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# Impact of Geometric Features on Color Similarity Perception of Displayed 3D Tablets

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**Abstract.** *To explore the effects of geometric features on the color similarity perception of displayed three-dimensional (3D) tablets designed by color 3D modeling techniques or printed by color 3D printing techniques, two subjective similarity scaling tasks were conducted for color tablets with four shape features (circular, oval, triangular-columnar, and rounded-cuboid shapes) and four notch features (straight V, straight U, crisscross V, and crisscross U shapes) displayed on a calibrated monitor using the nine-level category judgement method. Invited observers were asked to assort all displayed samples into tablet groups using six surface colors (aqua blue, bright green, pink, orange yellow, bright red, and silvery white), and all perceived similarity values were recorded and compared to original samples successively. The results showed that the similarity perception of tested tablets was inapparently affected by the given shape features and notch features, and it should be judged by a flexible interval rather than by a fixed color difference. This research provides practical insight into the visualization of color similarity perception for displayed personalized tablets to advance precision medicine by 3D printing. © 2020 Society for Imaging Science and Technology.*
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## 1. INTRODUCTION

Color similarity perception aims to understand how the visual system provides a psychological scale measuring observable color difference of reproduced or processed objects compared to original samples. In terms of similarity evaluation of three-dimensional (3D) reproduction of customized drugs, there is still a gap between digital 3D models and 3D printed objects regarding the reproduction of specific properties and chain delivery [1–3]. Many researchers focused on printing accuracy optimization and quality evaluation for different 3D printing processes and applications. However, there remains the unresolved issue of systematically analyzing and evaluating color perception for 3D printed products, which requires high color similarity [4–6]. Basically, color similarity and preference perception for color 3D object reproduction were usually discussed and estimated by perceptual psychology using digital color 3D models of entities [7–9]. Similarity perception is not only available for color 3D printed entities but is also applied to color 3D model retrieval, which is associated with accurate matching by considering shapes and colors among material databases from public online sites or private offline sources [10–12]. In fact, color similarity perception can be rated by subjective scales for color 3D objects with variant extrinsic properties. For example, color similarity perception of specific tablets was an interesting topic that dealt with a number of practical demands in precision medicine. Indeed, it is worth noting that drug colors played an important role in drug sales, therapeutic effects, and emotional interference [13–15]. Despite this, current works are still lacking in the evaluation of perceived color similarity for customized tablets. This issue is the main hindrance in 3D vision inspection of full-color 3D printed tablets or 3D rendered tablets to developing efficient objective similarity scaling devices.

Although the pharmaceutical industry has made significant advances in the development of novel drugs with typical features, a perennial problem is how to detect and evaluate color similarity of customized tablets in mass production to meet the requirements of precision medicine. This issue arises due to poor implementation of standard visual material appearance models [16, 17]. In mass production, automated real-time vision monitoring of color tablets in pharmaceutical blister packaging lines was developed early and applied to industrial production. However, this process

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considered only color recognition and target image segmentation rather than perceptual color similarity [18–21]. Additionally, usually red, yellow, orange, green, blue, white, black, and, infrequently, brown and purple were selected as tablet surface colors. Previous studies indicated that color–emotion association was easily influenced by the surface color of drugs [22–24]. Accordingly, the effect of color centers of tablet surface on participants' expectations arises from small changes in color attributes based on which subjective similarity perception could be evoked by psychological scaling experiments.

