Effects of lighting direction and beam angle on the appearance of a craft*

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Abstract

Lighting conditions significantly affect the perceived appearance of an object's surface, altering impressions of material properties and shape, especially in crafts and artworks. This study examines how variations in lighting direction and beam angles influence the visual impression of ceramic crafts, alongside underlying photometric factors. A black or a red Japanese Raku tea bowl was illuminated using a lamp with three lighting beam angles (narrow, 8 degrees; medium, 16 degrees; wide, 29 degrees) from three directions (30 deg. in front, directly above, and 30 deg. behind). Observers evaluated the appearance of the bowls in each condition using subjective rating scales. Results showed that the beam angle had little effect on the overall impression. As the light moved from front to back, ratings for glossiness, flamboyance, and brightness decreased while impressions of darkness and depth increased. Luminance analysis revealed that subjective impressions closely correlated with surface luminance distribution, suggesting that spatial luminance structure plays a key role in perceptual evaluation. Factor analysis further revealed that impressions related to low-level physical properties are more sensitive to lighting conditions. In contrast, impressions tied to higher-level object-related features were more stable. We have further replicated the experiment using a head-mounted display to evaluate the appearance of the bowls in a virtual reality (VR) environment. Preliminary findings suggest that the impressions in VR qualitatively replicate those observed with real objects. This supports the potential of VR for controlled lighting studies and the exploration of novel viewing conditions that are not feasible in physical space.

Keywords
Material, Lighting, Impression evaluation, Virtual Reality

1. Introduction

Lighting distribution influences an object's perceived texture and overall impression [1, 2, 3]; however, this effect has not been sufficiently quantified, leaving room for further investigation. The effect of lighting on the appearance of artworks is also a significant concern in art museums. Nishikawa et al. examined how changes in illuminance influence the perceived impression of paintings [4]. Tamane et al. suggested that luminance highlights, non-highlight areas, and contrast play a role in shaping the impression of lacquerware [5]. Similarly, Sato et al. indicated that average luminance and luminance differences affect the impression of a Japanese tea bowl [6]. However, the relationship between the appearance of craftworks and the spatial distribution of light remains insufficiently explored.

In this study, we investigate the effects of lighting direction and beam angle and the surface characteristics of crafts on the impression of crafts in both real and virtual reality (VR) space environments. We aim to apply the findings to the exhibition and lighting design of scenes that display crafts.

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2. Experiment

2.1. Experiment in real space

A schematic diagram of the experimental setup is shown in Figure 1. The experiment was conducted in a dark room. The distance between a light and a stimulus was 1 m, and between an observer and the stimulus was 57 cm. The illuminance at the stimulus position was 2200 lx. Black and red Raku tea bowls were used as stimuli. As shown in Figure 2, nine lighting conditions were applied, combining three beam angles of 8°, 16°, and 29° with three lighting directions: 30° in the front, directly overhead, and 30° from the rear.

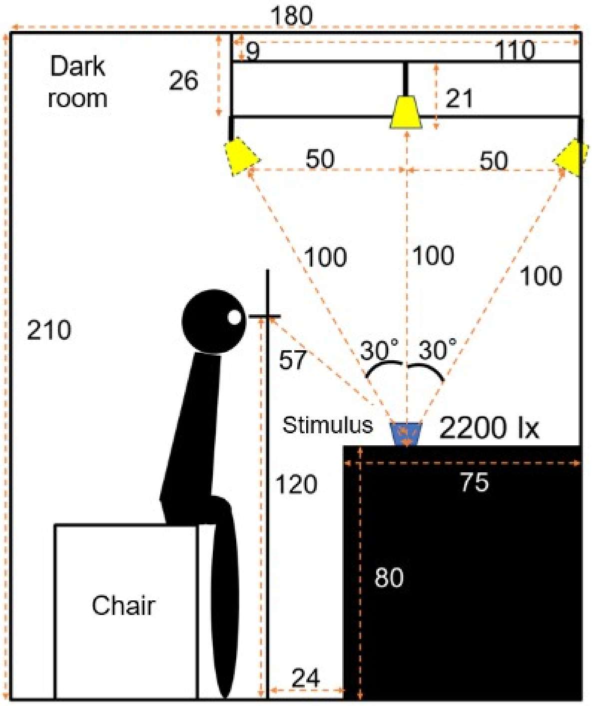


Figure 1: Schematic diagram of the experimental setup.

