays in public spaces.* Paper presented at the Proceedings of INTERACT.

Brown, B., Reeves, S., & Sherwood, S. (2011). *Into the wild: challenges and opportunities for field trial methods*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, BC, Canada.

Cannon, E. N., Yoo, K. H., Vanderwert, R. E., Ferrari, P. F., Woodward, A. L., & Fox, N. A. (2014). Action experience, more than observation, influences mu rhythm desynchronization. *PLoS ONE, 9*(3). doi:10.1371/journal.pone.0092002

Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proc Natl Acad Sci U S A, 100*(9), 5497-5502. doi:10.1073/pnas.0935845100

Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *Neuroimage, 12*(4), 478-484. doi:10.1006/nimg.2000.0635

Chatrian, G. E., Petersen, M. C., & Lazarte, J. A. (1959). The blocking of the rolandic wicket rhythm and some central changes related to movement. *Electroencephalography and Clinical Neurophysiology, 11*(3), 497-510. doi:10.1016/0013-4694(59)90048-3

Costantini, M., Ambrosini, E., Sinigaglia, C., & Gallese, V. (2011). Tool-use observation makes far objects ready-to-hand. *Neuropsychologia, 49*(9), 2658-2663. doi:10.1016/j.neuropsychologia.2011.05.013

Digital Signage Consortium. (2016). *Digital Signage 2020*. Tokyo, JAPAN: Tokyu Agency Inc.

Downing, P. E., Jiang, Y., Shuman, M., & Kanwisher, N. (2001). A cortical area selective for visual processing of the human body. *Science, 293*(5539), 2470-2473. doi:10.1126/science.1063414

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology, 73*(6), 2608-2611.

Fitzmaurice, G. W. (1996). *Graspable user interfaces.* University of Toronto.

Fitzmaurice, G. W., & Buxton, W. (1997). *An empirical evaluation of graspable user interfaces: towards specialized, space-multiplexed input.* Paper presented at the Proceedings of the ACM SIGCHI Conference on Human factors in computing systems.

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolotti, G. (2005). Neuroscience: Parietal lobe: From action organization to intention understanding. *Science, 308*(5722), 662-667. doi:10.1126/science.1106138

Forlines, C., Shen, C., Wigdor, D., & Balakrishnan, R. (2006). *Exploring the effects of group size and display configuration on visual search*. Paper presented at the Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work, Banff, Alberta, Canada.

Frey, S. H., Vinton, D., Norlund, R., & Grafton, S. T. (2005). Cortical topography of human anterior intraparietal cortex active during visually guided grasping. *Cognitive Brain Research, 23*(2-3), 397-405. doi:10.1016/j.cogbrainres.2004.11.010

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119 (Pt. 2)*, 593-609.

Gastaut, H. J., & Bert, J. (1954). EEG changes during cinematographic presentation; moving picture activation of the EEG. *Electroencephalogr Clin Neurophysiol, 6*(3), 433-444.

Grezes, J., Armony, J. L., Rowe, J., & Passingham, R. E. (2003). Activations related to "mirror" and "canonical" neurones in the human brain: an fMRI study. *Neuroimage, 18*(4), 928-937. doi:S1053811903000429 [pii]

Hart, R. A., & Moore, G. T. (1973). The development of spatial cognition: A review. In R. M. Downs & D. Stea (Eds.), *Image & environment: Cognitive mapping and spatial behavior* (pp. 246-288). New Brunswick, NJ, US: AldineTransaction.

Hassenzahl, M., Burmester, M., & Koller, F. (2003). AttracDiff: A questionnaire to measure perceived hedonic and pragmatic quality|AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualitat. *Mensch & Computer 2003. Interaktion in Bewegung*, 187-196.

Hawkey, K., Kellar, M., Reilly, D., Whalen, T., & Inkpen, K. M. (2005). *The proximity factor: impact of distance on co-located collaboration.* Paper presented at the Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work.

Hihara, S., Notoya, T., Tanaka, M., Ichinose, S., Ojima, H., Obayashi, S., Fujii, N., & Iriki, A. (2006). Extension of corticocortical afferents into the anterior bank of the intraparietal sulcus by tool-use training in adult monkeys. *Neuropsychologia, 44*(13), 2636-2646. doi:10.1016/j.neuropsychologia.2005.11.020

Horn, M. S., Leong, Z. A., Block, F., Diamond, J., Evans, E. M., Phillips, B., & Shen, C. (2012). *Of BATs and APEs: an interactive tabletop game for natural history museums*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Hornecker, E. (2008). *"I don't understand it either, but it is cool"-visitor interactions with a multi-touch table in a museum.* Paper presented at the Horizontal interactive human computer systems, 2008. TABLETOP 2008. 3rd IEEE International Workshop on.