The primary color of a tablet surface and its shape and surface structure are important factors that influence observers' expectations, thereby increasing the scaling complexity of similarity perception. Shape features of drugs can result in unequal visual impacts on potential patients or consumers to some extent [25, 26]. Round and angular shapes applied to a variety of drug contexts had been verified to influence brand preference [27]. Wan et al. [28] reported two subjective experiments that used images of circular-, oval-, and diamond-shaped tablets with pure-color multiple surfaces. Only one notch was designed as the test stimulus to obtain subjective expectations for the taste and efficacy of pills. As regards popular tablets sold by pharmaceutical companies, triangular-columnar- and rounded-cuboid-shaped tablets were easily chosen from over-the-counter drugs, which could be utilized as new shape features to explore complete perception evaluation of tablet samples. Considering the convenience and actual dosage of tablets for older or younger patients, some tablets were produced with a specific notch to divide one tablet into two or more parts during a sub-treatment. This notch can be defined as a small structure feature of tested tablets in subjective scaling experiments. Similarly, related studies reported the influences of tablet notches on the perceived expectation of drug consumers, mainly by using ergonomic approaches [29, 30]. Currently, this notch feature is primarily designed as a straight groove or a crisscross groove on the upper surface of color tablets along with V-, U-, and Z-shaped features. As such, some researchers analyzed preference perception of tablets containing straight U-shaped grooves in their subjective scaling tests. However, they did not conduct further surveys using a combination of two or more features [31–33].

Other studies illustrated the effects of subjective scaling experimental setups and practical rating methods on the similarity perception of entities or rendered image stimuli [34, 35]. For the similarity perception of a real object, samples were mostly selected from reproductive prints in the graphic printing field or 3D printed entities in the on-demand manufacturing field. For the visual perception of rendered stimuli, the specimen can be a specific digital image displayed on a monitor or a mobile screen. In the graphics printing field, soft proofing was accepted as an efficient criterion to examine the color similarity of reproductive prints compared to the original samples or digital specimens. Equivalently, the 3D rendered model displayed on a digital screen could also play a crucial role in providing a low-cost and convenient method for evaluating the visual perception of 3D rendered stimuli before 3D printing. Alternatively, 3D rendered stimuli displayed on a calibrated monitor are usually evaluated by specific observers in psychological scaling experiments based on regular scaling methods, such as the category judgement method, the pair comparison method, and the rank order method, to implement perceptual assessment of multiple attributes in single-rating experiments [36, 37]. In contrast, in the perception evaluation of 3D rendered stimuli composed of many samples, the performance of the category judgement method was good with high statistical accuracy [38].

Finally, four shape features and four notch features were applied to two subjective scaling tasks for displayed tablets with six primary colors. Moreover, experimental setups were in line with the guidelines for subjective evaluation experiments on gamut mapping image quality based on rendered stimuli in the International Commission on Illumination (CIE) technical report [39].

## 2. METHOD

### 2.1 *Apparatus and Materials*

All subjective scaling experiments were conducted in a dark and quiet chamber whose illumination was lower than 32 lux, which is recommended by the CIE for conducting an evaluation. An EIZO LCD monitor with an additional hood was placed horizontally on an extensible table, and observers were seated on an adjustable swivel chair to remain within a 4° visual field during the whole trial. Since each trial took about half an hour, observers could move their sight flexibly, and they did not configure with a fixed device to remain comfortable. All tested image samples were displayed on a 22-inch LCD screen calibrated using the X-Rite software and i1Pro2 spectrophotometer. The full screen mode of the monitor can provide $1680 \times 945$ pixels at a refresh rate of 75 Hz. In addition, D65 was selected as the target illuminant, the monitor brightness was set as 120 cd/m$^2$, the related gamma value was adjusted to 2.2, and the configured white point was (0.312, 0.328). For the verification of the repeatability test, the monitor was calibrated every 15 days.