In each trial, the observer adapted to and viewed the stimulus under one of nine lighting conditions for 30 seconds. They then evaluated each impression item using the semantic differential (SD) method on a seven-point scale. Twelve adjective pairs were used for evaluation, as listed in Table 1 (with the left side indicating 1 point and the right side indicating 7 points). The experiment was conducted in Japanese, and the meanings of the adjectives were thoroughly explained to the observers. Each observer repeated the same evaluation under nine lighting conditions, constituting one session. Seven observers participated in the experiment, each completing three sessions, resulting in every stimulus being evaluated all three times.

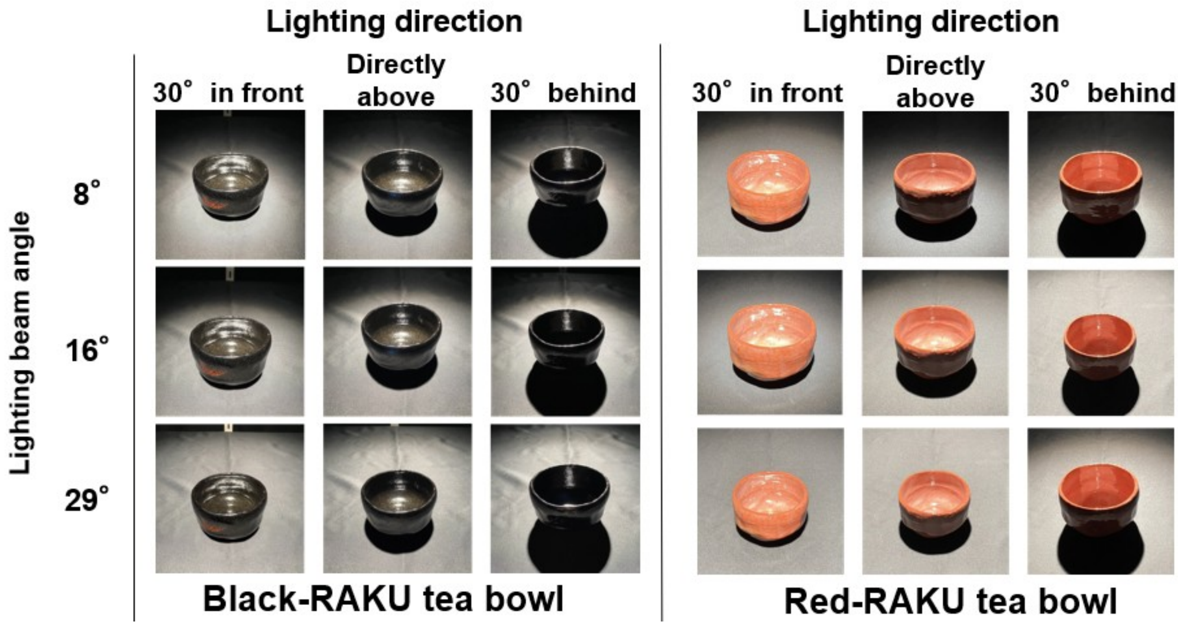


Figure 2: Experimental stimuli and lighting conditions (real space). Black Raku tea bowl (left) and red Raku tea bowl (right).

Table 1: Adjective pairs used in the experiment (English with Original Japanese).

Item	Adjective Pair
Glossiness (光沢感)	Non-glossy / Glossy (光沢感がない - ある)
Beauty (美しさ)	Ugly / Beautiful (醜い - 美しい)
Flamboyance (派手さ)	Plain / Showy (地味 - 派手)
Preference (好ましさ)	Dislike / Like (嫌い - 好き)
Smoothness (なめらかさ)	Rough / Smooth (ざらざらとした - なめらかな)
Brightness (明るさ)	Dark / Bright (暗い - 明るい)
Lightness (軽さ)	Heavy / Light (重い - 軽い)
Softness (やわらかさ)	Hard / soft (硬い - やわらかい)
Blackness (黒っぽさ)	Whitish / Blackish (白っぽい - 黒っぽい)
Depth (深み)	Non-deep / Deep (深みがない - ある)
Naturalness (自然さ)	Unnatural / Natural (不自然な - 自然な)
Luxury (ぜいたくさ)	Cheap / Luxurious (安っぽい - ぜいたくな)

2.2. Experiment in Virtual Reality

A VR environment resembling the real world was reproduced using Unity, a 3D game development platform. We used Oculus Quest 2 as a head-mounted display (HMD). As shown in Figure 3, a black tea bowl was modeled using Blender, a 3D computer graphics (3DCG) creation tool. We created nine different lighting conditions, identical to the real-space experiment. The observers rated their impression of the tea bowls under each lighting condition on a seven-point scale using 12 adjective pairs. Seven observers took part in the experiment, which was conducted once per observer.