Hornecker, E., & Buur, J. (2006). *Getting a grip on tangible interaction: a framework on physical space and social interaction.* Paper presented at the Proceedings of the SIGCHI conference on Human Factors in computing systems.

Hornecker, E., & Nicol, E. (2012). *What do lab-based user studies tell us about in-the-wild behavior?: insights from a study of museum interactives.* Paper presented at the Proceedings of the Designing Interactive Systems Conference, Newcastle Upon Tyne, United Kingdom.

Iacoboni, M. (2005). Neural mechanisms of imitation. *Curr Opin Neurobiol, 15*(6), 632-637. doi:10.1016/j.conb.2005.10.010

Iacoboni, M. (2009). Imitation, empathy, and mirror neurons. *Annu Rev Psychol, 60*, 653-670. doi:10.1146/annurev.psych.60.110707.163604

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Nature Reviews Neuroscience, 7*(12), 942-951. doi:10.1038/nrn2024

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science, 286*(5449), 2526-2528.

Ichino, J., Kanayama, N., Tano , S. i., & Hashiyama, T. (2012). Effects of Physical Display Size on Text Reading. *Trans. of Information Processing Society of Japan, 53*(5), 1570-1580.

Inkpen, K., Hawkey, K., Kellar, M., Mandryk, R., Parker, K., Reilly, D., Scott, S., & Whalen, T. (2005). *Exploring display factors that influence co-located collaboration: angle, size, number, and user arrangement.* Paper presented at the Proc. HCI international.

Ishii, H. (2008). The tangible user interface and its evolution. *Communications of the ACM, 51*(6), 32-36. doi:10.1145/1349026.1349034

Ishii, H., & Ullmer, B. (1997). *Tangible bits: Towards seamless interfaces between people, bits and atoms.* Paper presented at the Conference on Human Factors in Computing Systems - Proceedings.

Itoh, K., Kuwano, S., & Komatsubara, A. (2003). *Ergonomics Handbook*. Tokyo, JAPAN: Asakura Publishing Co., Ltd.

Jabbi, M., Swart, M., & Keysers, C. (2007). Empathy for positive and negative emotions in the gustatory cortex. *Neuroimage, 34*(4), 1744-1753. doi:10.1016/j.neuroimage.2006.10.032

Jarvelainen, J., Schurmann, M., & Hari, R. (2004). Activation of the human primary motor cortex during observation of tool use. *Neuroimage, 23*(1), 187-192. doi:10.1016/j.neuroimage.2004.06.010

Jeannerod, M., Arbib, M. A., Rizzolatti, G., & Sakata, H. (1995). Grasping objects: the cortical mechanisms of visuomotor transformation. *Trends Neurosci, 18*(7), 314-320. doi:016622369593921J [pii]

Johnson, R., Rogers, Y., Van der Linden, J., & Bianchi-Berthouze, N. (2012). *Being in the thick of in-the-wild studies: the challenges and insights of researcher participation*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Kendall, M. G. (1975). *Rank correlation methods* (4th ed.). London: Charles Griffin.

Kendon, A. (1990). *Conducting interaction: Patterns of behavior in focused encounters* (Vol. 7): CUP Archive.

Kortbek, K. J., & Grønbæk, K. (2008). *Interactive spatial multimedia for communication of art in the physical museum space*. Paper presented at the Proceedings of the 16th ACM international conference on Multimedia, Vancouver, British Columbia, Canada.

Kuikkaniemi, K., Jacucci, G., Turpeinen, M., Hoggan, E., & Müller, J. (2011). From Space to Stage: How Interactive Screens Will Change Urban Life. *Computer, 44*(6), 40-47. doi:10.1109/MC.2011.135

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *biometrics*, 159-174.

Müller-Tomfelde, C., Wessels, A., & Schremmer, C. (2008). *Tilted tabletops: In between horizontal and vertical workspaces.* Paper presented at the Horizontal Interactive Human Computer Systems, 2008. TABLETOP 2008. 3rd IEEE International Workshop on.