In the first task experiment, rendered 3D models of circular-, rounded-cuboid-, triangular-columnar-, and oval-shaped tablets designed by the 3dx Max software were used as the original subjective test stimuli (see Figure 1). The original stimuli were all rendered with a uniform single color on the whole surface of the above-mentioned tablets. Each shaped tablet group was compared with six colors, namely, aqua blue, bright green, pink, orange yellow, bright red, and silvery white. As regards contrast groups, three chromatic attributes (brightness, saturation, and hue) of specific samples in each group were adjusted by a random metric. Finally, 15 samples were tested for each shaped tablet with only a single surface color and 90 samples were tested for each shaped tablet group. Furthermore, regarding the variable combination of two surface notches, such as straight V-shaped and straight U-shaped grooves, there were a total

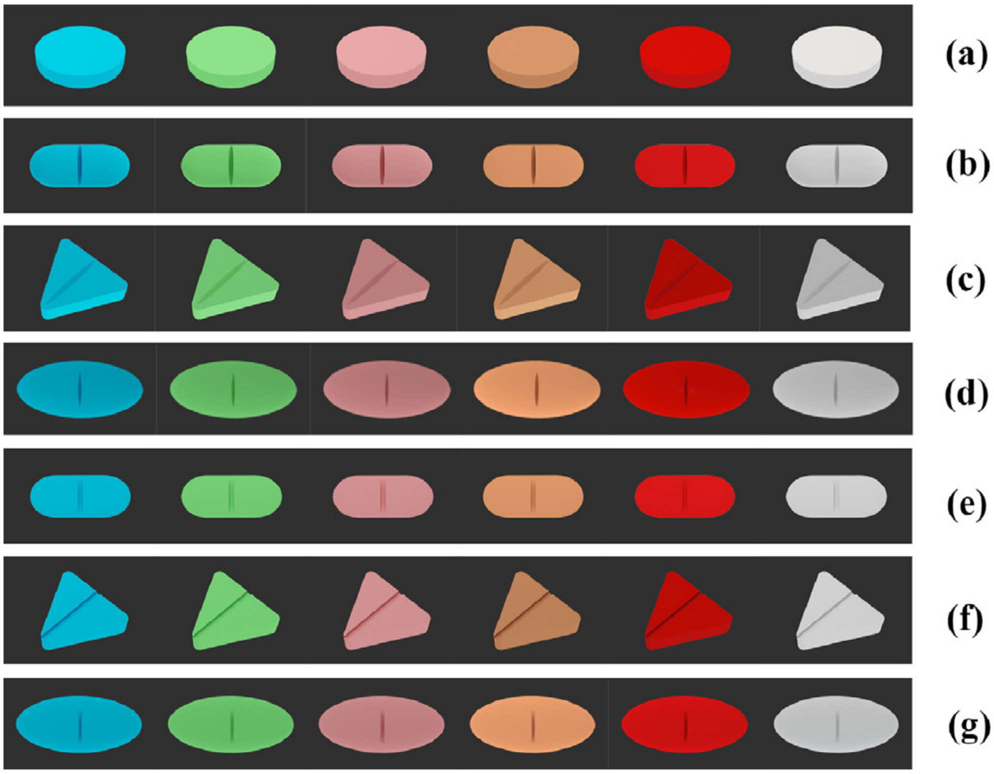


Figure 1. Original tablet samples designed with six surface colors and four surface notches in the first task experiment: (a) circular-shaped tablet without notch feature; (b) rounded-cuboid-shaped tablet with straight V-shaped groove; (c) triangular-columnar-shaped tablet with straight V-shaped groove; (d) oval-shaped tablet with straight V-shaped groove; (e) rounded-cuboid-shaped tablet with straight U-shaped groove; (f) triangular-columnar-shaped tablet with straight U-shaped groove; (g) oval-shaped tablet with straight U-shaped groove.

of 630 tablet samples for each observer. In the second task experiment, 3D rendered models of circular-shaped tablets were regarded as the original subjective test stimuli (see Figure 2). These original references were contrasted with four surface notches including straight V-shaped, straight U-shaped, crisscross V-shaped, and crisscross U-shaped grooves. The surface color was the same as that of the original test stimuli designed in the first task experiment.

