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ESTIMATION OF *Kansei* INFORMATION IN JUDGING COLORED WEIGHTS BY USING SHANNON'S INFORMATION THEORY

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Abstract: A subjective weight sensation was able to express as a physical information quantity with the aid of the well-known Shannon's information theory in order to estimate *Kansei* information processing in weight perception of colored balls. The *Kansei* information for the weight sensation of colored balls is obtained from combinations of actions such as looking, hefting, hearing and so on. In the weight sensation, the contribution of the *Kansei* information got from each action was quantitatively analyzed by calculating the Shannon's information quantity.

The experiment found that for all methods except H judgment subjects felt that colors with low reflectivity such as black and purple were heavier, whereas colors with high reflectivity such as white and yellow were lighter. It was also found that the absolute value of the perception of weight tended to be smaller when the subjects made their judgments as they held the balls.

The differences among the different weight judgment conditions were expressed quantitatively by the amount of information communicated to perception. In I judgment, the information on the sensation of weight communicated was 0.60 bit, whereas it was reduced to 0.16 bit under I&H judgment. Similarly, the information communicated under L judgment was 0.43 bit, but was reduced to 0.12 bit under L&H judgment.

The above findings suggested the possibility of quantitatively presenting any differences according to the number and combination of different senses involved in a judgment of weight, and controlling the perception of the weight of an object in virtual space through color and luster.

Keywords: *Color, Perception of the weight, Shannon's Information Theory, Kansei Information, Weight sensation*

1. INTRODUCTION

In the apparel industry, efforts are being made to put e-commerce into practical use through such applications as virtual shopping systems on the internet environment via artificial sense of reality[1]. To make this virtual shopping system, it is necessary to construct a system of tactile displays that conveys virtually the weight and texture of clothing. To create such a virtual reality, it is important to convey image information created by computers to users in an easy and natural manner. Furthermore, it is necessary to add the psychological dimensions that realities possess, rather than simply presenting the same physical quantities as real things reflect to human sensory organs. Normally, we perceive and recognize objects not with a single organ but with a combination of organs, such as eyes, ears and hands, simultaneously. Such an integration of the senses plays an important role in complementing and accommodating ambiguity in each piece of sensory information or lack of information. Moreover, psychological information may be communicated taking advantage of ambiguity and illusion before the sensory organs.

In the past, studies into perceptions of weight in colors were done in the fields of chromatics and psychology, with reports that "the brighter colors are, the lighter people perceive them, and vice versa." [2-9] In a study of the combined use of sensory organs, Taylor [10-12] et al reported that there was no perceived tendency between luminosity and weight when judgment was made while subjects held the object in their hand, and revealed relationships between holding conditions and judgment of weight on the basis of sensory information only by excluding visual information [13]. Bower [14] reported that it is vision that integrates other sensory information when more than one sensory organ is used for perception [15]. However, little has been known about how much color affects the perception of weight of an object to humans, or to what degree sensory integration mitigates ambiguity. To apply such sensory integration concerning weight to technologies for artificial sensations of reality, it is necessary that mutual relationships between the perception of weight in real space and its perception in an image be quantitatively understood.

In this study, a comparison was made between perception in

the real world and as an image by conducting experiments on judgment of perception of weight in real space: when subjects held a colored ball while looking at it and while imagining it. Shannon's Information Theory was employed to express the differences among judgment conditions in a probable and quantitative manner.

2. METHODOLOGY

2.1 Stimulus

To investigate how the perception of the weight of an object varies according to color, wooden balls in eight different colors of black, gray, white, red, yellow, green, blue and purple were made. The balls were coated with color spray (Nippe Wide Spray, Nippe Home Products, Co., Ltd.). The colored balls' Yxy color space value was measured with a chromatic meter (CR-200b, MINOLTA). Y is the reflectivity and corresponds to luminosity, and x and y, to chromaticity. Colors were measured three times for each specimen, and the average value was used to express reflectivity. Table 1. shows the color space values of the eight colors. All the colored balls weighed 100 grams (within ± 0.5 gram of margin of error) and measured 6 cm in diameter. Judgment of the weight of the colored balls was performed under north window daylight to unify conditions for the visual environment. The room temperature was set at 20°C.

