Chapter 13
Shape Evaluation Properties in Real Space and Virtual Space

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Abstract These days, not only designers but also general people have the chance to evaluate the design of products, such as cars, clothes, and electrical appliances, on computer displays or in virtual space. However, there is a high possibility of disagreement between the evaluation of shape in virtual space and that in real space. In this chapter, a 3D shape evaluation support system is introduced which integrates the visual information in virtual space and the tactile and gazing line-action information in real space. The proposed system can control information, for example, visual or tactile, and the linkage between motion and gazing line, which are used to evaluate the product shape, and investigate the role this information plays in evaluation. The preference for 3D shapes in the proposed virtual space is compared with that of real photoformed products made from the same data by the sensory evaluation of paired comparison and questionnaire analysis. It was found that the preference for shapes in both spaces was consistent with the relation of preferences based on the Bradley–Terry model for sensory evaluation. This indicates that the proposed system provides almost the same environment for shape evaluation as in real space. The results of questionnaires also indicate that the proposed system is enough to evaluate 3D shapes in virtual space. Moreover, the influence of differences in the point of view on the evaluation of shapes in virtual space is investigated using the proposed system by the sensory evaluation of paired comparison and questionnaire analysis. As a result, it is found that, for the evaluation of shapes in virtual space, subjects prefer a point of view from which they can see only their forearms' motion. The system enables the investigation of human's sense for shape evaluation by handling visual, tactile, and gazing line-action information.

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13.1 Introduction

We evaluate an object on a computer display in place of the real object, for example, in 3D CAD, Internet shopping, and so on. The validity of evaluating the 3D shape in virtual space through the display or a head mounted display (HMD) may be based on the assumption that the evaluation of the shape image in virtual space almost agrees with that of the real object in real space (Figure 13.1). However, it is indicated that there is a high possibility of disagreement between the evaluation of the shape in virtual space and that in real space [1].

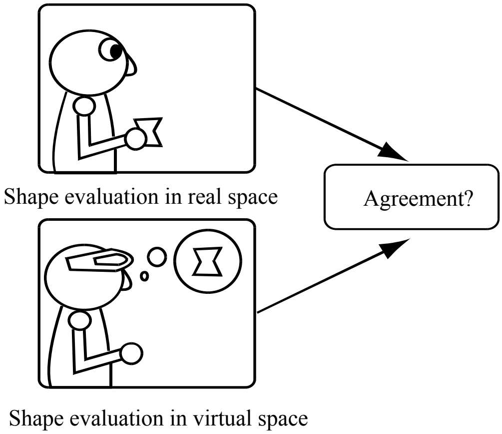


Figure 13.1 Shape evaluation in real and virtual space. The subject handles the two objects in his/her hands in real space and he/she is able to watch the objects' image in virtual space through the HMD. The objects' images that the subject watches are produced in virtual space on the PC on the basis of the angle and position measured by the magnetic sensors (Polhemus FASTRAK) attached to the top of the subject's head and to the objects

In order to clarify the difference between them, a shape evaluation support system has been proposed which integrates the visual information in virtual space and the tactile and gazing line-motion information in real space. The proposed system consists of a PC, an HMD, and magnetic sensors, and enables the handling of tactile and gazing line-action information in virtual space. The subjects obtain visual information about the models of the 3D objects from the HMD, and tactile information from real photoformed products that they hold in their hands. The gazing line-action information is produced on the PC using the output of the magnetic sensors attached to the subject's head and to the objects. The proposed system enables the handling of information on the PC, and analyzes how the subject evaluates the 3D shapes using this information. The system configuration is shown in Figure 13.2.

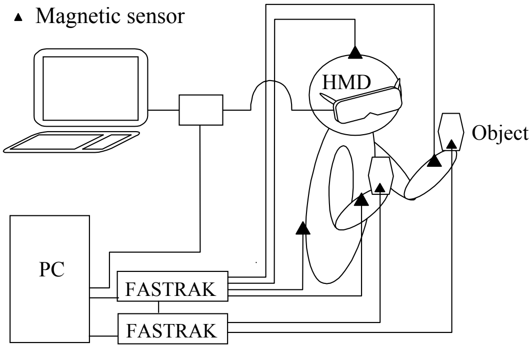


Figure 13.2 3D shape evaluation support system

13.2 System Evaluation

The system was evaluated to confirm the usability of the proposed system. To compare the evaluation of shape in real space and in virtual space, experiments were performed in both spaces for each subject.

