Human Perception of Dental Porcelain Translucency Correlated to Spectrophotometric Measurements

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Abstract

Purpose: This study evaluated the relationship between instrumental measurements and subjective visual assessment of differences in dental porcelain translucency.
Materials and Methods: Unshaded feldspathic porcelain was used with controlled amounts of tin oxide to create two groups of 12-mm diameter disks with incremental changes in opacity. Contrast ratio (CR = Yb/Yw) was determined with a spectrophotometer, and used as a measure of porcelain translucency (Group A = 0.20 to 0.40; Group B = 0.6–0.8). Within each group, there were 14 specimens with 11 CRs. Three observer groups (first year dental students, residents, faculty with >10 years of shade matching experience) were recruited to assess the translucency between porcelain disks under two lighting conditions (reflected light, transmitted light). Each subject's ability to distinguish between specimens of differing translucency was determined. Descriptive statistics and three-way ANOVA followed by a post-hoc Tukey-Kramer test were used to evaluate the translucency perception threshold (TPT) of subjects ($\alpha = 0.05$).
Results: The overall mean TPT (ΔC) was 0.07, while 50% of the subjects could perceive a 0.06 CR difference between porcelain specimens. Three-way ANOVA revealed a significant difference in translucency perception among the observer groups ($p < 0.0001$), whereas the main effects for porcelain opacity ($p = 0.3038$) and lighting condition ($p = 0.0645$) were not significant, and no significant interactions were found. Post-hoc Tukey-Kramer test indicated that the mean TPT observed in the faculty group (ΔC = 0.04) was significantly lower than those observed in student (ΔC = 0.09) and resident groups (ΔC = 0.08), while there was no significant difference between students and residents.
Conclusions: The overall mean TPT of all subjects was 0.07, and 50% of the study population perceived a 0.06 CR difference in translucency. Increased shade matching experience ($\geq$10 years) significantly improved the ability to perceive differences in translucency; however, neither the viewing condition nor porcelain opacity affected the perceived translucency threshold.

To achieve a favorable shade match of a restoration, three major elements of color, hue, chroma, and value, have been conventionally considered; however, a fourth element, translucency, has become an important factor for the clinical selection of restorative materials.[1] Translucency is the property of a substance that permits the passage of light, but also disperses the light, so objects cannot be seen through the material.[2]

Instrumental measurements of translucent restorative materials using spectrophotometer,[3–11] colorimeter,[12–18] spectroradiometer,[19] and digital camera and software[20] have been reported. Most studies use Contrast Ratio (CR) as the measure of translucency. CR is the ratio between the daylight apparent reflectance of a specimen (typically 1-mm thick) when backed by a black standard (Yb) and its reflectance when backed by a white standard (Yw). The equation for CR is defined as: CR = Yb/Yw. The CR value of a perfectly transparent material is 0, while the value of a completely opaque material is 1.

There is substantial variation among the reported CRs of ceramic restorative materials in the literature. Heffernan et al[9] evaluated the CRs of six all-ceramic core materials compared with a PFM alloy and Vitadur Alpha dentin porcelain, using a spectrophotometer. The CRs of the six core materials tested ranged from 0.64 to 1.00. In the second part of the study, the CRs of the six all-ceramic cores with their corresponding veneer porcelains increased and ranged from 0.78 to 1.00.[10] A glaze cycle resulted in a significant increase in translucency (CR 0.75–1.00). Lee et al[21] reported the mean CRs of Empress 2 ranged from 0.19 to 0.27 at 0.8-mm thickness, 0.33 to 0.43 at 1.3-mm thickness, and 0.66 to 0.73 at 1.8-mm thickness. Empress 2 ceramic showed increased CRs in some shades after thermocycling. Color change of the three materials after thermocycling was not significant. Chen et al[22] assessed the relative translucencies of four ceramic core materials and reported the CRs of Cercon Base Zirconia (1.00 ± 0.01) and VITA In-Ceram Zirconia (1.00 ± 0.01). Zhang et al[23] found that the mean CRs of enamel and dentin porcelains were affected by porcelain type, but insensitive to a change in powder : liquid ratio. The influences of thickness, porcelain type, layering, and thermocycling on the translucency of veneering porcelains were also evaluated;[24–26] however, the natural combination of light reflection, absorption, and transmission of layered restorative materials may not be accurately detected by instrumental measurements.[26] Spectrophotometers and colorimeters are designed to use a single light source from a small window and a sensor to detect the amount of reflecting light. This is different from the natural situation in which a combination of a variety of light sources and a complicated visual system prevail. Therefore, the instrumental measurements presented in these studies need to be verified for their clinical relevance.