Eventually, 15 kinds of circular-shaped tablets configured by different chromatic attributes in the above-mentioned desired matrix were all designed with only one notch feature by using the Photoshop software. Thus, 90 tablets were tested for each notch tablet group and a total of 360 tablet samples for the same observers to record their perceived similarity scales. Figure 3 illustrates circular-shaped samples in aqua blue with the corresponding naming rule and detailed adjustments of three chromatic attributes.

To conduct a tablet similarity scaling experiment and record the results, an efficient MATLAB GUI tool was developed for observers to finish all subjective similarity rating tasks based on the category judgement method. The screenshot of MATLAB GUI for circular-shaped tablets in aqua blue is shown in Figure 4. Observers were required to enter their rating values into the corresponding blank text box at the bottom.

### 2.2 *Observers and Procedures*

Eighteen voluntary observers (9 females and 9 males; age range 18–22 years) participated in the above-mentioned two perception experiments. All observers were naive as to the aim of the tablet perception test. Moreover, they had passed the Snellen visual acuity test and the Ishihara color blindness test. In addition, all observers were provided color sensitivity training, which was based on the X-Rite Pantone Online Color Challenge test, until the final score of all observers was lower than 20, which is regarded as a score indicating a fine sense of color. The X-Rite Pantone Online Color Challenge test is a training tool for judging the order of color samples based on two different primary colors with high saturation. The lower the score, the better the fine color discrimination.

Observers were told explicitly before two perception tasks that they need to give the perceived similarity category of each sample compared to the original stimuli as shown in Fig. 4. Then, one color tablet group was displayed, and participants were instructed successively to make them familiar with the steps to be followed and to control the test time. When the developed MATLAB GUI code was run, participants clicked the “Next original sample” control button. Then the original tablet stimuli was displayed on the left axes with the corresponding tag in the upper-left text box. Following this, they clicked the “Next process sample” control button, and each tested tablet sample was


Figure 2. Original tablet samples designed with six surface colors and four surface notches in the second task experiment: (a) circular-shaped tablet with straight V-shaped groove; (b) circular-shaped tablet with straight U-shaped groove; (c) circular-shaped tablet with crisscross V-shaped groove; (d) circular-shaped tablet with crisscross U-shaped groove.

**Table I.** Contrast of similarity perception for rounded-cuboid-shaped samples.

| Shape feature | Surface color | Notch feature | Marker size difference | Marker size types | Symbols' linear association |
|---|---|---|---|---|---|
| Rounded-cuboid-shaped samples | Aqua blue | Straight V-shaped | Significant | 4 | Global obvious |
| | | Straight U-shaped | Significant | 4 | Global obvious |
| | Bright green | Straight V-shaped | Inapparent | 3 | Vague |
| | | Straight U-shaped | Inapparent | 3 | Local obvious |
| | Pink | Straight V-shaped | Inapparent | 3 | Vague |
| | | Straight U-shaped | Inapparent | 2 | Local obvious |
| | Orange yellow | Straight V-shaped | Significant | 4 | Global obvious |
| | | Straight U-shaped | Significant | 5 | Global obvious |
| | Bright red | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Global obvious |
| | Silvery white | Straight V-shaped | Inapparent | 2 | Vague |
| | | Straight U-shaped | Inapparent | 3 | Vague |

also displayed on the right axes with the related tag in the upper-right text box.

Finally, each participant was required to compare two samples discreetly and truthfully in a very short period of time and type the perceived category scaling value into the blank text box at the bottom. After that, this tool required participants to click the "Next process sample" control button again until they finished each designed tablet group. In the first task, observers were encouraged to complete all test groups including 630 tablet samples with a 10-minute break. In the second task experiment, they were required to finish all test groups including 360 tablet samples without a break. For the repeatability test verification, there was an interval of 15 days between the first and second tests for two selected observers.