13.2.1 3D Models and Objects Used in the Experiment

The 3D models on display were made using 3D CAD and the corresponding real objects were made using a photoforming system (NTT DATA CMET SOUP400GH-SP). To make the 3D models for the shape evaluation experiments, lip motion data was used, because the 3D structures made from lip motion aren't familiar to most people. These 3D models and objects have discrete shapes, so subjects aren't able to visualize an actual use of them. The lip motion images were captured and then sliced into each frame. The 3D models were made from a set of lip contour data on the 3D CAD. Figure 13.3 shows an example of a photoformed product made using this system. The product was made from the lip motion data produced when a person pronounced five concatenated Japanese vowels (/a/, /i/, /u/, /e/, /o/) in 2.3 s, and used approximately 70 frames.

The size of each object was 65 mm in mouth width, 50 mm in mouth height, and 70 mm (1 mm per second) in length. The product characterized the speaker's pronunciation where the speaker's under lip was distorted to the left when he pronounced the vowel /a/. Figure 13.4 shows the photoformed products and 3D models used in the sensory evaluation, which are based on the lip motion data shown in Figure 13.3: Figure 13.4 (a) is an elliptical column and the diameter of each ellipse is the same as each lip contour, Figure 13.4 (b) is also an elliptical column and all ellipses are centered in the column, Figure 13.4 (c) is a column and the area of each circle is the same as each lip area, Figure 13.4 (d) is a column and each section is a dodecagon, Figure 13.4 (e) is a column and each section is a hexagon.

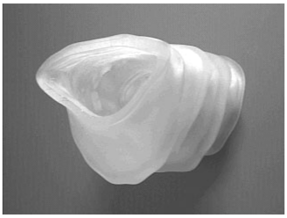


Figure 13.3 Photoformed product made from lip motion data

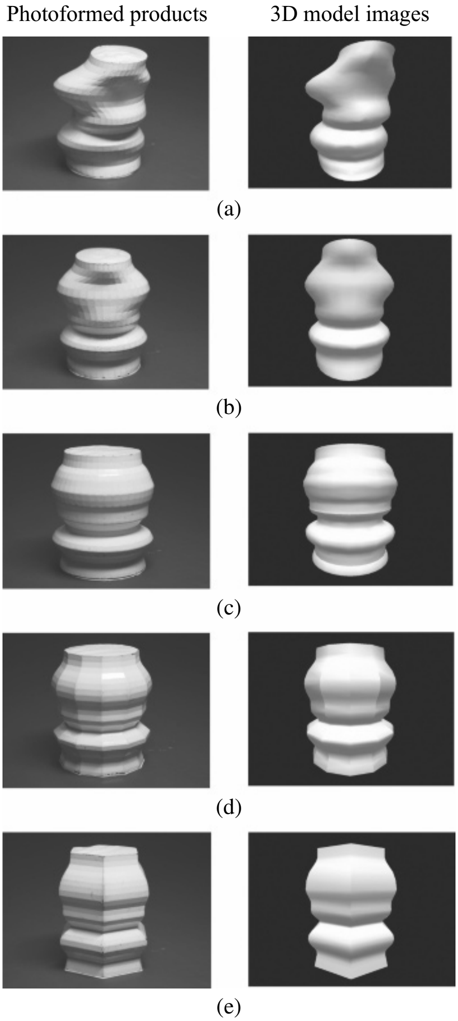


Figure 13.4 Photoformed products and 3D model images used in the experiment: (a) ellipse based on Figure 13.3 (El.), (b) ellipse centered (Ec.), (c) circle centered (Cc.), (d) dodecagon circumscribed (Dc.), and (e) hexagon circumscribed (Hc.)

13.2.2 Sensory Evaluation

The 3D shapes shown in Figure 13.4 (a–c) were used in the sensory evaluation of paired comparison. First, the subject put on the HMD and the magnetic sensors were attached to the subject's head and objects. Two of the three objects were simultaneously presented to each subject in virtual spaces (Figure 13.5), and the subject watched the objects' images from various viewpoints by moving his/her head and/or handling the real objects, as shown in Figure 13.6 (a). Then the subject was asked to say which object he or she preferred. After that, the subject took off the HMD and the same experiment was carried out in real space, as shown in Figure 13.6 (b).