Many authors have evaluated human color perception correlated to instrumental measurement. Marcus and Billmeyer[28] showed a correlation between ΔE^*ab values and visual assessment over a limited region. Kuehni and Marcus[29] found that 50% of subjects could detect a color difference between specimens with a ΔE^*ab value of one. Seghi et al[14] evaluated the color perception of 23 experienced dentists and laboratory technicians and also reported $\Delta E = 1$ as the average detectable color difference. Johnston and Kao[30] evaluated the relationship between colorimetric measurement and color difference perception of lay people. They found that intraoral visual match between composite veneers and natural teeth had a ΔE^*ab of 3.7. Shade-matching experience and the lighting condition seemed to have effects on the color-perception threshold.

There are no studies investigating the human perception of translucency for restorative materials with controlled illuminations and viewing geometry. Influences of training experience, lighting condition, and opacities of materials on translucency perception are also not available. Therefore, the purpose of this study was to evaluate the capability of human subjects to detect differences in the translucency of ceramic materials determined by a spectrophotometer using CR. In addition, this study compared the capabilities of novice dental students, residents, and senior faculty with more than 10 years of shade-matching experience to determine translucency differences under two viewing conditions.

Materials and methods

Specimen fabrication

Unshaded feldspathic porcelain (Ceramco 3, Dentsply, Burlington, NJ) was used with controlled amounts of tin oxide to create 12-mm diameter disks with incremental changes in opacity. The disks were finished to 1-mm thickness and polished to a high shine using silicone carbide papers (Buehler Carbimet, Lake Bluff, IL). Twenty-eight porcelain specimens with different opacities were prepared and separated into two test groups. The luminous reflectance (Y) of the specimens with a black (Yb) and a white backing (Yw), was recorded by a Lambda 35 spectrophotometer (Perkin-Elmer, Corp., Waltham, MA). CRs were calculated (Yb/Yw) with CIE illuminant D65 and a two-degree observer function. The translucency range of Group A (CR = 0.20 to 0.40) was equivalent to that of enamel porcelain, whereas Group B (CR = 0.60 to 0.80) represented dentin porcelain translucency. Within each group, there were 14 specimens with 11 CRs. Four specimens with CR 0.20 in Group A, and 4 with CR 0.60 in Group B served as the baseline (Tables 1 and 2).

Visual assessments

Thirty-one observers were recruited to assess the translucency between porcelain disks under two lighting conditions (reflected or transmitted light). The protocol was approved by the institutional IRB, and informed consent was obtained from each subject. The subjects were divided into three groups by training

Table 1 Test groups and contrast ratios of group A specimens

Test groups	Contrast ratios* (CR)	CR difference (ΔC)
1	0.20, 0.20, 0.20, 0.20, 0.40	0.20
2	0.20, 0.20, 0.20, 0.20, 0.38	0.18
3	0.20, 0.20, 0.20, 0.20, 0.36	0.16
4	0.20, 0.20, 0.20, 0.20, 0.34	0.14
5	0.20, 0.20, 0.20, 0.20, 0.32	0.12
6	0.20, 0.20, 0.20, 0.20, 0.30	0.10
7	0.20, 0.20, 0.20, 0.20, 0.28	0.08
8	0.20, 0.20, 0.20, 0.20, 0.26	0.06
9	0.20, 0.20, 0.20, 0.20, 0.24	0.04
10	0.20, 0.20, 0.20, 0.20, 0.22	0.02

*The spectrophotometric CR measurement of each specimen was rounded to the 2nd decimal place.
The same four specimens with CR 0.20 were repeatedly used. The ΔC among all four specimens with approximately the same CR was less than 0.005.