Müller, J., Alt, F., Michelis, D., & Schmidt, A. (2010). *Requirements and design space for interactive public displays*. Paper presented at the Proceedings of the 18th ACM international conference on Multimedia, Firenze, Italy.

Müller, J., Eberle, D., & Tollmar, K. (2014). *Communiplay: a field study of a public display mediaspace*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada.

Müller, J., Walter, R., Bailly, G., Nischt, M., & Alt, F. (2012). *Looking glass: a field study on noticing interactivity of a shop window*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Maravita, A., & Iriki, A. (2004). Tools for the body (schema). *Trends Cogn Sci, 8*(2), 79-86. doi:10.1016/j.tics.2003.12.008

Marquardt, N., Hinckley, K., & Greenberg, S. (2012). *Cross-device interaction via micro-mobility and f-formations*. Paper presented at the Proceedings of the 25th annual ACM symposium on User interface software and technology, Cambridge, Massachusetts, USA.

Marshall, P., Morris, R., Rogers, Y., Kreitmayer, S., & Davies, M. (2011). *Rethinking 'multi-user': an in-the-wild study of how groups approach a walk-up-and-use tabletop interface*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, BC, Canada.

Marshall, P., Rogers, Y., & Pantidi, N. (2011). *Using F-formations to analyse spatial patterns of interaction in physical environments*. Paper presented at the Proceedings of the ACM 2011 conference on Computer supported cooperative work, Hangzhou, China.

Matoba, Y., Takahashi, Y., Tokui, T., Phuong, S., Yamano, S., & Koike, H. (2013). *AquaTop display: a true "immersive" water display system*. Paper presented at the ACM SIGGRAPH 2013 Emerging Technologies, Anaheim, California.

McNeill, D. (2005). Gesture, gaze, and ground. In S. Renals & S. Bengio (Eds.), *Machine Learning for Multimodal Interaction* (Vol. 3869, pp. 1-14).

Mecklinger, A., Gruenewald, C., Besson, M., Magnie, M. N., & Von Cramon, D. Y. (2002). Separable neuronal circuitries for manipulable and non-manipulable objects in working memory. *Cereb Cortex, 12*(11), 1115-1123.

Michelis, D., & Müller, J. (2011). The Audience Funnel: Observations of Gesture Based Interaction With Multiple Large Displays in a City Center. *International Journal of Human-Computer Interaction, 27*(6), 562-579. doi:10.1080/10447318.2011.555299

Molenberghs, P., Cunnington, R., & Mattingley, J. B. (2009). Is the mirror neuron system involved in imitation? A short review and meta-analysis. *Neurosci Biobehav Rev, 33*(7), 975-980. doi:10.1016/j.neubiorev.2009.03.010

Murata, A., Fadiga, L., Fogassi, L., Gallese, V., Raos, V., & Rizzolatti, G. (1997). Object representation in the ventral premotor cortex (area F5) of the monkey. *J Neurophysiol, 78*(4), 2226-2230.

Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu rhythm modulation during observation of an object-directed grasp. *Brain Res Cogn Brain Res, 19*(2), 195-201. doi:10.1016/j.cogbrainres.2003.12.001

Nakajima, K., Itoh, Y., Tsukitani, T., Fujita, K., Takashima, K., Kitamura, Y., & Kishino, F. (2011). *FuSA^2 touch display: a furry and scalable multi-touch display*. Paper presented at the Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, Kobe, Japan.

Nakamura, I., & Ishido, N. (2009). *Digital Signage Revolution*. Tokyo, JAPAN: Asahi Shimbun Publications Inc.

National Council of University Museology Course of Japan. (2008). *New Museology*: Fuyo－Syobo Syuppann.

O'Malley, C., & Fraser, D. S. (2004). Literature review in learning with tangible technologies. *A NESTA Futurelab Research report, report 12*.

Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altschuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Brain Res Cogn Brain Res, 24*(2), 190-198. doi:10.1016/j.cogbrainres.2005.01.014

Oberman, L. M., McCleery, J. P., Ramachandran, V. S., & Pineda, C. (2007). EEG evidence for mirror neuron activity during the observation of human and robot actions: Toward an analysis of the human qualities of interactive robots. *Neurocomputing, 70*(13-15), 2194-2203

Oberman, L. M., Pineda, J. A., & Ramachandran, V. S. (2007). The human mirror neuron system: A link between action observation and social skills. *Soc Cogn Affect Neurosci, 2*(1), 62-66. doi:10.1093/scan/nsl022

Oshima, M., & Okubo, T. (2005). *Encyclopedia of ergonomics*. Tokyo, JAPAN: Maruzen Co., Ltd.