Table 1: Yxy color space value in 8 samples

	Y	x	y
white	85.87	0.32	0.33
yellow	59.23	0.46	0.47
gray	37.33	0.31	0.33
green	16.17	0.26	0.42
red	12.6	0.51	0.32
blue	12.37	0.22	0.23
purple	5.57	0.27	0.21
black	4.8	0.31	0.32

Y : reflectance(%), x and y : chromaticity

2.2 Judgment

Weight of the balls in eight different colors was judged by Sheffe's method of paired comparisons and Haga's variation method[16]. Subjects were asked to judge if they felt sample (1) was heavier than sample (2) in the following seven stages, and the results for each judgment method were scored.

(1) Feels "very much lighter"	-3
(2) Feels "much lighter"	-2
(3) Feels "slightly lighter"	-1
(4) Feels "neither lighter nor heavier"	0
(5) Feels "slightly heavier"	+1
(6) Feels "much heavier"	+2

(7) Feels "very much heavier"	+3

Since subjects were allowed to make repeated comparisons between a pair, the order of comparison was not considered and one subject performed all the comparisons. Since the effect of order was disregarded, there were twenty-eight combinations of specimens for each judgment method. To study how the sources of stimulus affect judgment of the weight of the same object, the following five methods were employed to compare the perception of weight.

[H judgment] Perception of weight when holding a colored ball with eyes closed but without letting the subjects know what color it is

[L judgment] Perception of weight when looking at a colored ball

[L&H judgment] Perception of weight when holding a colored ball while looking at it

[I judgment] Perception of weight when imagining a colored ball

[I&H judgment] Perception of weight when holding a colored ball while imagining it

2.3 Procedures

A total of sixty-eight men and women aged 16 to 25 were asked to sit at a distance of 10 cm from a table covered with a gray cloth ($Y = 48.90\%$, $x = 0.32\%$, $y = 0.34\%$) to make their judgments of weight. Judgment was conducted as follows without regard to the effect of order.

[Procedures for H judgment] Subjects were asked to place their writing hand on the table with the palm facing up. The experimenter first quietly placed sample (1) and then sample (2) on the subject's palm to let them judge the perception of weight they got through the hand. Subjects were asked to keep their eyes closed throughout the experiments.

[Procedures for L judgment] Subjects were asked to place their hands in their laps and not to touch the balls. Specimens were placed on the table at an interval of approx. 20 cm each. The experimenter presented pairs of specimens in turn, and subjects judged the relative perception of weight for all the pairs.

[Procedures for L&H judgment] Subjects were asked to place their writing hand on the table with the palm facing up. Specimens were placed in the palm in the same manner as for H judgment. Subjects were asked to heft sample (2) and sample (1) in that order with their writing hand to judge the weight of sample (1) relative to sample (2) while looking at colored balls on the table. Subjects were allowed to take as much time as they wished to compare the pairs. Subjects were asked to judge the relative perception of weight for all the pairs of specimens they hefted as they looked at them.

[Procedures for I judgment] Subjects were asked to place their hands in their laps and not to touch the balls. The eight balls were put on the table at a distance of 20 cm from the edge for 30 seconds each, and subjects were asked to memorize their shape and color. Then, subjects were asked to close their eyes. The experimenter had them develop images of the colored balls by telling subjects which pair of specimens they were. Subjects were asked to judge the relative perception of weight for all the pairs of specimen balls they imagined.

[Procedures for I&H judgment] Subjects were asked to place their writing hand on the table with the palm facing up. The eight balls were presented before them for 30 seconds each to let them memorize shape and color. Then, subjects were asked to close their eyes. The experimenter had them develop images of the colored balls by telling subjects which pair of specimens they were. Subjects were asked to judge the perception of weight for all the pairs of specimen balls that were put on their palms by the experimenter. Subjects were asked to judge the relative perception of weight for all the pairs of specimen balls.