Table 2 Test groups and contrast ratios of group B specimens

Test groups	Contrast ratios* (CR)	CR difference (ΔC)
1	0.60, 0.60, 0.60, 0.60, 0.80	0.20
2	0.60, 0.60, 0.60, 0.60, 0.78	0.18
3	0.60, 0.60, 0.60, 0.60, 0.76	0.16
4	0.60, 0.60, 0.60, 0.60, 0.74	0.14
5	0.60, 0.60, 0.60, 0.60, 0.72	0.12
6	0.60, 0.60, 0.60, 0.60, 0.70	0.10
7	0.60, 0.60, 0.60, 0.60, 0.68	0.08
8	0.60, 0.60, 0.60, 0.60, 0.66	0.06
9	0.60, 0.60, 0.60, 0.60, 0.64	0.04
10	0.60, 0.60, 0.60, 0.60, 0.62	0.02

*The spectrophotometric CR measurement of each specimen was rounded to the 2nd decimal place.
The same four specimens with CR 0.60 were repeatedly used. The ΔC among all four specimens with approximately the same CR was less than 0.005.

experience: freshman dental students (n = 11), prosthodontic residents (n = 10), and senior faculty who had more than 10 years of shade-matching experience (n = 10). Tests were performed under two light conditions (Figs 1 and 2), using a GTI light booth (PDV-TR2e/D-SW, Newburgh, NY), which provided D65 artificial daylight.

Each combination of specimens consisted of five tabs. Only one porcelain disk in each set was different from the others. The CR differences (ΔC) among the four specimens considered to have "equal translucency" were less than 0.005. The ΔC of the fifth specimen within each group varied from 0.02 to 0.20 in increments of 0.02. The examinees were asked to pick the specimen that looked "different in light transmission" within a 10-second time constraint. The same procedure was repeated three times for each combination of five porcelain disks. A subject was considered to be able to distinguish the translucency difference between specimens when she/he selected the correct specimen two out of three times. Specimens were seated on a neutral gray background when being viewed with reflected light, whereas they were directly seated on the light booth when tested with the transmitted light. The testing sequences, including light conditions (reflected or transmitted), porcelain groups (A or B), and the ten combinations (ΔC = 0.02 to 0.20), within each group were randomized.

Each subject's ability to distinguish between specimens of differing translucency was determined by calculating the mean perceivable minimal difference in CR (ΔC), which was called the Translucency Perception Threshold (TPT). In addition, the translucency difference 50% of the subjects tested could detect was also determined and defined as the 50% TPT.

Determination of translucency perception threshold

A subject's TPT (ΔC) was ranked on a scale of 1 to 10. The 10 levels of the scale denoted CR difference in increments of 0.02, with level one having the greatest difference in porcelain translucency among the specimens (ΔC = 0.20) and level 10 denoting the smallest difference (ΔC = 0.02). After the test, the TPT of each subject was arranged in order, and the pattern of correct and incorrect responses was evaluated. When evaluating the response pattern to determine the perception threshold, the first correct response from level 1 to 10 was identified. The number and frequency of the correct responses were evaluated to determine the subject's TPT (ΔC).

1. If the subject failed all of the subsequent evaluations after the first incorrect response, their TPT (ΔC) was ranked as the last correct response.
2. If there were two (or more) correct responses in a row after the first incorrect response, the first incorrect response was considered as a random event and ignored. The TPT was then ranked as in Number One above.
3. If there was only one correct response or no two consecutive correct responses after the first incorrect response, the subsequent correct responses were considered as random events and insignificant. Therefore, the last of the consecutive correct responses was considered as the TPT (ΔC) for that subject.

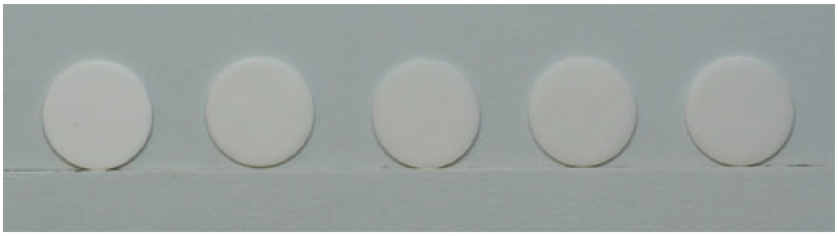

Figure 1 An example of one test group with reflected light and neutral gray background in the visual assessment.

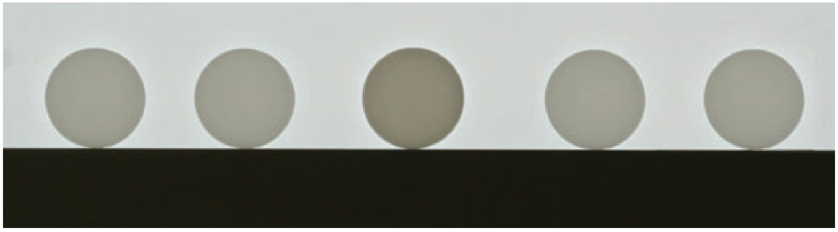

Figure 2 An example of one test group with transmitted light in the visual assessment. No background was used.