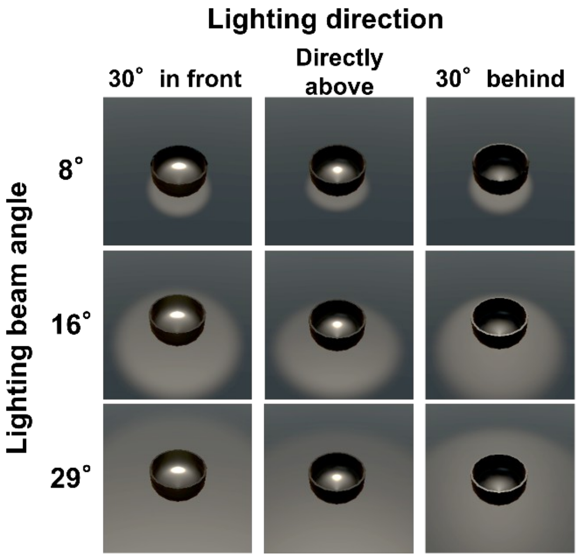


Figure 3: Experimental stimuli and lighting conditions (VR space).

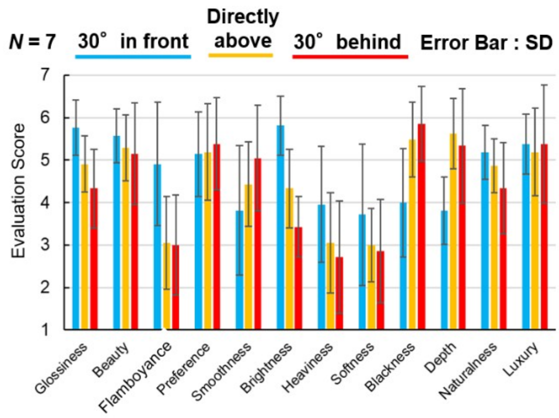
3. Result

Figure 4(a) shows the average evaluation scores across all observers for each lighting direction in the real space, with the beam angle fixed at 8° for a black tea bowl. As the lighting direction shifted toward the rear, the evaluation scores for glossiness, flamboyance, and brightness decreased, while the scores for blackness and depth increased. A one-way ANOVA was conducted for each impression evaluation item. Significant main effects were found for five items: glossiness (F(2,18) = 6.31, p = 0.0084), flamboyance (F(2,18) = 5.80, p = 0.011), brightness (F(2,18) = 16.5, p < 0.001), blackness (F(2,18) = 6.37, p = 0.0081), and depth (F(2,18) = 6.37, p = 0.0081). The same trend was observed when the beam angle was set to 16° and 29°. In addition, as shown in Figure 4(c), no significant differences were found in evaluation scores across different beam angles.

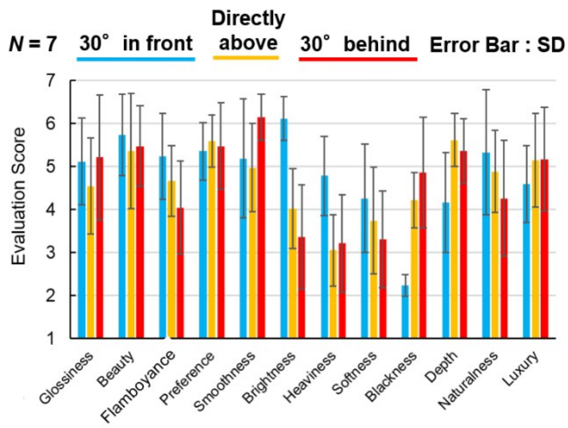
Figure 4(b) shows the average evaluation scores for each lighting direction for the red tea bowl, with the beam angle fixed at 8°. As the lighting direction shifted toward the rear, the evaluation scores for flamboyance, brightness, lightness, and naturalness decreased, while the evaluation scores for blackness and depth increased. Significant main effects were found for five items: flamboyance (F(2,18) = 3.70, p = 0.045), brightness (F(2,18) = 16.7, p < 0.001), lightness (F(2,18) = 6.88, p = 0.0060), blackness (F(2,18) = 18.3, p < 0.001), and depth (F(2,18) = 5.45, p = 0.014). Similar trends were observed when the beam angle was set to 16° and 29°. Furthermore, as shown in Figure 4(d), no significant differences in evaluation scores were observed across the different beam angles.

