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Come on in! : A Strategic Way to Intend Approachability to a Space by Using Motions of a Robotic Partition

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***Abstract*— Interactive space has been suggested as a future direction for architectural development on the basis of technological advances, and the design factors that affect the user experience of space thus need to be explored. Motion is one of the critical means of affective expression for facial-constrained and verbal-constrained robots such as functional robots. This paper introduces an interactive robotic partition that recognizes a person around it and reacts to the person by expressing physical motions. Using the robotic partition, we conducted a 7 (type of motions: moving toward, moving away, expanding, contracting, incurving, outcurving, and trembling) x 2 (user perspective: approaching to the partition vs. sitting inside the partition) within-participants experiment (*N*=28). Participants showed higher approachability to the space and greater preference for *incurving* and *expanding* motions than *trembling* motion. The results also showed an interaction effect between motion and user perspective. When the partition expressed *moving toward* and *expanding* motions, participants in a sitting perspective reported higher approachability and greater preference than participants with an approaching perspective whereas opposite results were revealed when the partition showed *moving toward* and *contracting* motions. Implications for design are discussed.**

I. Introduction

Since the 1960's architecture group, Archigram and Metaboilist, developed an adaptive space design, researchers have predicted the generalizability of interactive space in our daily lives with technological advances. Negroponte predicted human-made environments that interact with humans and is meaningful to human [1]. Weiser suggested the concept of ubiquitous space that is thoroughly integrated with everyday computation in every daily objects [2]. Furthermore, people in general have become accustomed to the concept of adaptive space through exposure to movies such as Howl's Moving Castle, Harry Potter, Inception, etc. In Harry Potter, there is a room that can change its function and shape according to a passenger's needs by reading his/her mind. The paradigm in interactive space is thus now shifting from space as a machine for living [3] to space as a robot for living [4].

There are two ways of interaction with a space: using immaterial factors such as light, temperature and sound and using motion of physical objects that can change their position and shape. Research in the field of Human-Robot Interaction (HRI) has revealed higher effectiveness of motion than other modalities on inducing people's familiarity to an abstract shaped robot [5]. Motion can be divided into three types: embedded, dynamic, and deployable [6]. Among these three types, dynamic motion can directly affect the size and composition of a space and further, it can influence on people's experience of the space.

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Figure 1. The robotic partition reacting to people around it

This study focuses on the physical motion of a robotic partition that composes a certain space and affects people's experience of the space. We designed a robotic partition and investigated the effect of motion on people's perceived approachability with considering two user perspectives: a user approaching to the partition and a user sitting inside the partition, as described in Fig. 1.

II. Related Works

A. Interaction with Space

Technological development allows us to interact not only with a product, but also with a space. Research has suggested interactive structure composing space from emotional [7, 8], physiological [9], and functional perspectives [10].

Oosterhuis proposed Emotive House which can react to the movement of users and change in the weather by expanding, shrinking, contracting and relaxing its structures [7]. Yiannoudes suggested a conceptual framework for designing affective and socially engaging kinetic architectural structures on the basis of the argument that architecture can convey emotional information like the human body [8]. From a physiological perspective, Schnadelbach defined adaptive architecture as buildings or spaces that are adaptive to their environment, their inhabitants and objects within them and

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developed ExoBuilding having a tent-like structure, which moves by user's physiological data such as breathing [9]. People felt comfortable when they stayed in ExoBuilding because they perceived the structure as being adaptive to them.

Ju and Takayama [10] developed an automatic door that moves with different speeds and trajectories and demonstrated the effect of the door's motion on people's sense of approachability based on the theory of implicit interactions and theory of affordance. The results showed the possibility of using people's gesture in interactive device design.

Research also has revealed the relationship between form and motion of intelligent structure. Yiannoudes defined an intelligent kinetic structure as a physical object that is able to change its form proactively or reactively to a human's behavior and presence [11]. He contended that the structure needs to be perceived as an animate entity to enhance the interaction with a user, and there is an interaction effect between form and motion of the structure on people's perceived animacy. Applying rapid exaggerated motion is desirable for a structure comprised of simple form and geometrics while a structure having an exaggerated form do not need complex motion. Thus, it is plausible that exaggerated motions are effectible factors for walls and doors, composing a space with simple form, to be perceived as interactive creatures and further, living creatures.