Table 3 Summary of the mean translucency perception thresholds

Observers	Reflected light		Transmitted light		Total
	Group A	Group B	*Group A*	*Group B*	
Students	0.084 ± 0.041	0.095 ± 0.041	0.111 ± 0.034	0.084 ± 0.032	0.093 ± 0.044
Residents	0.088 ± 0.036	0.096 ± 0.040	0.058 ± 0.035	0.088 ± 0.044	0.083 ± 0.042
Faculty	0.050 ± 0.037	0.060 ± 0.038	0.026 ± 0.010	0.034 ± 0.027	0.043 ± 0.037
All	0.079 ± 0.050		0.068 ± 0.045		
	0.073 ± 0.042				

Table 4 Three-way ANOVA

Source	d.f.	Type II SS	MS	*F*	*p*-value
Observer	2	0.0587	0.0294	23.21	<0.0001
Porcelain opacity	1	0.0014	0.0014	1.07	0.3038
Lighting condition	1	0.0044	0.0044	3.49	0.0645
Observer × Porcelain opacity	2	0.0040	0.0020	1.58	0.2110
Observer × Lighting condition	2	0.0066	0.0033	2.63	0.0768
Porcelain opacity × Lighting condition	1	0.0003	0.0003	0.22	0.6365
Observer × Porcelain opacity × Lighting condition	2	0.0048	0.0024	1.91	0.1525
Error	112	0.1417	0.0013		

d.f.: degrees of freedom; SS: sum of squares; MS: mean square.

4. If a subject had correct responses from Level 1 to 8, an incorrect response at Level 9 followed by a correct response at Level 10, the subject was ranked Level 10.

Statistical analysis

Descriptive statistics were used to generate the mean, median, and standard deviation of the TPT (ΔC) in each observer group controlling for the lighting condition and porcelain opacity. The overall mean CR combining all three variables was also calculated. The mean TPTs for three observer groups (students, residents, and faculty) at each test condition were compared using three-way ANOVA, followed by post-hoc Tukey-Kramer test. All tests had a 0.05 level of statistical significance. In addition, the CR at which 50% of the subjects could perceive a difference in translucency (50% TPT) was also determined. All tests employed a 0.05 level of statistical significance. SAS for Windows (v9.1, SAS Institute Inc, Cary, NC) was used for the data analysis.

Results

The mean TPT (ΔC), varied for each range of porcelain opacities, the different lighting conditions, and the level of experience (Table 3). When pooling the data for the two light conditions and two porcelain types, the mean ΔCs of three observer groups were: 0.09 (students), 0.08 (residents), and 0.04 (faculty). The overall mean TPT of all subjects was 0.07 in CR difference.

Three-way ANOVA revealed a significant main effect for the observer group ($p < 0.0001$) (Table 4). The main effects for porcelain opacity and lighting conditions were not significant, and no significant two- or three-factor interactions were found. The post-hoc Tukey-Kramer test ($\alpha = 0.05$) indicated that the mean CR value observed in the faculty group (0.04) was significantly lower than those observed in student (0.09) and resident groups (0.08), while there was no significant difference between and students and residents (Table 5).

The results of visual assessment were also evaluated without determining the TPT of each subject. All the data from the three repetitive tests in each test group were pooled, and the relationship between the CR difference and the frequency that 50% of the subjects could perceive a change in translucency are illustrated in Figures 3–6. The 50% TPT of all subjects combining data from all lighting conditions and porcelain opacities was approximately 0.06 (Fig 6). In general, the 50% TPT for the faculty group (~0.04) was substantially lower than those of the student and resident groups (~0.08). That is, the faculty group generally had better translucency perception and could detect smaller differences in porcelain translucency. This observation corresponds to the results of the statistical analysis, which showed that the mean CR observed in the faculty group (0.04) was significantly lower than the student and resident groups.