To examine intra-observer consistency, the standard deviation of the three evaluations was calculated for each observer, and the average standard deviation across all observers was then obtained. The standard deviations for all adjective pairs ranged from 0.6 to 1.5, suggesting that the observers' ratings were generally consistent. However, only the item "depth" showed a relatively large variation in ratings, which may be attributed to the difficulty in interpreting the term "depth."

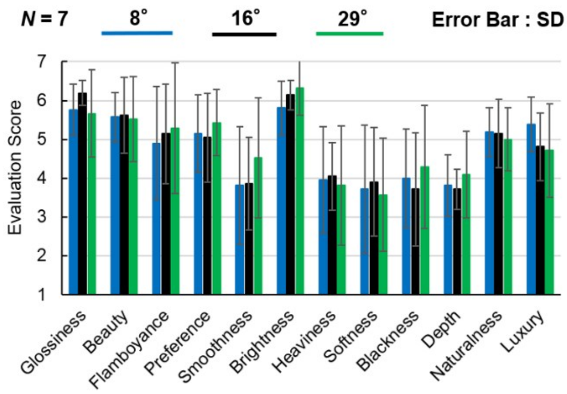
Figure 5(a) shows the average evaluation scores across observers for each lighting direction in the VR environment, with the beam angle fixed at 8°. The glossiness, brightness, and naturalness evaluation scores changed depending on the lighting direction. Figure 5(b) shows that the beam angle did not affect impression evaluation.



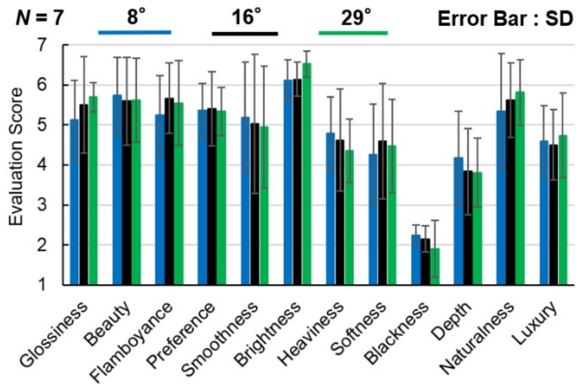
(a) Lighting direction (Black-RAKU).



(b) Lighting direction (Red-RAKU).

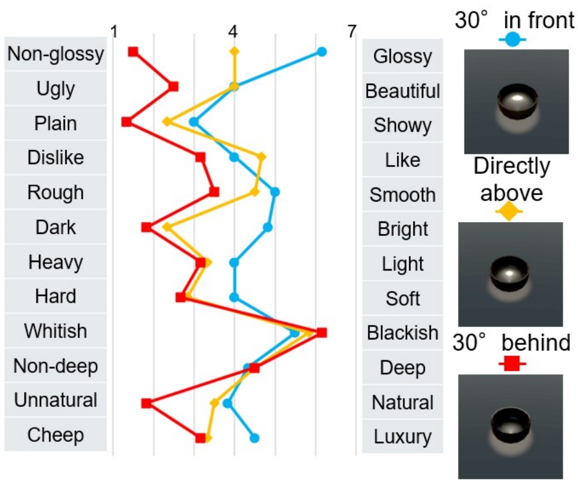


(c) Beam angle (Black-RAKU).