### 2.3 *Data Processing*

The data presented in this study comprised preset parameters and subjective raw values. Moreover, configured parameters were designed into the desired matrix including the above LCh attributes. For the subjective raw values, in the beginning, the repeatability between the first and second records of the same observers should be verified based on linear-regression analysis and its goodness of fit should be computed. In this case, 15 observed raw results were selected from 18 participants with the best consistent performance judged by the distance beyond the mean of overall samples. Two of them were selected randomly for the repeatability test in similarity rating experiments. Thus, the final subjective rating data was converted from the primary category scores based on the mean opinion score (MOS) transform given in Eq. (1), where $n$ is the number of all observers and $M_k$ is the category score recorded from observer $j$ during subjective experiments:

$$\mathrm{MOS} = \frac{1}{n}\sum_{k=0}^{n} M_k \quad \mathrm{MOS}^* = \mathrm{ROUND}(\mathrm{MOS}). \tag{1}$$

With respect to the effect of the changed LCh attributes on similarity perception, $\Delta L$, $\Delta C$, and $\Delta h$ of each tablet

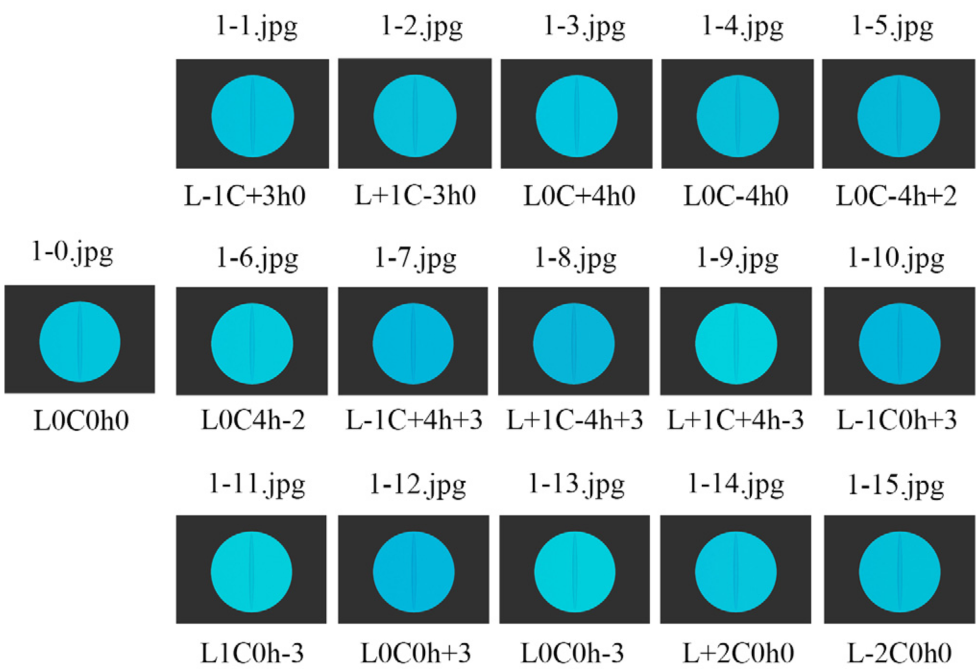


Figure 3. Detailed LCh attribute changes and corresponding test name numbers for the circular-shaped tablet sample group focused on aqua blue in the second task experiment. For example, the notation "L-1C+3h0" shows that one unit is subtracted from the L attribute value, three units are added to the C attribute value, and the h attribute value remains unchanged from the above original tablet sample. All three attributes could be adjusted independently by Photoshop software simultaneously.

