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COMPARISON OF SPACE PERCEPTION BETWEEN A REAL ENVIRONMENT AND A VIRTUAL ENVIRONMENT

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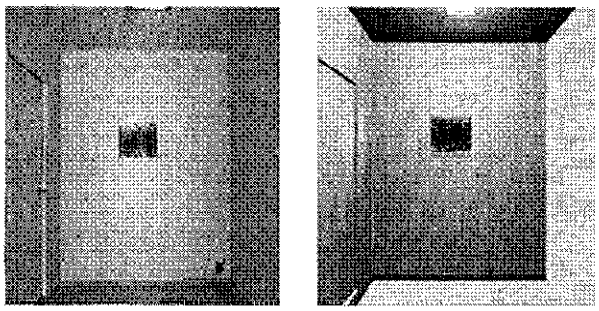
Virtual reality technologies are being applied to diverse industrial fields. However, the degree to which a virtual environment is faithful to a real one has not been assessed rigorously. This paper assessed the fidelity of a virtual environment to a real environment. More specifically, it examined 3 major issues: (1) Are a real room and an equivalently modeled virtual room perceived same? (2) How accurate are the estimated sizes and ratios? (3) Does presentation order affect subjects' estimation? We employed a real room and an equivalently modeled virtual room in the experiment. The sizes of the room elements are as follows: width 258cm, depth 380cm, and height 245 cm. Seven females and five males ranging in age from 20 to 42 years served as subjects. All subjects experienced the real room and the virtual room, and the presentation order of the rooms was counterbalanced. Subjects experienced the virtual room wearing the HMD. After subjects observed each room, they were asked to answer a questionnaire. The questionnaire included items on the perception of the physical and psychological properties of the room. The space perceptions in both rooms were not significantly different. When the estimated sizes in both conditions were compared with the actual sizes, the estimations related to height in both conditions were different from the actual ones. This pattern of results suggests that virtual environments instead of the real ones could be used for design and architecture with the adjusted height. Further studies on human space perception using better navigation methods are needed.

Virtual reality(VR) technologies are being applied to diverse industrial fields for product development, product presentation, and process control. One of the fields to which present technologies are readily applied would be architecture. Many construction companies in Korea are trying to use VR technologies to show around the model house of apartment buildings to the perspective home buyers. Spaciousness and openness seems to be important factors that affect perspective home buyers' decision making processes. *Spaciousness* is operationally defined as the subjective feeling of having much space and vast scope and *openness* as the subjective feeling of being in an open space and unobstructed.

The use of VR technologies could save us a lot of efforts and time and reduce the cost. However, in order for VR technologies to be applied to various fields, fidelity should be high. Fidelity is defined as the extent to which the virtual environment and interaction with it are indistinguishable from the participant's observations of and interactions with a real environment (Waller et al., 1998). Nevertheless, it has not received rigorous research attention. Because we were interested in the application of virtual technologies to architecture, we focused on the following questions: (1) Are a real room and an equivalently modeled virtual room perceived same? (2) How accurate are the subjects' estimations? Are the subjects' estimations about size and ratio of room elements(i.e., width, depth, and height) in both rooms are



(a) (b)

Figure 1. The Rooms Used for the Experiment
(a) the real room, (b) the virtual room

different from the actual sizes and ratios of the real room? (3) Are subjects' estimations affected by the presentation order?

METHODS

Subjects. Seven females and five males ranging in age from 20 to 42 years participated.

Design. One-way within subjects design was employed.

Stimuli. A real room and an equivalently modeled virtual room in the experiment were used. The room had a door and a window. The sizes of the elements of the rooms are as follows: width 258 cm, depth 380 cm, and height 245 cm. A chair was located in each room to give size cues to subjects.

Apparatus. Silicon Graphics Indigo2 Maximum Impact machine and an HMD(V8 of Virtual Research Systems, Inc.) were used to generate and display the virtual room.

Procedure. Subjects practiced size estimation with 3 real rooms before the main experimental session began. Subjects made size estimations about the room elements and their ratios. The correct figure was given as feedback after each estimation.

During the main experiment all subjects experienced the real room and the virtual room one by one, and the presentation order of the rooms was counterbalanced. Subjects navigated freely in the real room. In the virtual room, they wore the HMD and the viewpoint in the virtual room was set to the eye height of each subject. Because the operation of mouse wearing the HMD was not easy, subjects told the direction of the navigation(i.e. left, right) to the experimenter and the experimenter operated the mouse.

After subjects observed each room, they were asked to answer a questionnaire. The questionnaire included items on the perception of the physical and psychological properties of the rooms. The asked physical properties were the width, depth, height(i.e., What is the size of the width? ___m ___cm) and their relative magnitudes with each other. The relative magnitudes(ratios) were obtained using the method of magnitude estimation(i.e., If the width is set to 100, the depth is ____, the height is _____).

The asked psychological properties were the perceived brightness, openness, and spaciousness. Subjects rated on nine-point scales for the psychological properties (i.e. How bright the room is?).