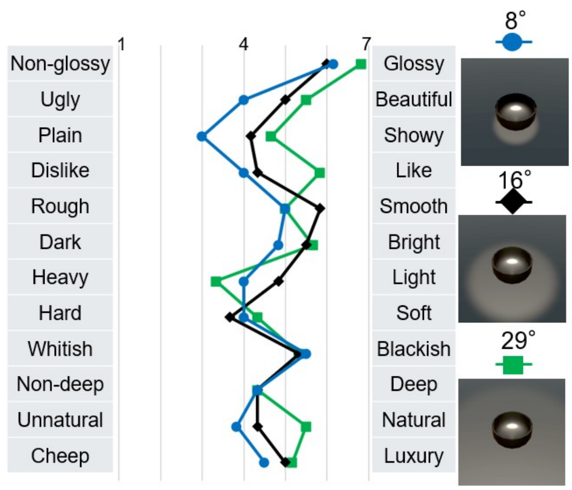


(d) Beam angle (Red-RAKU).

Figure 4: Comparison of average evaluation score (real space).



(a) Lighting direction



(b) Beam angle

Figure 5: Comparison of average evaluation score (VR space).

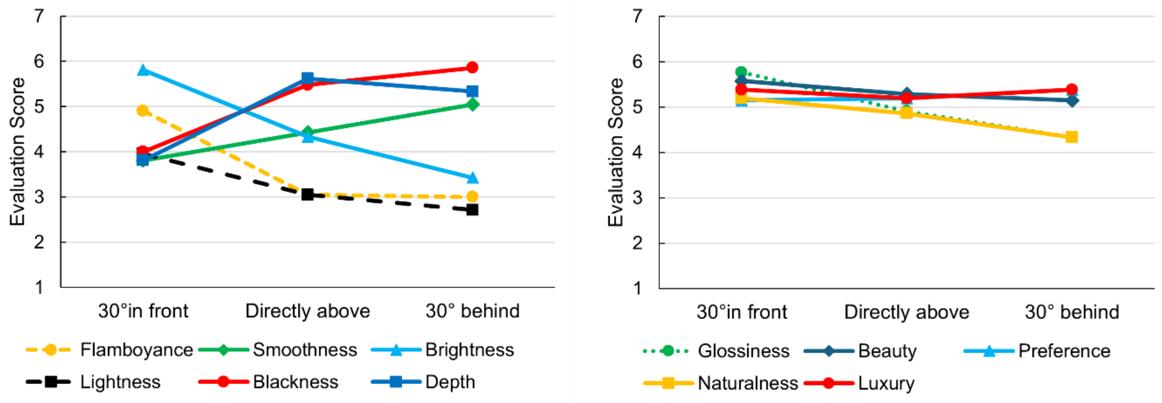
4. Analyses

A factor analysis examined the relationship between the evaluation scores and lighting conditions. The analysis was based on 378 samples (9 lighting conditions × 3 repetitions × 7 observers × 2 types of tea bowls). The maximum likelihood method was used for factor extraction, and promax rotation was applied. The results are presented in Table 2. The first factor group included six items: brightness, blackness, depth, flamboyance, lightness, and smoothness. Since many of these items describe the surface properties of objects, this factor was labeled as the "surface characteristics group". The second factor group included five items: beauty, luxury, preference, naturalness, and glossiness. Since many of these items reflect human sensibilities, this factor was labeled the "sensibility characteristics group".

Table 2: Result of factor analysis (real space).

Items	Factor 1	Factor 2	Factor 3	Commonality
Brightness	**-.721**	.259	.113	.536
Blackness	**.699**	-.136	.155	.670
Depth	**.620**	.279	-.038	.409
Flamboyance	**-.481**	.272	-.182	.456
Lightness	**-.454**	-.170	-.382	.578
Smoothness	**.408**	.127	-.172	.120
Beauty	-.057	**.789**	.087	.641
Luxury	.403	**.674**	.010	.580
Preference	.250	**.651**	-.065	.442
Naturalness	-.340	**.531**	.063	.408
Glossiness	-.195	**.349**	-.122	.208
Softness	.185	-.009	**-1.015**	.846
Contribution	2.853	2.202	2.127	

Figure 6 shows the relationship between lighting direction and evaluation scores for each factor group. The results indicate that the surface characteristics group is more strongly influenced by changes in lighting direction, whereas the sensibility characteristics group is less affected by changes in lighting direction. This suggests that the sensibility impressions are primarily judged based on the inherent characteristics of the object, regardless of the lighting conditions. However, since depth and glossiness scores are typically associated with the surface characteristics group, further investigation is needed to clarify their classification.



(a) Surface characteristics group. (b) Sensibility characteristics group.