Patten, J., & Ishii, H. (2000). *A comparison of spatial organization strategies in graphical and tangible user interfaces.* Paper presented at the Proceedings of DARE 2000 on Designing augmented reality environments.

Pedersen, E. W., & Hornbæk, K. (2012). *An experimental comparison of touch interaction on vertical and horizontal surfaces*. Paper presented at the Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design, Copenhagen, Denmark.

Peeters, R., Simone, L., Nelissen, K., Fabbri-Destro, M., Vanduffel, W., Rizzolatti, G., & Orban, G. A. (2009). The representation of tool use in humans and monkeys: common and uniquely human features. *J Neurosci, 29*(37), 11523-11539. doi:10.1523/JNEUROSCI.2040-09.2009

Peltonen, P., Kurvinen, E., Salovaara, A., Jacucci, G., Ilmonen, T., Evans, J., Oulasvirta, A., & Saarikko, P. (2008). *"It's mine, don't touch!": Interactions at a large multi-touch display in a city centre.* Paper presented at the Conference on Human Factors in Computing Systems - Proceedings.

Perry, A., & Bentin, S. (2009). Mirror activity in the human brain while observing hand movements: a comparison between EEG desynchronization in the mu-range and previous fMRI results. *Brain Res, 1282*, 126-132. doi:10.1016/j.brainres.2009.05.059

Pfurtscheller, G., & Neuper, C. (1997). Motor imagery activates primary sensorimotor area in humans. *Neurosci Lett, 239*(2-3), 65-68. doi:S0304-3940(97)00889-6 [pii]

Pfurtscheller, G., Neuper, C., & Krausz, G. (2000). Functional dissociation of lower and upper frequency mu rhythms in relation to voluntary limb movement. *Clinical Neurophysiology, 111*(10), 1873-1879. doi:10.1016/S1388-2457(00)00428-4

Pineda, J. A. (2005). The functional significance of mu rhythms: translating "seeing" and "hearing" into "doing". *Brain Res Brain Res Rev, 50*(1), 57-68. doi:10.1016/j.brainresrev.2005.04.005

Pineda, J. A., Allison, B. Z., & Vankov, A. (2000). The effects of self-movement, observation, and imagination on mu rhythms and readiness potentials (RP's): toward a brain-computer interface (BCI). *IEEE Trans Rehabil Eng, 8*(2), 219-222.

Potvin, B., Swindells, C., Tory, M., & Storey, M.-A. (2012). Comparing horizontal and vertical surfaces for a collaborative design task. *Advances in Human-Computer Interaction, 2012*, 6.

Preston, S. D., & de Waal, F. B. M. (2002). Empathy: Its ultimate and proximate bases. *Behavioral and Brain Sciences, 25*(1), 1-20. doi:10.1017/S0140525X02000018

Reeves, S., Benford, S., O'Malley, C., & Fraser, M. (2005). *Designing the spectator experience.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Rizzolatti, G., Cattaneo, L., Fabbri-Destro, M., & Rozzi, S. (2014). Cortical mechanisms underlying the organization of goal-directed actions and mirror neuron-based action understanding. *Physiol Rev, 94*(2), 655-706. doi:10.1152/physrev.00009.2013

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annu Rev Neurosci, 27*, 169-192. doi:10.1146/annurev.neuro.27.070203.144230

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Brain Res Cogn Brain Res, 3*(2), 131-141.

Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., & Fazio, F. (1996). Localization of grasp representations in humans by PET .1. Observation versus execution. *Experimental Brain Research, 111*(2), 246-252.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience, 2*(9), 661-670. doi:10.1038/35090060

Rizzolatti, G., & Matelli, M. (2003). Two different streams form the dorsal visual system: Anatomy and functions. *Experimental Brain Research, 153*(2), 146-157. doi:10.1007/s00221-003-1588-0

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nat Rev Neurosci, 11*(4), 264-274. doi:10.1038/nrn2805

Rogers, Y. (2011). Interaction design gone wild: striving for wild theory. *Interactions, 18*(4), 58-62.

Rogers, Y., & Lindley, S. (2004). Collaborating around vertical and horizontal large interactive displays: which way is best? *Interacting with Computers, 16*(6), 1133-1152.