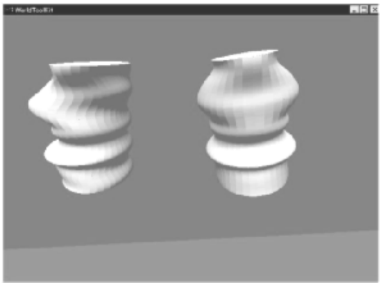


Figure 13.5 Two objects' images in virtual space

(a) (b)

Figure 13.6 Experimental scenes: (a) in virtual space, and (b) in real space

13.2.3 Experimental Results

Table 13.1 (a) shows the result of paired comparison for photoformed products in real space, and Table 13.1 (b) shows that for images viewed on the HMD in virtual space. Each table shows the number of subjects who preferred the object in the column over the object in the row.

Table 13.1 Result of paired comparison: (a) in real space, and (b) in virtual space

(a)

Product	El.	Ec.	Cc.	Total
El.	–	6	6	12
Ec.	22	–	6	28
Cc.	22	22	–	44

(b)

Product	El.	Ec.	Cc.	Total
El.	–	7	6	13
Ec.	21	–	5	26
Cc.	22	23	–	45

The Bradley–Terry model is assumed to evaluate the preference of 3D shape quantitatively, defined as follows [2]:

$$P_{ij} = \frac{\pi_i}{\pi_i + \pi_j}, \tag{13.1}$$

$$\sum_i \pi_i = \text{const.}\ (= 30), \tag{13.2}$$

where π_i is the intensity of i and P_{ij} is the probability of judgment that i is better than j. π_i shows the intensity of preference of the object.

The model enables the preference to be determined based on the paired comparison. The maximum likelihood method is used to solve π_i. We obtain $\hat{\pi}_i$ by the following formula, where $\hat{\pi}_i^0$ $(i = 1, 2, 3)$ were used as initial values:

$$\hat{\pi}_i = \frac{T_i}{\sum_{j(\neq i)} \frac{N}{\hat{\pi}_i^0 + \hat{\pi}_j^0}}, \tag{13.3}$$

where N is the number of objects, and T_i is the total number of winning is. Then $\hat{\pi}_i$ is scaled up or down to satisfy the next formula:

$$\sum_i \hat{\pi}_i = K, \tag{13.4}$$

where K is 30. Therefore,

$$\hat{\pi}_i^1 = \frac{K\hat{\pi}_i}{\sum_i \hat{\pi}_i}. \tag{13.5}$$

We iterated the series of calculation until π_i was settled. The result of the above process is shown in Figure 13.7. As a result, the same shape (Cc.) tends to be preferred on every experiment. It is also obvious that the experimental result using the proposed system is closer to the result in real space than by using 3D CAD.

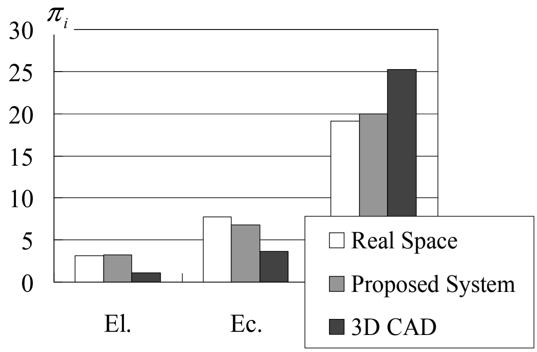


Figure 13.7 Preference of 3D shape

To approve the matching of the models, we apply the goodness-of-fit test and the likelihood ratio test. First, we apply these tests to the Bradley–Terry model of shape evaluation in real space, shown in Figure 13.6.

The goodness-of-fit test for the Bradley–Terry model is as follows:

$$\chi_0^2 = \sum\sum \frac{(X_{ij} - X_{1ij})^2}{X_{1ij}} (= 2.74), \tag{13.6}$$

where X_{ij} is the number of is winning over j, and

$$\chi^2(1, 0.05) = 3.84 > \chi_0^2.$$

The likelihood ratio test is as follows:

$$r = 2\sum\sum X_{ij} \times \log\left(\frac{X_{ij}}{X_{1ij}}\right)(= 2.69), \tag{13.7}$$

$$\chi^2(1, 0.05) = 3.84 > r.$$

These results show that the matching of the model in real space is consistent.