2.4 Analysis of weight judgment by Shannon's Information Theory

The five judgment conditions can be compared to information processing systems with input of information from each sensory organ and output of information on the perception of weight. One of the methods that mathematically evaluate how information is communicated in the system is Shannon's Information Theory[17]. Therefore, the amount of information here refers to the degree of uncertainty and ambiguity. The larger the amount of information is, the more uncertain it is, and the smaller the amount of information is, the less uncertain it is.

Using Shannon's Information Theory, the amount of information concerning sources of stimulus $\hat{H}(x)$ obtained from sensory organs can be obtained in the following equation.

$$\hat{H}(x) = \log n - \frac{1}{n} \sum_i n_i \log n_i \quad (1)$$

Note that when numbers of combinations for each specimen are equal, that is, $n_1 = n_2 = \dots = n_i = \dots = n_k$, $\hat{H}(x) = \log k$. In this experiment, $\hat{H}(x) = \log_2 28 = 4.81$ bit.

The result of weight judgment is responsive information to $\hat{H}(x)$. The amount of information in the responsive information source $\hat{H}(y)$ can be gained from the following equation.

$$\hat{H}(y) = \log n - \frac{1}{n} \sum_j n_j \log n_j \quad (2)$$

To evaluate this input/output system, it is necessary to calculate the amount of information communicated $\hat{T}(x; y)$, or how much of the amount of stimulus information $\hat{H}(x)$ that is

presented is communicated relative to the amount of responsive information $\hat{H}(y)$. The amount of information communicated $\hat{T}(x; y)$ can be obtained in the following equation.

$$\hat{T}(x; y) = \hat{H}(x) + \hat{H}(y) - \hat{H}(x, y) \quad (3)$$

Now, the following equation shows the amount of information of stimulus and reaction that occur simultaneously.

$$\hat{H}(x, y) = \log n - \frac{1}{n} \sum_{i,j} n_{ij} \log n_{ij} \quad (4)$$

3. RESULTS

3.1 Five judgment conditions and perception of weight

On the basis of the data gathered with L, L&H, I, I&H and H judgment methods, analysis of variance was conducted to see if subjects' perception of the weights of the eight balls differed (Table 2). It was found that the main effect was meaningful (1%) for all five methods. The combination effect was meaningful for none of the methods. Because of this, it was found that subjects derived their perception of weight from the colored balls when they made their judgments.

Fig. 1 shows the results of the perception of weight for L, L&H and H judgment methods. Fig. 2 shows those for I, I&H and H judgment methods. On the x-axis is reflectivity of the colored balls, and on the y-axis, the average preferences as a scale of the perception of weight for each colored ball. For adjectives, "heavy" and "light" were used. The closer to 1.5 the value is, the heavier the sample feels, and the closer to -1.5 the value is, the lighter the sample feels. Variant values of the perception of weight for each specimen were shown as a bar. As the variance value was small, results of subjects' judgment agreed.

Fig. 1 shows the relationships between the perception of weight of the eight balls and their reflectivity under L judgment. Subjects felt balls with low reflectivity such as black and purple were heavy, but those with high reflectivity such as white and yellow were light. On the other hand, they felt only a little weight for blue, red, green and gray balls. The order agreed with the order of reflectivity from low to high. The coefficient factor between reflectivity and the perception of weight was 0.91. Fig. 2 shows the relationship between the perception of weight of the eight balls and their reflectivity under I judgment. Subjects felt balls with dark colors such as black and purple were heavy, but those with bright colors such as white and yellow were light. On the other hand, they felt only a little weight for blue, red, green and gray balls. The order agreed with

Table 2: F value of main effect deviations from subtractivity in method

("**" shows being significant at 0.01 level of significance)

	F value					F0.01
	L	L&H	I	I&H	H	
Main effect ($S\alpha$)	349.91**	23.07**	337.04**	42.88**	5.96**	2.66
Deviations from subtractivity ($S\gamma$)	1.80	1.02	1.35	1.13	0.82	1.90

Figure 1: The perception of weight of the eight balls and their reflectivity under L judgment

Figure 2: The perception of weight of the eight balls and their reflectivity under I judgment

that under L judgment and that of reflectivity. The coefficient factor between reflectivity and the perception of weight was 0.93.