Rummel, R. J. (1975). *Understanding conflict and war Vol. 1: The Dynamic Psychological Field.* Beverly Hills, California: Sage Publications.

Ryall, K., Forlines, C., Shen, C., & Morris, M. R. (2004). *Exploring the effects of group size and table size on interactions with tabletop shared-display groupware.* Paper presented at the Proceedings of the 2004 ACM conference on Computer supported cooperative work.

Sato, M., Katsuura, T., Sato, H., Tochihara, Y., & Yokoyama, S. (1992). *Ergonomics standard numerical formula handbook.* Tokyo, JAPAN: Gihodo Shuppan Co., Ltd.

Schmidt, C., Müller, J., & Bailly, G. (2013). *Screenfinity: extending the perception area of content on very large public displays.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Paris, France.

Schraa-Tam, C. K. L., Rietdijk, W. J. R., Verbeke, W. J. M. I., Dietvorst, R. C., Van Den Berg, W. E., Bagozzi, R. P., & De Zeeuw, C. I. (2012). fMRI activities in the emotional cerebellum: A preference for negative stimuli and goal-directed behavior. *Cerebellum, 11*(1), 233-245. doi:10.1007/s12311-011-0301-2

Shaer, O., & Hornecker, E. (2009). Tangible User Interfaces: Past, present, and future directions. *Foundations and Trends in Human-Computer Interaction, 3*(1-2), 1-137. doi:10.1561/1100000026

Shigemasu, H., Morita, T., Matsuzaki, N., Sato, T., Harasawa, M., & Aizawa, K. (2006). *Effects of physical display size and amplitude of oscillation on visually induced motion sickness.* Paper presented at the Proceedings of the ACM symposium on Virtual reality software and technology.

Shmuelof, L., & Zohary, E. (2005). Dissociation between ventral and dorsal fMRI activation during object and action recognition. *Neuron, 47*(3), 457-470. doi:10.1016/j.neuron.2005.06.034

Sommer, R. (1969). Personal Space. The Behavioral Basis of Design.

Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., O'Malley, C., Wilson, J., & Pridmore, T. (2001). *Classroom collaboration in the design of tangible* *interfaces for storytelling.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*: Cambridge university press.

Suzuki, H., & Kato, H. (1995). *Interaction-level support for collaborative learning: AlgoBlock—an open programming language.* Paper presented at the The first international conference on Computer support for collaborative learning.

Tan, D. S., Gergle, D., Scupelli, P., & Pausch, R. (2006). Physically large displays improve performance on spatial tasks. *ACM Transactions on Computer-Human Interaction, 13*(1), 71-99. doi:10.1145/1143518.1143521

Ten Koppel, M., Bailly, G., Müller, J., & Walter, R. (2012). *Chained displays: configurations of public displays can be used to influence actor-, audience-, and passer-by behavior.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

The Japan Society for Exhibition Studies. (2010). *Exhibitionology*: Yuzankaku.

Ulloa, E. R., & Pineda, J. A. (2007). Recognition of point-light biological motion: mu rhythms and mirror neuron activity. *Behav Brain Res, 183*(2), 188-194. doi:10.1016/j.bbr.2007.06.007

Van Den Hoven, E., Frens, J., Aliakseyeu, D., Martens, J. B., Overbeeke, K., & Peters, P. (2007). *Design research & tangible interaction.* Paper presented at the TEI'07: First International Conference on Tangible and Embedded Interaction.

Van Elk, M., Van Schie, H. T., Zwaan, R. A., & Bekkering, H. (2010). The functional role of motor activation in language processing: Motor cortical oscillations support lexical-semantic retrieval. *Neuroimage, 50*(2), 665-677. doi:10.1016/j.neuroimage.2009.12.123

Vogel, D., & Balakrishnan, R. (2004). *Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users.* Paper presented at the Proceedings of the 17th annual ACM symposium on User interface software and technology, Santa Fe, NM, USA.

Vogt, S., Buccino, G., Wohlschlager, A. M., Canessa, N., Shah, N. J., Zilles, K., Eickhoff, S. B., Freund, H. J., Rizzolatti, G., & Fink, G. R. (2007). Prefrontal involvement in imitation learning of hand actions: Effects of practice and expertise. *Neuroimage, 37*(4), 1371-1383. doi:10.1016/j.neuroimage.2007.07.005

Wakkary, R., Muise, K., Tanenbaum, K., Hatala, M., & Kornfeld, L. (2008). Situating approaches to interactive museum guides. *Museum Management and Curatorship, 23*(4), 367-383. doi:10.1080/09647770802517423

Wallace, J. R., Mandryk, R. L., & Inkpen, K. M. (2008). *Comparing content and input redirection in MDEs.* Paper presented at the Proceedings of the 2008 ACM conference on Computer supported cooperative work.