B. *Interaction using Motions*

Research has revealed that a robot's motion is a useful interaction modality for people to understand the robot's mind and states, even when the robot has lower anthropomorphism [5, 12, 13, 14].

Based on human body language, Jung, Bae, Lee, and Kim suggested a motion design method for interactive product designers and researchers to induce affective user experience of movable objects [12]. X-axis motions sent intentions such as 'bowing', 'yes' and 'listening', while y-axis motions expressed 'thinking' and 'dubious'. Gerlinghaus et al. designed a robotic desk lamp that is capable of expressing the four basic Ekman emotions (e.g., joy, sadness, surprise, fear) by imitating human body language [14]. Joy and sadness were recognized well by people, but fear and surprise were misunderstood as surprise and disgust.

Harris and Sharlin showed the emotional impact of abstract robot motion on social interaction between humans and robots [13]. Even without a functional context and a specific appearance, frequency and directions of an abstract robotic motion delivered different emotions of a robot to people. Thus, it seems likely that people's perception of a robotic product's expression is more dependent on its motion than its appearance.

This paper presents a robotic partition, a partition that can automatically change its position and form. A partition is a wall or screen that separates one part of a room from another. By moving a partition, the spatial characteristics of a space, such as space size, open and closed space, and structure of the space are changed. Even though the form of a partition is simple, it is plausible that the robotic partition can convey a specific interactional intention by showing specific motions in a space, and it consequently affect people's experience of the space.

Section Ⅲ of this paper describes what kind of motions of a movable partition are expected, and how we designed the robotic partition in order to realize those motions. In Section Ⅳ, we explored how those motions affect people's experience of a space, especially approachability to a space.

III. Robotic Partition Prototype Design

A. *Motions of a Partition*

We extracted the available motions of a partition by conducting a workshop with eight designers from an engineering school who are familiar with both technology and product design.

In the initial session, we let the designers draw physical motions they expected from a movable partition. Next, we asked them to talk and write about possible activities that can happen in a public space. After that, participants made appropriate matches between the extracted motions and activities. The motions the designers suggested were categorized into four types: move, expand, curve, and tremble, as shown in Table 1.

TABLE I. Physical Motions of a Partition

Category	**Motions**
Move	Move as it is, move with horizontally or vertically folded
Expand	One-way, two-way, horizontally
Curve	Curve, curve upper part or lower part
Tremble	Tremble, shake, wave

B. *Prototype of a Robotic Partition*

A prototype of a robotic partition was designed to express the motions noted above. Its height is 120cm common to provide screening a person seated. Its width ranges from 50cm to 200cm. It is framed by three columns: two columns on both ends can move on both the x and y axes, and the middle column can only move from side to side on the x-axis, by having two motors and three wheels controlled by Arduino as illustrated in Fig. 2. To operate the robotic partition by remote controller, we attached X-bee Shields on each arduino. The upper part of the robotic partition is made with a light-weight paper and thin lumbers. We folded the paper into honeycomb structure to make its shape stable without sagging. The paper is attached between the columns, which were framed by thin lumbers. The partition's weight is about 1.8 kg, light enough to be carried by a person. The moving speed of the partition is about 28cm/s.

Experiment Setup

The experiment used 7 (type of motions: moving toward, moving away, expanding, contracting, incurving, outcurving, and trembling) x 2 (user perspective: approaching to the partition vs. sitting inside the partition) within-participants experiment design.