Under H judgment conditions, yellow specimens showed a meaningful difference in the test with analysis of variance. Like L judgment, the order for L&H judgment agreed with the order of reflectivity from low to high. But L&H judgment was 75% lower for black and 72% lower for white than the value of the perception of weight under L judgment. Like I judgment, the order for I&H judgment agreed with the order of reflectivity from low to high. It was 66% lower for black and 64% lower for white than the perception of weight under I judgment. A comparison between compound judgment conditions shows that L&H judgment reduced by larger margin than I&H judgment.

3.2 Five judgment methods and the amount of information communicated

Based on the information theory, the amount of information on input for weight judgment and that of the perception of weight were calculated. Then, the amount of information communicated, which showed the condition of communications from input to output, was calculated. Table 3 shows the amount of information calculated for the eight different colored balls.

For L judgment, the amount of information $\hat{H}(x, y)$ for both input information and the perception of weight was 6.87 bit, which indicates a high level of uncertainty. The amount of information communicated $\hat{T}(x, y)$ was 0.43 bit, that is, of the amount of information that can be communicated

$\hat{H}(x) = 4.81$ bit, only 0.43 bit was communicated. Under the other judgment methods, the amount of information communicated was 0.08 bit for H judgment, 0.60 bit for I judgment, 0.12 bit for L&H judgment and 0.16 bit for I&H judgment. As a result, the order of the amount of information is I, L, I&H, L&H and H, with the first being the largest. Furthermore, the amount of information communicated for L&H judgment was not a simple average between that for H judgment and that for L judgment, but a quarter of the sum of the amount of information communicated for H judgment and L judgment. Likewise, similar results were obtained for I&H judgment.

Table 3: The amount of information under the judgments

Judgments	The amount of information (bit)		
	$\hat{H}(x)$	$\hat{H}(x, y)$	$\hat{T}(x, y)$
L	4.81	6.87	0.43
L&H	4.81	6.74	0.12
I	4.81	6.79	0.60
I&H	4.81	6.78	0.16
H	4.81	6.75	0.08

4. CAPITAL

4.1 Colors and apparent weight

This experiment showed that the eight balls visibly convey different senses of weight, with black and purple being heavy, white and yellow being light and blue, green and red coming in between. Similar results have been reported by many researchers since Bullough^[2], and Taylor's^[10] apparent weight produced nearly the same order of black, red, blue, green,

yellow and white.

What causes apparent weight for different colors has been explained by psychological luminosity such as brightness and apparent lightness. Payne^[5] reported that there was a 0.94 correlation between the reflectivity of six colors and their apparent weight. In the results of this study, too, a 0.91 correlation was established between the reflectivity of colored balls and their apparent weight. When there is a gap in the reflectivity of two balls, it can be said that the higher the reflectivity, the bigger it looks. This is a kind of illusion.

4.2 Difference in judgment methods and perception of weight

When judgment methods are combined – the perception of weight as subjects imagine colored balls, or holding them while looking at them – what impact these might have on the perception of weight was examined. When the subjects lifted the balls with all visual information cut off, the perception of weight was almost the same, since the balls had the same shape and weight. However, results of analysis of variance show a meaningful difference in the combination effect of yellow specimens, although this can be attributed to an error of judgment.

Then, with I judgment, where the colors of the balls are given verbally, samples received almost the same weight assignments as with L judgment, where subjects could actually see them. This may be attributed to the phenomenon that the weight one perceives for different colors has a lot to do with individual past experience and learning. It was also revealed that the perception of weight can be communicated by audio information.