On the other hand, for the tests with the model shape evaluation in virtual space, the goodness-of-fit test is as follows:

$$\chi_0^2 = 2.82 (< \chi^2(1, 0.05) = 3.84).$$

The likelihood ratio test is as follows:

$$r = 2.76 (< \chi^2(1, 0.05) = 3.84).$$

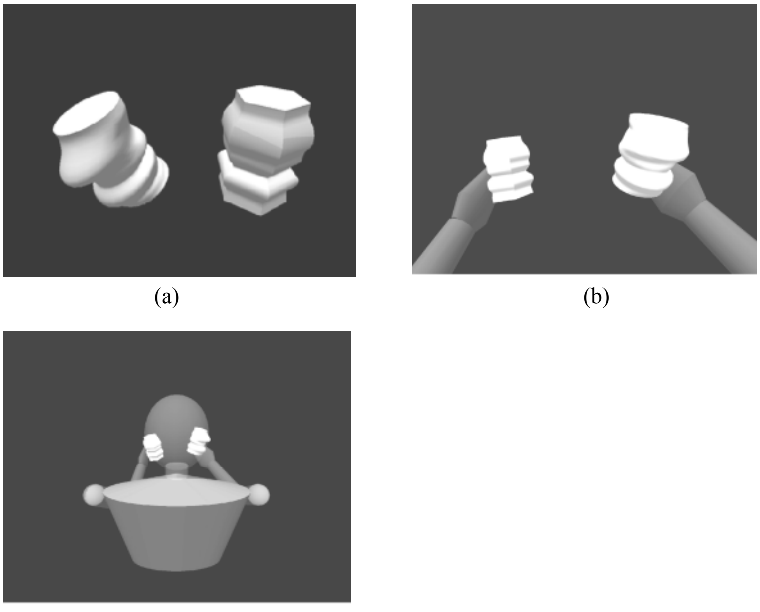
These results show that the matching of the model in virtual space using the proposed system is also consistent. In previous research, however, the matching of the model in virtual space using 3D CAD was inconsistent. This indicates that the tactile, gazing line-action information plays an important role in 3D shape evaluation. This proposed system also enables us to analyze the information which the subjects use in shape evaluation by handling the information.

13.3 Influence of Viewpoint on Shape Evaluation in Virtual Space

In virtual space, we can fix the viewpoint anywhere – although some of these give impossible scenes in real space. However, these viewpoints sometimes encourage the user to do something, *e.g.*, playing a driving game, communicating with a remote partner using the avatars, and so on. In this section, the influence of viewpoint on shape evaluation is described.

13.3.1 Three Types of Viewpoint

We have developed an embodied virtual communication system for human interaction analysis by synthesis, in which remote talkers can share the embodied interaction by observing the interaction of their VirtualActors in the same virtual space [3, 4]. From the user's viewpoint, not only the partner's motion images but also his/her own motion images in virtual space should be supplied in the collaboration system. However, motion images that include themselves would discourage them from performing the individual tasks. Then, the influence of avatar's images in virtual space on the 3D shape evaluation is investigated using the proposed system.



(a) (b) (c)

Figure 13.8 Three types of viewpoint: (a) only objects, (b) objects and forearms of user's avatar, and (c) objects and translucent upper body of user's avatar

Three types of view were prepared for the 3D shape evaluation in virtual space by the sensory evaluation of paired comparison. Figure 13.8 shows images from the HMD that show the two 3D models in virtual space. The colors of the objects are almost the same as that of the real objects. The subjects can change the viewpoint by moving their heads, and/or the objects in the case of Figure 13.8 (a, b).

13.3.2 Influence of Avatars' Forearms on 3D Shape Evaluation

To investigate the influence of the user's avatar's forearms on the 3D shape evaluation in virtual space, the subjects were first put on the HMD and magnetic sensors were attached to the subject and to the objects. Two of the five 3D models shown in Figure 13.4 were simultaneously presented to each subject in virtual space, and the subject watched the objects' images from various points of view by moving his/her head and handling the real objects in his/her hands in Experiment I-1 (Figure 13.8 (a)). Then the subject was asked to say which object he or she preferred. Next, the same experiment was performed in virtual space with the forearms of the user's avatar visible (Figure 13.8 (b)) in Experiment I-2. Then, the subject took off the HMD and was handed two of the five photoformed products shown in Figure 13.4 to compare them in real space in Experiment I-3. After each experiment, the subjects answered questionnaires about the shape evaluation environment and the system under each experimental condition.