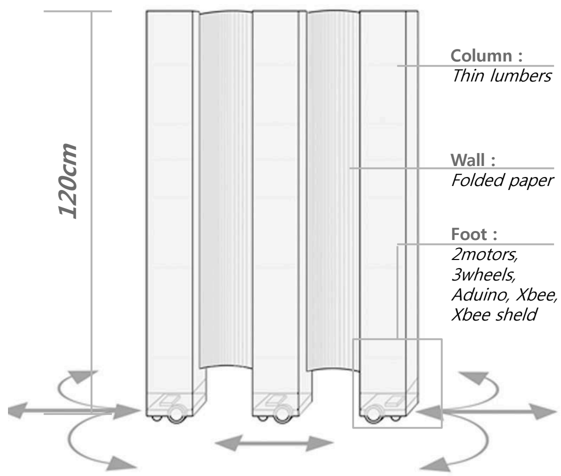

Figure 2. Direction and range of motion for the robotic partition

Research in the field of HRI has shown that abstract motions can deliver different emotions to people [7, 10, 11, 12]. Following Mehrabian and Russel's argument that people's emotion toward a space affects their attitude toward the space, especially approachability [15], it seems likely that the robotic partition's motions would affect the user's experience toward the space where the partition is located. In addition, approachability indicates willingness to enter the space inside the partition for the case of a person approaching the partition while it indicates willingness to stay in the space for the case of a person sitting inside the partition. This allows us to predict that people's perspective can affect their approachability of a space.

The research hypotheses are as follows:

H1. The degree of people's approachability will vary according to motion of a robotic partition.

H2. The degree of people's approachability will be affected by an interaction between motion and user perspective.

A. Participants

Twenty-eight engineering school students who are familiar with technology participated in the study. The age of the participants ranged from 24 to 33 years (*M*=27.44, *SD*=2.89).

B. Design of Motions for a Robotic Partition

We designed seven motions of the robotic partition referring to the four categories of physical motions extracted from the workshop noted above. Six motions are in pairs (move: *moving toward* vs. *moving away*; expand: *expanding* vs. *contracting*; curve: *incurving* vs. *outcurving*) and the last motion is *trembling*, as shown in Fig. 3.

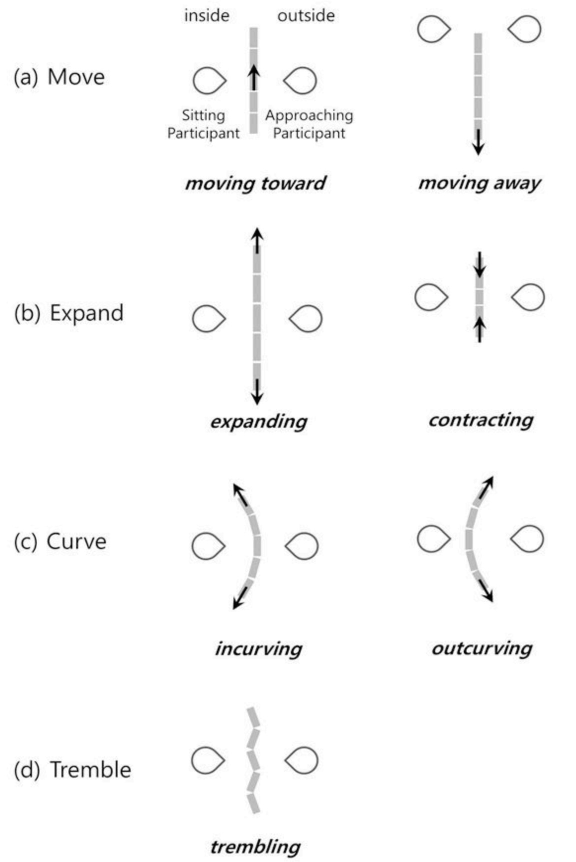

Figure 3. Seven motions of a robotic partition: (a) move (moving toward vs. moving away), (b) expand (expanding vs. contracting), (c) curve (incurving vs. outcurving), and (d) trembling

C. Materials

Two sets of seven video prototypes recording robotic partition's motions were used in this study. To overcome the experimental limitation caused by short maintenance time of batteries, video prototypes were used on the basis of research that has demonstrated that videotaped trials could be used as a complementary research tool for testing HRI scenario [16]. The video prototypes were recorded from a first person viewpoint. The two sets have different user perspectives; one takes the perspective of an approaching person who is located outside of the partition, and the other is the perspective of a sitting person who is located inside of the partition, as shown in Fig. 4. 22 inch size monitor was used to show the video. The sound was muted in order to focus on the motion of the robotic partition.