On the other hand, when two senses were combined for judgment, namely, L&H judgment – holding as they looked – and I&H judgment – holding as they imagined – the magnitude of the perception of weight decreased, though the order of colors and apparent perception of weight didn't change. In other words, they showed similar tendencies with those of L and I judgment methods, but the perception of weight was heavily affected by H judgment. This demonstrates that the subjects placed precedence on the perception of weight when they held the balls, while feeling apparent weight and imagined weight. Taylor^[10] reported that judgment becomes irregular if colored objects are lifted with the hands as a subject looks at them, and that the brighter the objects are, the heavier they feel. In any case, the addition of a judgment by holding leads the perception of the weight of objects to an actual physical amount and inhibits illusions.

4.3 Five judgment methods and amount of information communicated

Development in information equipment has brought with it rapid progress in technology for communicating visual information, and some types of information can communicate *Kansei* information such as feelings and emotions. Visual information that offers color arrangements, in particular, is expected to affect the feelings of those who see the colors. Therefore, it becomes necessary to define qualitative relationships with the amount of sensory input of colors. So far, psychological, qualitative analysis into colors has been done^{[18]-[20]}, but almost no quantitative study has been carried out in terms of the amount of physical impact of colors. If it becomes possible to quantitatively represent differences in colors and recognition methods, it may be used for the communication of color images and the handling of colors by information equipment, such as artificial representations of reality.

As regards methods to represent sensory effects such as apparent weight, Sato et al^[9] reported that a negatively high correlation is established between Munsell Values and the perception of weight. For the technology to be employed in information equipment, however, it is desirable that the manner in which colors and shapes of objects are communicated to human sensory organs be represented in the amount of information.

Kobayashi^[21] attempted to quantitatively represent the sensory amount using the information theory. He put the tactile sensory amount for textiles into entropy, and revealed the sensory amount of unevenness of ladies' woolen cloth to have between -0.2 and -0.4 bit of information. He also succeeded in quantitatively expressing how much of the perception of weight of colors of balls can be communicated to humans using a similar method. He found that the order of ambiguity was H judgment (0.08 bit), L&H judgment (0.12 bit), I&H judgment (0.16 bit), L judgment (0.43 bit) and I judgment (0.60 bit) in the order of ambiguity from low to high. Comparison between the amount of information communicated and tactile sensory amount of L judgment shows that the two have almost a similar level of ambiguity. For I judgment, ambiguity was further increased. This may be attributed to the fact that images are created by individual experience, memories and learning, and that their combination helps boost the ambiguity. Judgment using more than one of the senses does not produce an average value; rather, H judgment, which is more advantageous for judgment of weight, takes precedence, thus reducing the amount of information communicated.

As described above, differences among judgment methods for the perception of weight were quantitatively expressed using the information theory.

5. CONCLUSION

In this study, an experiment employing five judgment methods was conducted to see how perception differs between the real world and images. By comparing sensory amounts and employing Shannon's Information Theory, the perception of weight according to different methods was expressed in the amount of information communicated.

1) Under all the judgment conditions except H judgment, a negative correlation was established between reflectivity and the perception of weight. This also showed that regularity of the perception of weight for colors is established not only when subjects judge while looking at or holding objects but also when holding them while developing images of them in the imagination.

2) Analysis of the amount of information communicated helped infer the judgment conditions under which information is communicated accurately. The amount of information communicated for the perception of weight was 0.08 bit for H judgment, 0.12 bit for L&H judgment, 0.16 bit for I&H judgment, 0.43 bit for L judgment and 0.60 bit for I judgment.

3) In comparison with judgment using either images or apparent weight, the amount of information communicated through judgment using more than one sense (L&H judgment) was a quarter of the sum of that communicated by H judgment and L judgment. A similar result was obtained for I&H judgment. Thus it was revealed that the perception of weight using more than one sense can communicate information more accurately than with a single sense.

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