Figure 6: Relationship between evaluation score and lighting directions for each perceptual factor group (real space).

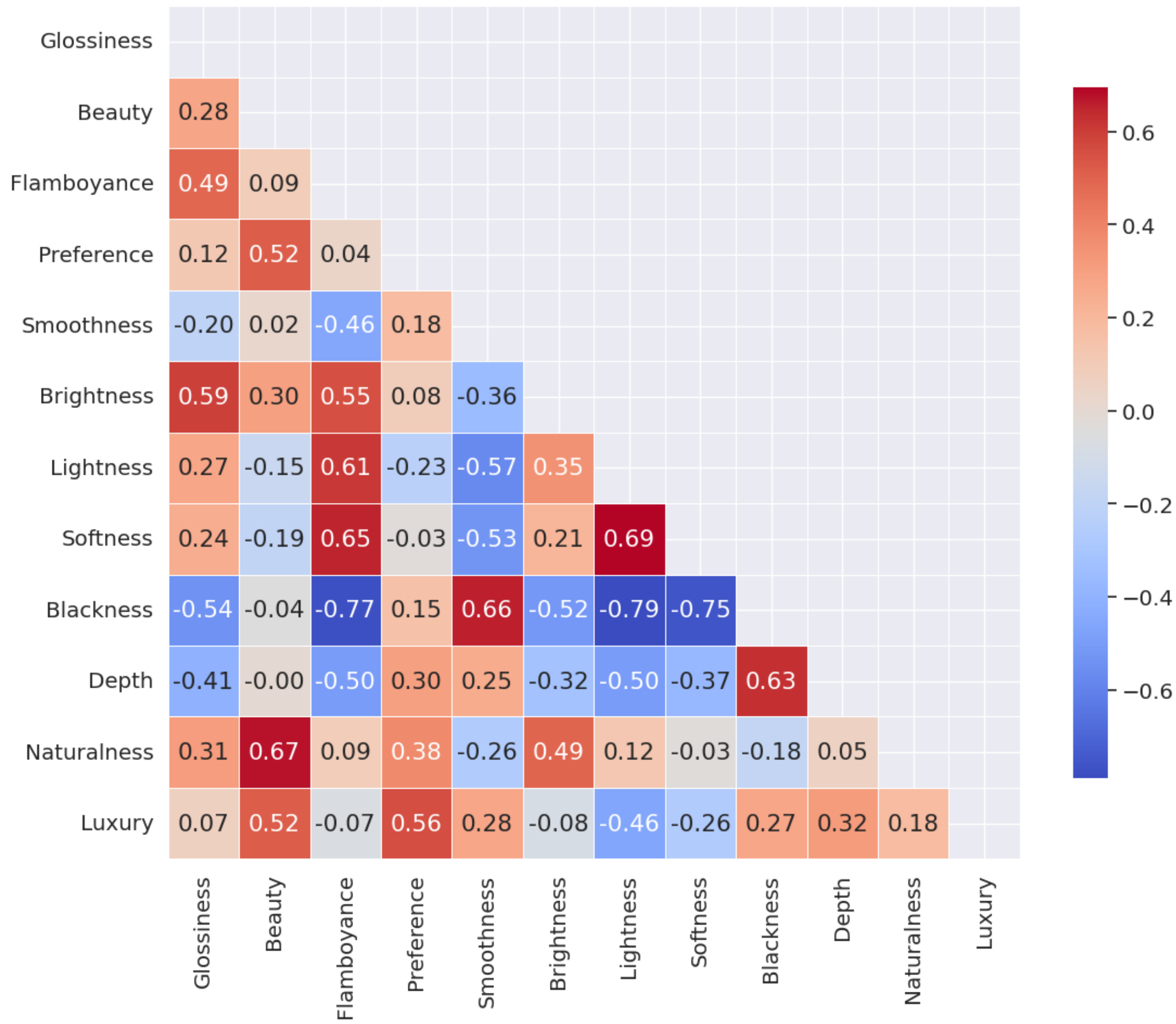


Figure 7: Heat map of the correlation coefficients between adjectives

Figure 7 shows a heat map of the correlation coefficients between adjective pairs. Glossiness, Flamboyance, Brightness, Lightness, Blackness, and Depth exhibit high absolute correlation coefficients with one another, resembling the first group identified in the factor analysis. Similarly, Beauty, Preference, Naturalness, and Luxury also show strong correlations other, reflecting a trend similar to the second group in the factor analysis.