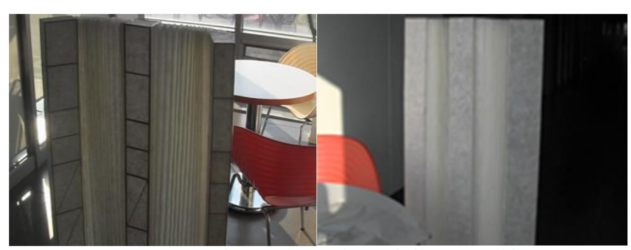

Figure 4. Two types of user perspectives: (left) approaching person's perspective, (right) sitting person's perspective

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D. *Procedure*

Researchers briefly introduced the research and gave a consent form to participants. If the participant agreed, researchers showed them two video clips that help participants to distinguish an approaching person's and a sitting person's perspective. Next, participants watched 14 video clips with seven motions and two user perspective. The order of the video clips was randomized. After watching all video clips, participants were asked to complete a questionnaire, and researchers conducted an interview.

E. *Measures*

We used the Verbal Measures of Approach–Avoidance to measure participants' reaction to the motion of the robotic partition, drawn from the field of environmental psychology. The three dimensions, desire to stay, desire to experience, and desire to affiliate, were evaluated with both positively and negatively expressed questions, as described in Table 2. The score of positive question and the reversed score of negative question were averaged.

Also, we asked participants to rate their preference for the motions of the robotic partition. All measures were answered by a 7-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree."

TABLE II. VERBAL MEASURES OF APPROACH –AVOIDANCE

Desire to stay in the situation (+) How much time would you like to spend in this situation (–) How much would you try to leave or get out of this situation?
Desire to explore the situation (+) Once in this situation, how much would you enjoy exploring? (–) How much would you try to avoid any looking around or exploration of this situation? (0=no avoidance)
Desire to affiliate in the situation (+) To what extent is this a situation in which you would feel friendly and talkative to a stranger who happens to be near you? (–) Is this a situation in which you might try to avoid other people, avoid having to talk to them? (0=no avoidance)

IV. RESULTS

A. *Effect of a Robotic Partition's Motions*

The motion of the robotic partition significantly affected people's approachability, especially their desire to stay, $F(6,385)=3.36$, $p<.01$. Pairwise comparisons showed that *expanding* and *incurving* induced higher desire to stay than *trembling* (*expanding-trembling*: $t=3.52$, $df=0.55$, $p<.01$, *incurving-trembling*: $t=3.44$, $df=0.55$, $p<.05$). When comparing through the mean values, the desire to stay is affected in the order of *incurving, expanding, moving away, outcurving, moving toward, contracting,* and *trembling*, as shown in Fig. 5 (a).

Desire to explore, $F(6,385)=1.18$, $p=.31$ and desire to affiliate, $F(6,385) = 0.92$, $p=.47$ were not significantly different according to the motion of the robotic partition.

The motion of the robotic partition significantly affected people's preference, $F(6,385)=2.29$, $p<.05$. When comparing through the average values, the motions were preferred in order of *expanding, incurving, moving away, moving toward, outcurving, contracting,* and *trembling*, as shown in Fig. 5 (b).

B. *Interaction Effect between a Motion and User Perspective*

User perspective alone did not affect desire to stay, $F(1,390)=0.41$, $p=.52$, desire to explore, $F(1,390)=1.89$, $p=.17$, and desire to affiliate, $F(1,390)=0.01$, $p=.91$. The results, however, showed a significant interaction effect between user perspective and motion of the robotic partition on participants' desire to stay, $F(6,378)=16.00$, $p<.01$, desire to explore, $F(6,378)=1.80$, $p<.10$, and desire to affiliate, $F(6,378)=4.60$, $p<.01$.