In the next step, the influence of the avatar's motion images were investigated by comparing the two types of viewpoint in virtual space. One is fixed on the rear space and user can see the objects and his avatar's translucent upper body (Figure 13. 8(c)) in Experiment II-1, the other is put on the avatar's head and the user can see the objects and the avatar's forearms (Figure 13.8(b)) in Experiment II-2. To compare the result of sensory evaluation in these virtual spaces with that in real space, Experiment II-3 was carried out in the same way as Experiment I-3.

13.3.3 Experimental Results

Table 13.2 shows the results of paired comparison in Experiment I. Each table shows the number of subjects who preferred the object in the column to the object in the row. The Bradley–Terry model is assumed to evaluate the preference of 3D shape quantitatively.

The Bradley–Terry models for each virtual and real spaces in Experiment I are shown in Figure 13.9. As a result, the same shape (Cc.) tends to be preferred in each experiment. To check that the models match, we applied the goodness-of-fit test and likelihood rate test. We applied these tests to the Bradley–Terry model shown in Figure 13.9.

Table 13.2 Result of paired comparison (Experiment I): (a) in virtual space (Exp. I-1), (b) in virtual space (Exp. I-2), and (c) in real space (Exp. I-3)

(a)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	4	2	4	4	14
Ec.	14	–	2	6	9	31
Cc.	16	16	–	13	12	57
Dc.	14	12	5	–	13	44
Hc.	14	9	6	5	–	34

(b)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	5	4	5	7	21
Ec.	13	–	4	7	9	33
Cc.	14	14	–	13	13	54
Dc.	13	11	5	–	11	40
Hc.	11	9	5	7	–	32

(c)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	4	3	4	5	16
Ec.	14	–	3	6	8	31
Cc.	15	15	–	11	15	56
Dc.	14	12	7	–	16	49
Hc.	13	10	3	2	–	28

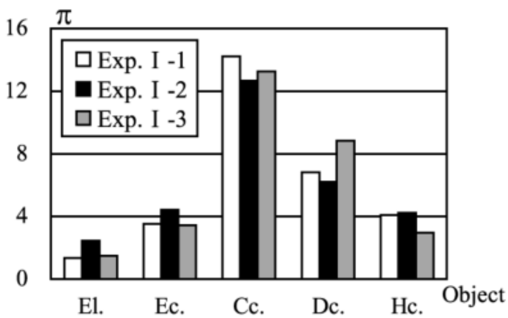


Figure 13.9 Preference of 3D shape in virtual and real space

As a result, the matching of the model in each virtual space using the proposed system and in real space is also consistent. These demonstrate that the forearms of the user's avatar in virtual space do not appear to affect the 3D shape evaluation in virtual space.

To analyze the individual evaluation environment in detail, the number of subjects who changed the selection between paired comparisons in virtual space and

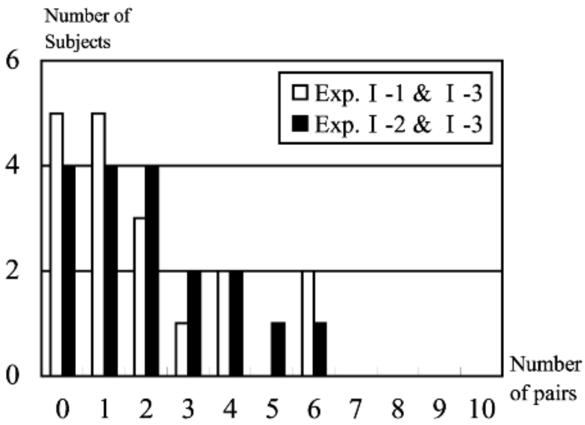


Figure 13.10 Frequency distribution of subjects for the number of changes of selection between paired comparisons in virtual and real space