Weinschenk, S. (2011). *100 Things Every Designer Needs to Know About People* CA, USA: Pearson Education, Inc.

Wigdor, D., Shen, C., Forlines, C., & Balakrishnan, R. (2006). *Effects of display position and control space orientation on user preference and performance.* Paper presented at the Proceedings of the SIGCHI conference on Human Factors in computing systems.

Zuckerman, O., & Gal-Oz, A. (2013). To TUI or not to TUI: Evaluating performance and preference in tangible vs. graphical user interfaces. *International Journal of Human Computer Studies, 71*(7-8), 803-820. doi:10.1016/j.ijhcs.2013.04.003

Appendix

Appendix A: 28 items of the questionnaire in AttrakDiff (http://www.attrakdiff.de/).

Hedonic quality–identification (HQI)	isolating—integrating amateurish—professional gaudy—classy cheap—valuable noninclusive—inclusive takes me distant from people—brings me closer to people unpresentable—presentable
Hedonic quality–stimulation (HQS)	typical—original standard—creative cautious—courageous conservative—innovative lame—exciting easy—challenging commonplace—new
Pragmatic quality (PQ)	technical—human complicated—simple impractical—practical cumbersome—direct unpredictable—predictable confusing—clear unruly—manageable
ATT	unpleasant—pleasant ugly—beautiful disagreeable—likable rejecting—inviting bad—good repelling—appealing discouragin—motivating

Appendix B: Observing social communication using the anonymized data.

Depth video (3D depth sensor of Kinect)		- Our study used depth videos and manually coded transitions between different types of space in the model by Brignull et al., spatial arrangement of users, and physical and visual contact. Since visual contact is momentary action, it was necessary to examine the depth videos multiple times, more often (still Cohen's Kappa = 0.73).
		- Although our study did not code gender and age ranges (measured in a 10 to 20 year interval) of users and relationship between users, they were easily obtainable from the videos.
		- Similarly to any real-time image processing, time stamp of the depth image file does not match the time the image was actually taken. Because of this, manual adjustment is necessary for synchronizing multiple Kinects and also synchronizing Kinect and other devices.
Skeleton (3D depth sensor of Kinect)	Body	- Our study used skeleton to obtain an approximate number of users near the display and how such number changes over time (**Figure 5.4**).
		- Skeleton may be used to evaluate spatial arrangement of users and proximity of users (Marquardt, Hinckley, & Greenberg, 2012). However, when a body was facing sideways to the camera or when multiple bodies overlap, skeleton failed to provide accurate information regarding user bodies. Thus, skeleton may not be suitable for the environment where users dynamically move. Our use of skeleton in the field resulted in low accuracy, and we decided not to use skeleton for this purpose.
	Face	- The position and direction of the head may be used to determine if the user is either in *focal awareness* (Brignull & Rogers, 2003) or *viewing and reacting* (Müller et al., 2010) (e.g., Schmidt et al., 2013). However, our use of skeleton in the field resulted in low accuracy, and we decided not to use skeleton for this purpose.
Volume level (mic of Kinect)		- We failed to capture the volume level in this study.
		- Volume level may be used to measure the activity level of discussion.
RFID access log		- Our study used RFID access logs to determine whether a user is in front of the display.
		- When using a model that classifies types of space based on the distance (e.g., Vogel & Balakrishnan, 2004), RFID access logs may easily identify different types of space.
Display Interaction log (content access log)		- When two or more users interact through the display, identifying which user carried out which operation may be useful in determining the activity level of social communication and group dynamics.
		- However, linking users and operations is difficult. In the 10th exhibit, while we were collecting touch interaction logs, we linked them to RFID access logs on a real time basis. A set of touch interaction logs and RFID access logs was not sufficient to determine which user carried out a given operation, when there are two or more users. Because of this, and because our study focuses on social communication among users, our study did not use the touch interaction log. This issue may be addressed through linking the touch interaction log to sensor-obtained information (body and arm placement and direction).
		- When considering gesture-based interactions, this is not an issue, as examining gesture-based interactions require identifying each individual user to begin with.