For the case of desire to stay, when the robotic partition showed *moving away* and *contracting* motions, the participants having an approaching perspective more strongly desired to stay than the participants having an sitting perspective (*moving away*: $F(1,54)=21.59$, $p<.01$, *contracting*: $F(1,54)=32.00$, $p<.01$) while the participants having an sitting perspective more strongly desired to stay than the participants having an approaching perspective when the robotic partition showed *incurving, outcurving, moving toward,* and *expanding*

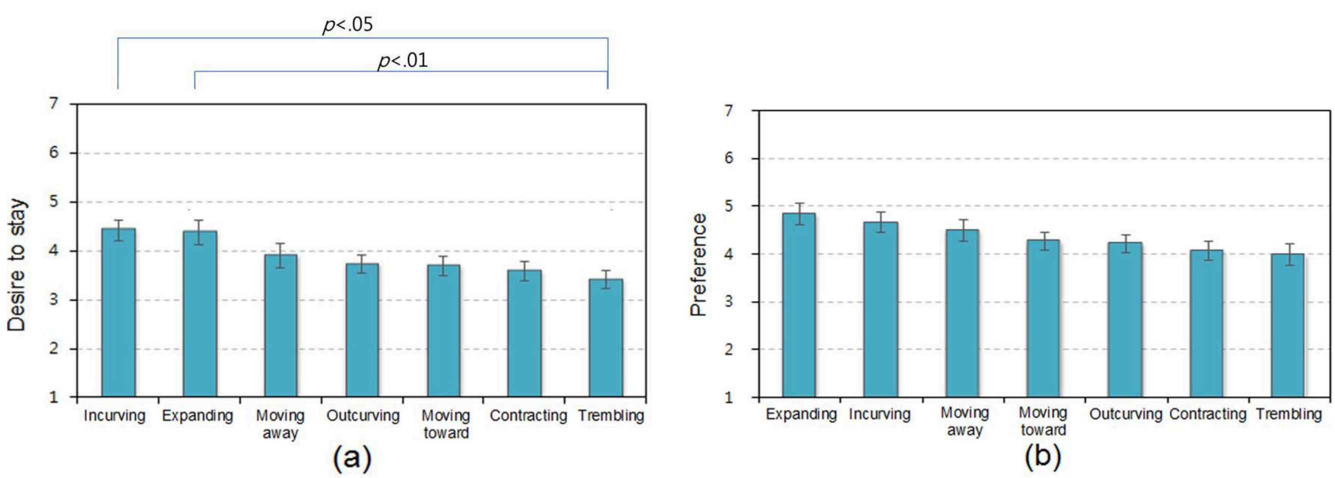

Figure 5. Effect of motions (a) on desire to stay and (b) on people's preference

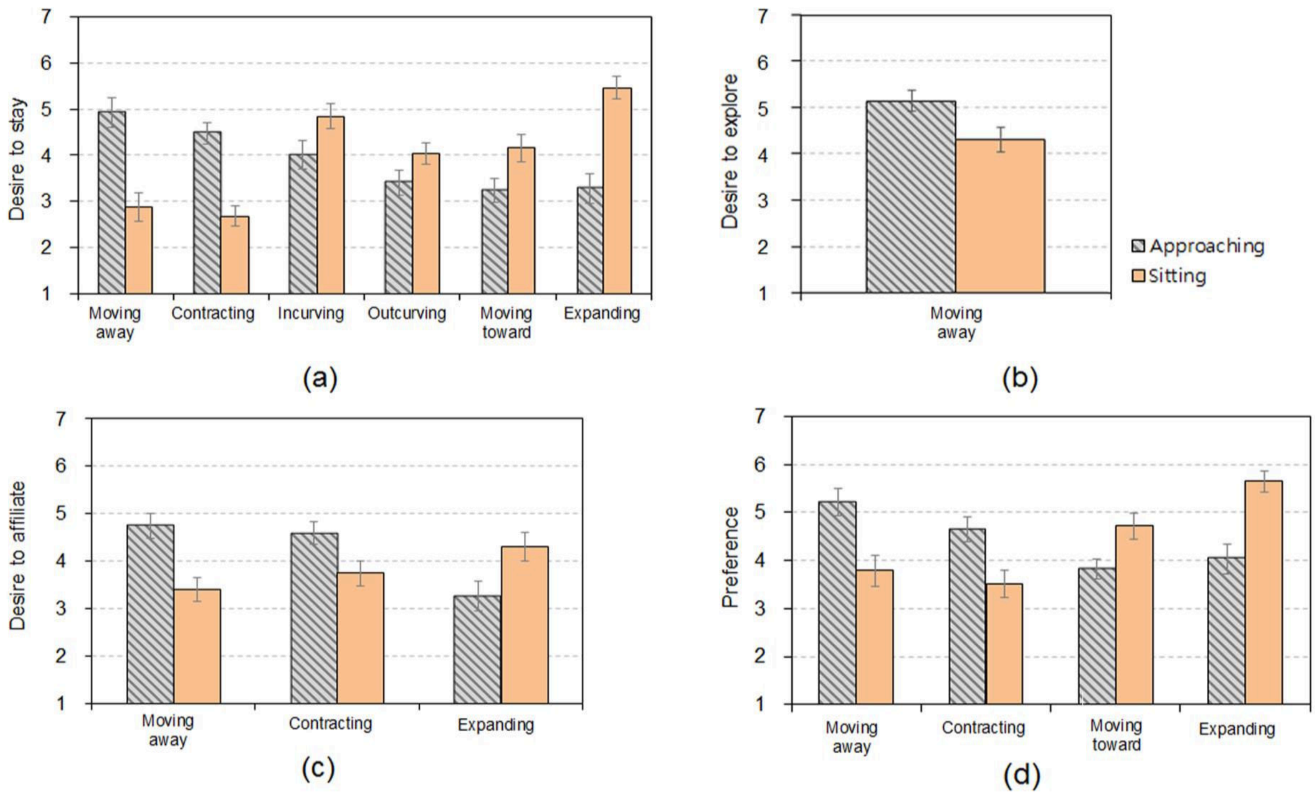

Figure 6. Interaction effect between motion and user perspective (a) on desire to stay, (b) on desire to explore, (c) on desire to affiliate, and (d) on people's preference

motions (*incurving*: $F(1,54)=4.22$, $p<.05$, *outcurving*: $F(1,54)=3.23$, $p<.10$, *moving toward*: $F(1,54)=5.76$, $p<.05$, and *expanding*: $F(1,54)=30.10$, $p<.01$). These results are illustrated in Fig. 6 (a).

For the case of desire to explore, the participants having an approaching perspective were more interested in the partition and the given situation than the participants having a sitting perspective when the partition showed the *moving away* motion, $F(1,54)=5.98$, $p<.05$, while participants' desire to explore was not significantly affected by the user perspective when the partition showed the remaining motions except *moving away motion,* as shown in Fig. 6 (b).