Table 5 Tukey-Kramer post-hoc test for TPT among observers

Observer	Mean TPT value	Group comparisons**
Students	0.093	A
Residents	0.083	A
Faculty	0.043	B

**Means with the same letter are not significantly different; comparisons using Tukey-Kramer test at $\alpha = 0.05$.

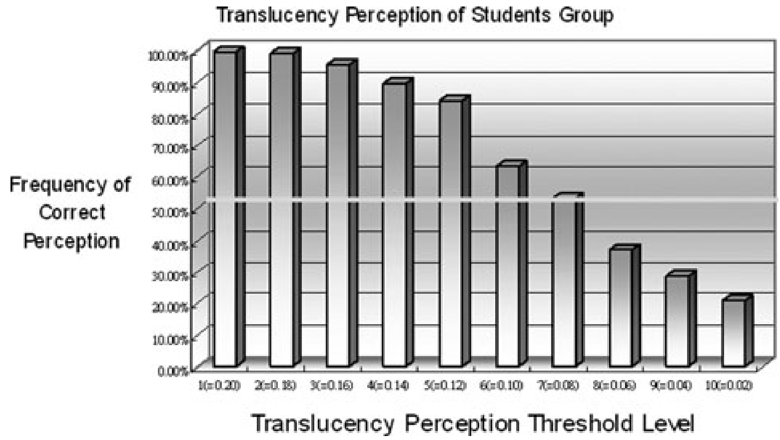

Figure 3 Overall Translucency Perception Threshold (TPT) of students.

Discussion

This study attempted to identify the TPT of individuals using standardized porcelain specimens. Based on the results of this study, a CR difference greater than 0.06 to 0.07 can be considered as clinically perceivable and comparable to perceivable color differences (ΔE^*ab) previously reported in the literature;[14,28,30] however, the mean TPT of the inexperienced subjects (students) was 0.09. Therefore, a CR difference less than 0.09 may be considered clinically undetectable to lay people. An acceptable difference may be even higher intraorally because of the poor lighting condition in the oral cavity. Statistical analysis supported that more than 10 years of shade-matching experience significantly improved the mean TPT. This finding is in agreement with previous color perception studies.[14,15,30]

Comparing the ranges of CRs for six ceramic core systems evaluated by Heffernan et al[9,10] with the overall mean TPT ($\Delta C = 0.07$) and 50% TPT ($\Delta C = 0.06$) in the present study, some of the statistically significant differences in CR reported may not be clinically detectable. For example, the CR differences between In-Ceram Spinell (0.67), Empress 2 at 0.5-mm thickness (0.68), and Procera (0.72) were all less than 0.06 to 0.07. In addition, the statistically significant differences in mean CRs before and after glazing of veneered specimens ranged from 0.00 to 0.03, which is less than the mean TPT of 0.04 for the most experienced faculty group. Lee et al[24] reported a positive correlation between thickness and CR and a significant CR increase in some shades and thicknesses of Empress 2 after thermocycling. When the thickness of specimens increased by 0.5 mm (from 0.8 to 1.3 mm), the CR differences (0.14 to 0.20) substantially exceeded both the overall mean TPT ($\Delta C = 0.07$) and 50% TPT ($\Delta C = 0.06$) and therefore would have a clinically significant impact on translucency. On the other hand, the CR difference induced by thermocycling (0.01 to 0.08) would not be perceivable by most individuals.

In general, the CR differences between enamel/dentin-type porcelains and natural teeth were within the range of the overall 0.07 TPT and the 0.06 50% TPT.[4] The natural enamel and dentin were more translucent than the corresponding dental ceramic materials. Antonson and Anusavice[25] evaluated the translucency for four groups of veneer porcelains in various thicknesses (0.70, 1.10, 1.25, and 1.50 mm) and the effect of the underlying ceramic core or alloy framework on translucency. O'Brien[26] reported that the thickness of porcelain required to screen out the effect of the backing on total surface reflectance was found to be 6 mm, which was called the infinite optical thickness. Since the average thickness of the body porcelain

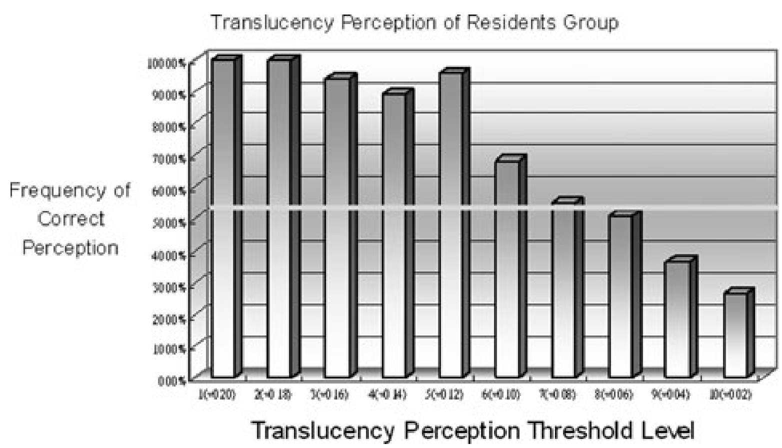

Figure 4 Overall Translucency Perception Threshold (TPT) of residents.