As a photometric analysis, the luminance of the tea bowl surface was measured using a two-dimensional colorimeter. Luminance statistics were calculated from the measured data, and Table 3 shows the correlation with the evaluation items that exhibited significant differences. The evaluation scores for the black tea bowl showed moderate to strong correlations with the mean luminance and the Michelson contrast. For the red tea bowl, moderate to strong correlations were observed between the evaluation scores and both the mean luminance and kurtosis. These findings suggest that the luminance characteristics of the tea bowl surface are related to how the tea bowls are visually evaluated.

Table 3: Relationship between evaluation scores and luminance statistics in real space (top: Black RAKU tea bowl, bottom: Red RAKU tea bowl).

Black RAKU	Average	Michelson Contrast	Skewness	Kurtosis
Glossiness	0.89	-0.65	-0.37	-0.43
Flamboyance	0.92	-0.73	-0.32	-0.23
Brightness	0.97	-0.70	-0.63	-0.54
Blackness	-0.88	0.57	0.13	0.12
Depth	-0.79	0.64	0.31	0.31

Red RAKU	Average	Michelson Contrast	Skewness	Kurtosis
Lightness	0.93	-0.50	-0.07	-0.43
Flamboyance	0.97	-0.37	0.06	-0.43
Brightness	0.95	-0.51	-0.22	-0.65
Blackness	-0.98	0.38	0.00	0.49
Depth	-0.85	0.65	0.34	0.59

Figure 8 shows the change rate in evaluation scores relative to the 30° front lighting condition in both the real and VR environments. The rates of change for flamboyance, brightness, lightness, and softness were similar in both environments, whereas the trends for smoothness, blackness, and depth differed. The observed differences may be attributed to the unnatural representation of the tea bowls, such as an overly smooth surface texture. These results suggest that, in this study, the accuracy of reproducing the tea bowls and lighting conditions in the VR experiment remains limited. Nevertheless, a notable outcome was that the VR environment exhibited the same overall tendency as the real-space experiment: lighting direction had a greater influence on the impression of the tea bowl than the beam angle.

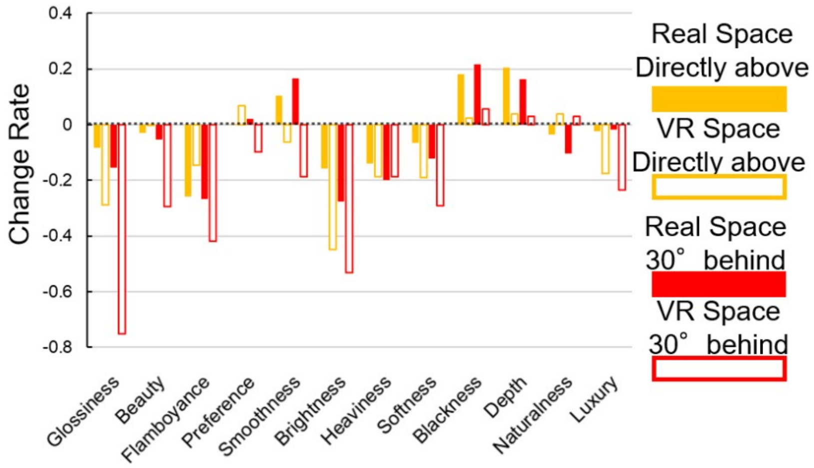


Figure 8: Change rate in evaluation scores relative to the 30° front lighting condition.

5. Conclusion

In the impression evaluation of Japanese tea bowls, it was found that changes in luminance distribution caused by variations in lighting direction conditions affected the evaluation scores. The evaluation scores were also clustered into two groups: those influenced mainly by lighting angle changes and those relatively unaffected. However, since some items did not clearly align with the characteristics of these groups, further investigation is needed.

In the VR experiment, a similar trend was observed as in the real-world experiment, but several rendering quality issues remain that need to be addressed.

This study suggests that, since lighting influences the appearance of tea bowls, it may be possible to control the visual impression of craft items by controlling the lighting conditions.

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Declaration on Generative AI

During the preparation of this work, the authors used GPT-4o and Grammarly in order to: Grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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