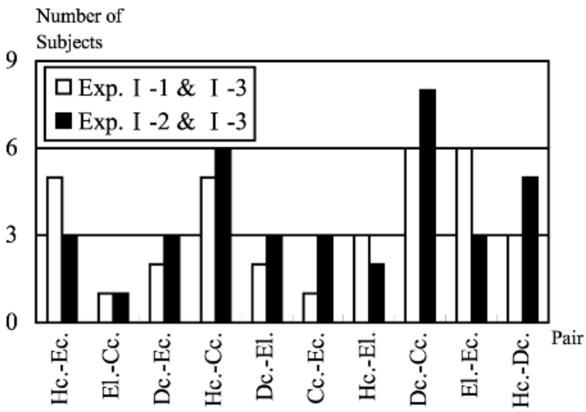


Figure 13.11 Number of subjects who switch to an alternative at paired comparisons in virtual and real space

in real space is investigated. Figure 13.10 shows the frequency distribution of subjects for the number of selection changes between paired comparisons in virtual space without the avatar's forearms (Exp. I-1) and in real space (Exp. I-3), shown as white bars, and between them in virtual space with the avatar's forearms (Exp. I-2) and in real space (Exp. I-3), shown as black bars. It can be seen from this figure that there is no significant difference between them.

Figure 13.11 shows the number of subjects who changed the selection for the each paired comparison between Exp. I-1 and Exp. I-3 (white bars), and between Exp. I-2 and Exp. I-3 (black bars). The differences between each pair are not significant. These results indicate that displaying the avatar's forearms has no influence on the shape evaluation in virtual space.

13.3.4 Influence of Avatar's Upper Body Image

Table 13.3 shows the results of paired comparison in Experiment II. The Bradley–Terry models for each virtual and real space in Experiment II are also assumed and the results are shown in Figure 13.12. As a result, the same shape (Cc.) tends to be preferred in each experiment, as was found for Experiment I.

To approve the matching of the models, the goodness-of-fit test and likelihood rate test were also applied to the Bradley–Terry model. The results indicate that the matching of the model in each virtual space using the proposed system and in real space are both consistent. These demonstrate that the avatar's upper body in virtual space doesn't appear to affect the 3D shape evaluation in virtual space.

To analyze the individual evaluation in detail, the number of subjects who changed their selection between paired comparisons in virtual space and in real space is investigated.

Figure 13.13 shows the frequency distribution of subjects for the number of selection changes between paired comparisons in virtual space with the avatar's upper half of the body (Exp. II-1) and in real space (Exp. II-3), shown as white bars, and between them in virtual space with avatar's forearms (Exp. II-2) and in

Table 13.3 Result of paired comparison (Experiment II): (a) in virtual space with avatar's upper body (Exp. II-1), (b) in virtual space with avatar's forearms (Exp. II-2), and (c) in real space (Exp. II-3)

(a)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	8	6	7	7	28
Ec.	21	–	11	10	9	51
Cc.	23	18	–	16	21	78
Dc.	22	19	13	–	22	76
Hc.	22	20	8	7	–	57

(b)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	8	4	7	10	29
Ec.	21	–	8	10	6	45
Cc.	25	21	–	17	20	83
Dc.	22	19	12	–	18	71
Hc.	19	23	9	11	–	62

(c)

Product	El.	Ec.	Cc.	Dc.	Hc.	Total
El.	–	5	3	4	9	21
Ec.	24	–	4	7	13	48
Cc.	26	25	–	20	21	92
Dc.	25	22	9	–	23	79
Hc.	20	16	8	6	–	50

real space (Exp. II-3), shown as black bars. There is no significant difference between them. Also, the differences between the number of subjects who changed their selection for each paired comparison between Exp. II-1 and Exp. II-3, and between Exp. II-2 and Exp. II-3, are not significant. These results indicate that displaying the avatar's upper body has no influence on the shape evaluation in virtual space.

After each experiment, the subjects are asked some questions about each virtual environment for 3D shape evaluation and the difference between Exp. II-1 and Exp. II-2. The results of this questionnaire are shown in Figure 13.14. The results for all questionnaires about the difference between Exp. II-1 and Exp. II-2 are significant at a significance level of 1%. These results indicate that the subjects prefer a viewpoint from their own avatar's eyes to one from the rear space of their avatar when performing 3D shape evaluation in virtual space.