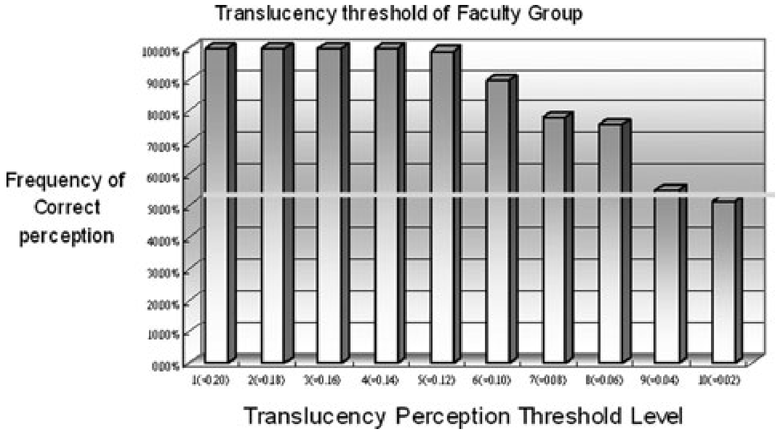

Figure 5 Overall Translucency Perception Threshold (TPT) of faculty.

is around 1 mm, the diffuse reflectance in instrumental measurement should be strongly influenced by the opaque substructure, opaque dentin porcelain, and stains. Because clinical tooth preparations are substantially less than 6 mm, the difference in optical transmission, absorption, scattering, and reflection between the natural dentition and approximately 1-mm veneering porcelain over an opaque body porcelain core (or alloy) system may result in a shade mismatch. Therefore, it would be wise to use restorative ceramic systems with color and translucency closely matched to natural structures. To be precise, the color difference (ΔE^*ab) should be less than 3.7 according to Johnston and Kao,[30] and the CR difference should be less than $\Delta C = 0.06$ to 0.07, the 50% TPT and the overall mean TPT, in the present study. Zirconia-based materials with high opacity ($CR = 1.0$),[22] which provide favorable mechanical properties, should be used with caution when matching translucent natural teeth. To appropriately select restorative materials and communicate with the laboratory, in addition to value, hue, and chroma, an ideal shade matching system should also specify translucency for the restoration.

Conclusions

Within the limits of the present study, the following conclusions were drawn:

1. The overall mean TPT of all subjects was 0.07. Differences in CR greater than 0.06 between ceramic restorations or other restorative materials and natural teeth may be perceived by 50% of the population.
2. Increased shade matching experience ($\geq$ 10 years) significantly improved the ability to perceive differences in translucency.
3. Neither viewing condition nor porcelain opacity affected the perceived translucency threshold.

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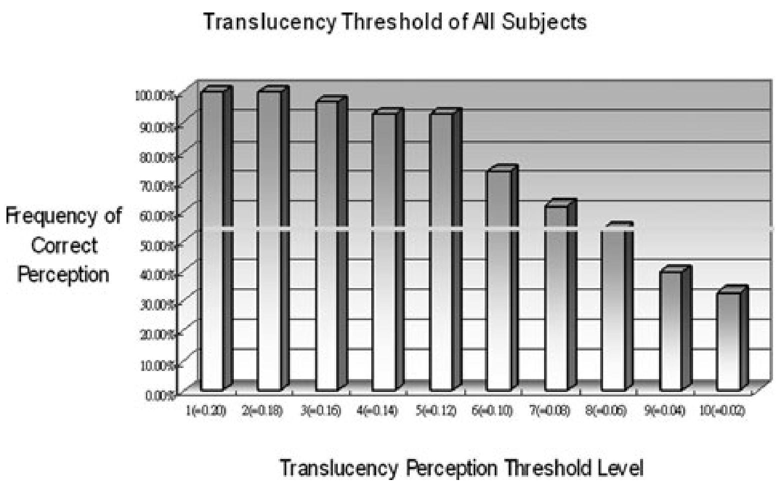

Figure 6 The Translucency Perception Threshold (TPT) of all subjects.

in the spectrophotometric measurements, and Dr. Oitip Chankanka and Mr. Henry Husemann for support in the experiment.

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