After subjects experienced both rooms, they were asked to answer the questionnaire directly comparing the real room and the virtual room in terms of the above psychological properties(i.e., Which room is brighter?). Subjects were also asked to make judgments on the above psychological properties using the method of magnitude estimation(i.e., If the spaciousness of the real room is set to 100, that of the virtual room is ____).

RESULTS

Three sets of analyses were performed based on the three main research questions. The significance level was .05 in all analyses.

Comparison between the perceived virtual room and the real room

T-tests were performed to compare the perceived physical properties of the virtual room and those of the real room. There were no significant differences in the physical properties. Wilcoxon tests were done to compare the perceived psychological properties. There were no significant differences in the psychological properties. Therefore, it was

concluded that space perception in both rooms wasn't significantly different.

Comparison between subjects' estimations and the actual sizes

Analyses for the virtual room and for the real room were done separately.

Virtual room. T-tests were used to compare subjects' estimations and the actual room specifications. The estimated sizes and ratios of the room elements were compared with the actual ones. The estimated height to width ratio ($t(11) = 2.7519$, $p < .05$) and estimated width to height ratio ($t(11) = 2.9641$, $p < .05$) were different from the actual ones.

Real room. T-tests were used. The estimated height to depth ratio was significantly different ($t(11) = 2.8824$, $p < .05$).

Based on the analyses for the virtual and real room, it was concluded that most of the estimated sizes and ratios in virtual and real environments were not different from actual sizes, except for the ratios related to height.

Effects of the presentation order

Three separate analyses were done: overall presentation order effect, estimation accuracy for the virtual room, and estimation accuracy for the real room.

Overall presentation effect. For the physical properties, t-tests were used. Subjects in the real room-first condition made significantly different estimation about width($t(5) = 3.450$, $p < .05$) and width to depth ratio($t(5) = 2.609$, $p < .05$) for the real and virtual room. On the other hand, subjects in the virtual room-first(real-room second) condition did not make significantly different estimations for the two rooms, even though height($t(5) = 2.409$, $p = .0610$), width to height($t(5) = 2.193$, $p = .0798$) approximated the significance level. For the psychological properties, Wilcoxon tests were used. There were no significant differences.

Estimation accuracy for the virtual room. The virtual room-first group made significantly different estimation from the actual width to height ratio($t(5) = 2.9259$, $p < .05$) and from the actual height to width ratio($t(5) = 3.8957$, $p < .05$), whereas the real room-first group did not make significantly different estimation from the actual ones.

Estimation accuracy for the real room. The real room-first group did not make significantly different estimation, whereas real room-second(virtual room-first) group made significantly different estimations for the actual depth to height ratio($t(5) = 3.1249$, $p < .05$) and the actual height to depth ratio ($t(5) = 3.6939$, $p < .05$).

Results from the estimation accuracy demonstrated that subjects made more accurate estimations when they experienced the real room first.

Direct comparisons between real and virtual rooms

When subjects were asked to compare the two rooms directly in terms of spaciousness, six persons responded that the real room is more spacious, three persons responded that the virtual room is more spacious, and three persons responded that both rooms are equivalently spacious. Two persons responded that the real room is more open, six persons responded that the virtual room is more open, and four persons responded that both rooms are equivalently open. Two persons responded that the real room is brighter, seven persons responded that the virtual room is brighter, and three persons responded that both rooms are equivalently bright.

Table 1. Pattern of Subjects' Responses for the Psychological Properties

	Spaciousness	Openness	Brightness
R > V	6	2	2
R < V	3	6	7
R = V	3	4	3

* R: real condition, V: virtual condition

Table 2 summarizes the results based on the method of magnitude estimation. The results showed that the virtual room was judged to be more voluminous, spacious, open, and bright than the real room, but the differences were not significant.

Table 2. Subjects' Responses to the Virtual Room When Values of the Real Room were set to 100

	Volume	Spacious-ness	Openness	Brightness
Mean	106.92	112.50	108.33	120.83
S.D.	24.74	21.79	24.43	39.93
t-value	0.9683	1.9868	1.1815	1.8072

DISCUSSION

The key outcomes are as follows: subjects' perceptions in the virtual and real environments were not different and subjects' estimations were quite accurate, except for the elements related to heights in both conditions. In addition, subjects were more accurate in prediction when they were exposed to the real environment first. Direct comparisons between real and virtual conditions showed that there were some differences between the two conditions in terms of spaciousness, openness, and brightness, but they did not reach the significance level.

The results that showed subjects' estimations were quite accurate and they had tendencies to overestimate are different from previous studies on distance estimation. Witmer and Kline (1998) reported that subjects underestimated distances in the VE and the real world. In their studies the errors in distance estimation were found to be greater in virtual environments than in the real world. One possible source of the discrepancy is the difference in shape and size of stimulus(environment). Witmer and Kline used a long rectangular box shaped corridor, while we used a small close to cubic shaped room.

A limitation of this experiment is the navigation method in the virtual room. In this study, subjects told the direction of navigation to the experimenter and the experimenter operated the mouse. This indirect navigation method might affect the nature of navigation and therefore the subjects' representations of the virtual environment.

One unexpected result was that subjects systematically made errors related to the height in the real and virtual environments. Further studies are needed to pursue these problems.

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