For the case of desire to affiliate, pairwise comparison showed that when the robotic partition expressed the *expanding* motion, the participants having a sitting perspective more strongly desired to affiliate than the participants having an approaching perspective, $F(1,54)=5.61$, $p<.05$ while the participants having an approaching perspective more strongly desired to affiliate than the participants having a sitting perspective when the robotic partition showed *moving away* and *contracting* motion (*moving away*: $F(1,54)=13.87$, $p<.01$, *contracting*: $F(1,54)=5.59$, $p<.05$). These results are illustrated in Fig. 6 (c).

The analysis also showed an interaction effect between motion and user perspective on people's preference, $F(6,378)=7.61$, $p<.01$. Pairwise comparison showed that when the robotic partition showed *moving away* and *contracting* motions, the participants having an approaching perspective more strongly preferred the motions than the participants having a sitting perspective (*moving away*: $F(1,54)=11.23$, $p<.05$, *contracting*: $F(1,54)=8.86$, $p<.05$) while the participants having a sitting perspective more strongly preferred the robotic partition's motions than the participants having an approaching perspective when the robotic partition showed *moving toward* and *expanding* motions (*moving toward*: $F(1,54)=6.56$, $p<.05$, *expanding*: $F(1,54)=18.18$, $p<.01$), as shown in Fig. 6 (d).