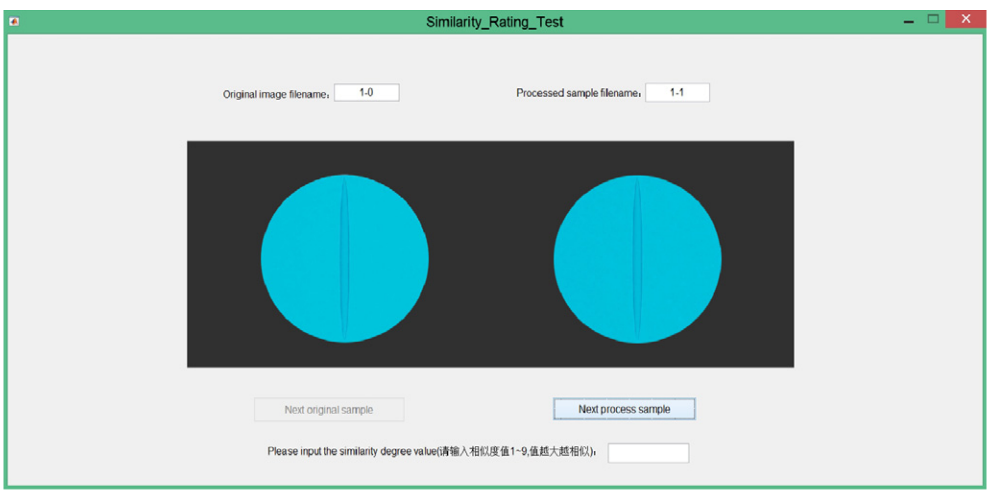


Figure 4. Screenshot of MATLAB GUI for circular-shaped tablets in aqua blue displayed for the original tablet sample and the no. 1 tested tablet sample. An observer can easily know the experiment's progress from the real-time updated image file name and the sample file name.

sample group were all displayed in the relative Δ LCh color space. Furthermore, the plotted marker size of each sample was determined by its MOS* value multiplied by 20 to compare more details. For the contrast among different color variables, the calculated MOS* values were linked to the distribution of the designed LCh attributes, which further indicated the effect of different shapes and surface notch features on perceived tablet similarity. In addition, the color difference ($\Delta E^*$) of each tablet sample was also used for the linear-regression analysis with its perceived MOS* value. It should be noted that the perceived MOS* values were directly implemented by using the MATLAB Round function from the perceived raw MOS values, each of which is marked as the corresponding numerical value of each concentric circle in a radar map.

## 3. RESULTS

In the above two subjective rating experiments, the verified repeatability of two observers for different contrast groups indicated an acceptable goodness of fit between the first and

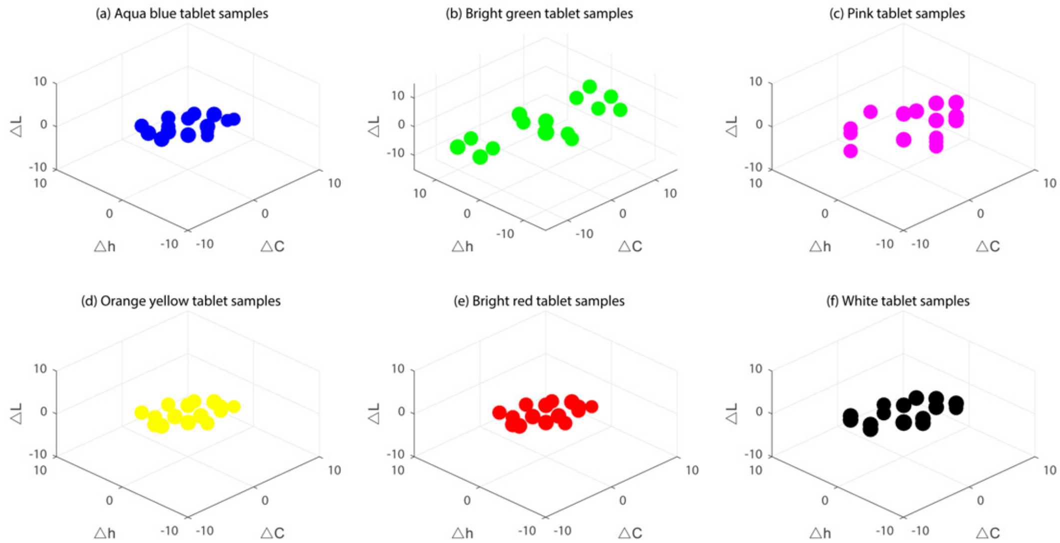


Figure 5. Scatter diagram of circular-shaped tablet samples without the notch feature in ΔLCh color space for six surface colors. The tablet surface color is indicated by the symbol color, while an opposite color is used in (f) to easily distinguish the symbol from its white background. Each symbol size of the tablet sample is determined by its computed MOS* value. There are 15 samples in each color tablet group. Some symbols may be obscured by nearby symbols.