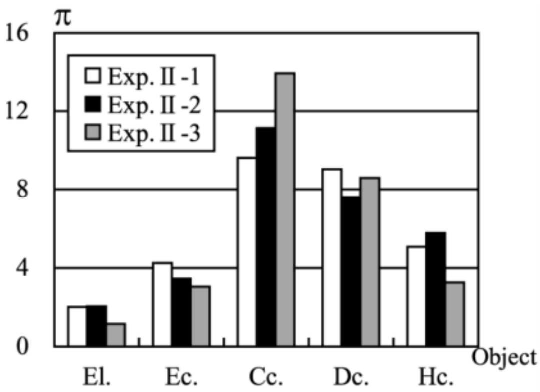


Figure 13.12 Preference of 3D shape using the Bradley–Terry model

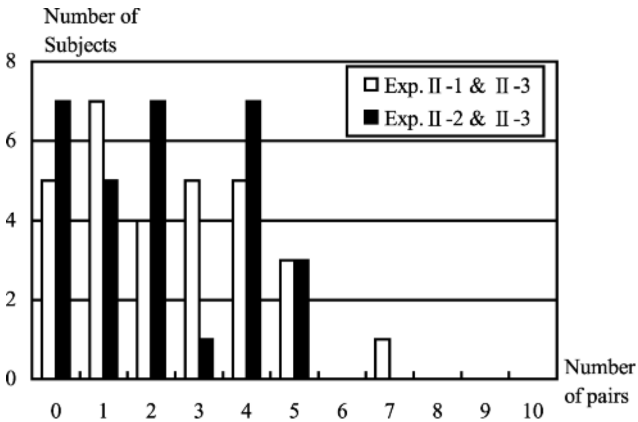


Figure 13.13 Frequency distribution of subjects for the number of changes of selection between paired comparisons in virtual and real space

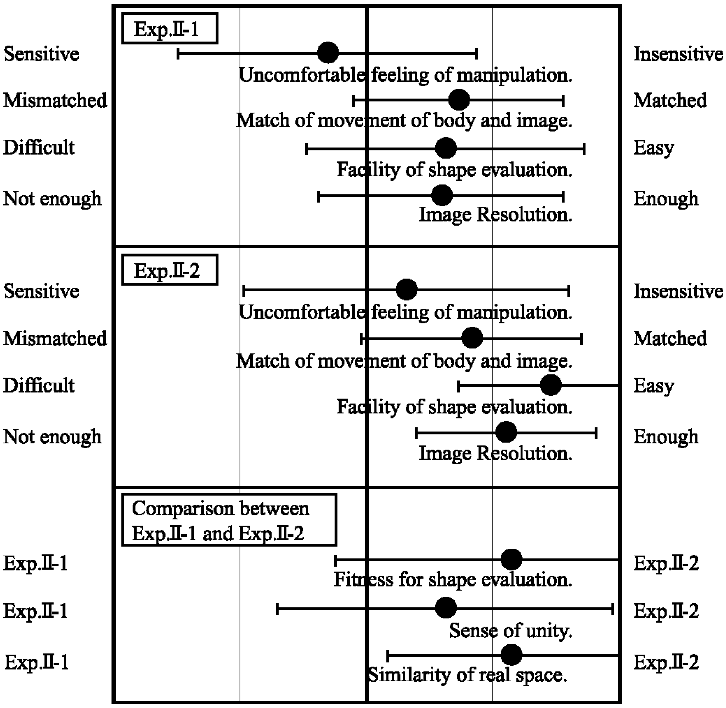


Figure 13.14 Result of questionnaires

13.4 Conclusions

We have proposed a virtual environment for 3D shape evaluation in order to clarify the differences in 3D shape evaluation in virtual and real spaces. Using this system, users are able to obtain visual information in virtual space and tactile and gazing line-action information in real space. The preference of the 3D shape images on a HMD was compared with that of real photoformed products made from the same data by the sensory evaluation of paired comparison. As a result, the same shape tended to be preferred in both spaces, and there was no significant difference in the relations of preference among shapes based on the Bradley–Terry model for the sensory evaluation. This indicates that tactile, gazing line-action information plays an important role in 3D shape evaluation. This proposed system enables us to analyze the information which the subjects use in shape evaluation by handling these information. Using this system, the influence of difference of the viewpoint on shape evaluation in virtual space is investigated by the sensory evaluation of paired comparison and questionnaire analysis. The subjects can see their actions performed by translucent avatars or see only the motion of their forearms. As a result, it is found that the subjects prefer a point of view which shows only the motion of their avatar's forearms in the case of shape evaluation in virtual space.

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