Discussion

A. *Summary and Interpretations of Results*

In this paper, we introduced a robotic partition that moves automatically and explored the effect of its motion on people's approachability to a space.

H1 predicted that the degree of people's approachability will vary according to motion of a robotic partition. The results provided support for H1. Participants desired to stay in the space and preferred the motion of the robotic partition when the robotic partition showed *incurving* and *expanding* motion over when it showed *trembling* motion.

H2 predicted that the degree of people's approachability will be affected by an interaction between motion and user perspective. The results provided conditional support for H2. When the robotic partition showed *incurving*, *outcurving*, *expanding* and *moving toward* motions, the participants in a sitting perspective felt greater approachability than the participants in an approaching perspective. On the contrary, the participants in an approaching perspective felt greater approachability than the participants in a sitting perspective when the robotic partition showed *moving away* and *contracting* motions. In addition, the participants in an approaching perspective preferred *moving away* and *contracting* motions compared to the participants in a sitting perspective while the participants in a sitting perspective preferred *moving toward* and *expanding* motions compared to the participants in an approaching perspective.

B. Implications of Research

The results of this study demonstrated that motion of a robotic partition affects people's willingness to stay in the space surrounded by the robotic partition, rather than their willingness to explore the place and affiliate with people in the place. This indicates that motion of the robotic partition elicits people's primary reactions reflecting their perceived approachability to the space and its effect is restrictively extended to secondary reactions that appear after the primary reaction.

Regarding people's preference on motion of a robotic partition, the results of this study showed that people's likes and dislikes are clear when the cues of approachability from the robotic partition's motions are precisely contrary to each other (e.g., *moving toward* vs. *moving away, contracting* vs. *expanding*). These findings provide evidence that there is a stereotype of motions related to approachability, and people prefer a robotic product that moves automatically when it meets their expectations.

C. Implications for Design

The findings from this study provide goal-specific guidelines of employing a robotic partition that automatically expresses motions as a result of interacting with people. The robotic partition can be used to attract people to shops and exhibition booths by expressing *contracting* and *moving away* motions and ultimately make them desire to step in. The robotic partition can also be used as a way to make people stay longer in a space where lengthy concentration and stay are required, such as a conference room and an office, by showing *expanding* and *moving toward* motions. Conversely, motion of the robotic partition mentioned above can be used to convey nonverbal cues both asking the person outside a room not to interrupt the person inside the room by expressing *expanding* and *moving toward* motions and asking the person inside a room to go out of the room by expressing *contracting* and *moving away* motions. For example, when the robotic partition expands its body width, people who are inside the room surrounded by the partition would feel protected from outside and feel comfortable while people who are outside the room would think that they are blocked by the partition and have a negative perception. Thus, considering user perspective is desirable for designing and expressing appropriate nonverbal cues of a robotic partition when there are multiple persons both inside and outside of a specific space.

D. Limitations and Future Research

There are several limitations of this study. First, our participant pool was limited to Korean university students. Replicating this study with people from different countries and comparing the results are important because the size of space in which a person feels comfortable varies by cultural differences according to Hall's proxemics [17]. Second, this study did not consider the robotic partition's speed and range of motions. Different nonverbal messages from the robotic partition may be conveyed according to those physical elements of motions. Further studies could explore this point of view. Third, this study was conducted by using video-prototypes. While this study considered two different user perspectives, further work should be conducted in more natural settings in order to investigate multiple persons' reactions toward the robotic partition's motions.

CONCLUSION

In this study, we found that the motion of a robotic partition influenced people's approachability to a space, especially their desire to stay in the space. In addition, user perspective, whether a person is inside the partition or outside the partition, should be considered to apply a certain motion because the motion can have a positive influence on a person in one perspective whereas it can have a negative influence on a person in another perspective. We believe that this study provides insights to interaction designers, engineers, and architects for designing robotic space.

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