the second recorded data among all tested tablet specimen groups. First, the results for color similarity perception of circular-shaped tablets without the notch feature, then the results for color similarity perception of differently shaped tablets with two notch features, and finally the results for color similarity perception of circular-shaped tablets with four notch features are presented.

### 3.1 *Color Similarity Perception of Circular-Shaped Tablets without Notch Feature*

In Figure 5, the total color similarity perception of circular-shaped tablets without the notch feature for six surface colors is contrasted by the vivid distribution of specific color symbols along with the symbol marker size being determined by the corresponding MOS* value. It can be found that circular-shaped tablet samples in aqua blue, bright green, and orange yellow show significant visual difference from the marker size of distributed symbols, while related marker size types are not the same just for orange yellow samples. Moreover, circular-shaped tablet samples in pink, orange yellow, and bright red are all smaller than those in other primary colors. Considering the symbols' linear association, circular-shaped tablet samples in aqua blue, orange yellow, and bright red exhibit a global obvious linear association. In short, it is shown that observers are not sensitive to the color similarity of pink and bright red samples, which can be ignored in the 3D vision inspection of accurate color tablets, while they pay more attention to circular-shaped tablets in aqua blue, orange yellow, and silvery white.

For a detailed quantitative analysis, the MOS* and $\Delta E^*$ values and the total color similarity perception of circular-shaped tablets without the notch feature for six surface colors are illustrated in Figure 6. For aqua blue tablet samples, all symbols are located in three concentric circles including no. 5, no. 6, and no. 7 circles, while symbols are very few in the no. 5 circle. The threshold interval in the no. 7 category is [2.0, 4.5], while that in the no. 6 category is [2.0, 5.4]. For bright green tablet samples, all symbols are located in no. 6, no. 7, and no. 8 circles, while only one sample is in the no. 8 circle. The threshold interval in the no. 7 category is [2.0, 15.8], while that in the no. 6 category is [5.1, 15.8] . For pink tablet samples, all symbols are divided equally into no. 6 and no. 7 circles. The threshold interval is found to be [5.0, 8.0] in the no. 6 category and [3.0, 8.0] in the no. 7 category. For orange yellow tablet samples, all symbols are also located in no. 5, no. 6, and no. 7 circles, while only one symbol is in the no. 5 circle. The threshold interval in the no. 7 category is [2.0, 5.4], while that in the no. 6 category is [3.0, 5.4]. For bright red tablet samples, all symbols are divided into no. 6 and no. 7 circles, while only one sample is in the no. 6 circle. The threshold interval in the no. 7 category is [2.0, 3.7]. For silvery white tablet samples, all symbols are located in no. 6, no. 7, and no. 8 circles, while only one sample is in the no. 8 circle. The threshold interval in the no. 7 category is [2.0, 6.2], while that in the no. 6 category is [3.0, 5.8].

Comparing the different threshold intervals of the above samples, it is interesting to note that a $\Delta E^*$ value is distributed into two nearby similarity categories and the range in the outer circle is wider than that in the inner circle. It is common that the higher the perceived similarity value of a tablet, the bigger the concentric circle. This abnormal phenomenon illustrates that the absolute $\Delta E^*$ value based on the Euclidean distance is not an efficient criterion, while the observed threshold interval should be a practical index for the vision inspection of the customized tablet quality judged by color similarity. Additionally, from the observed threshold intervals, it is verified that the pink

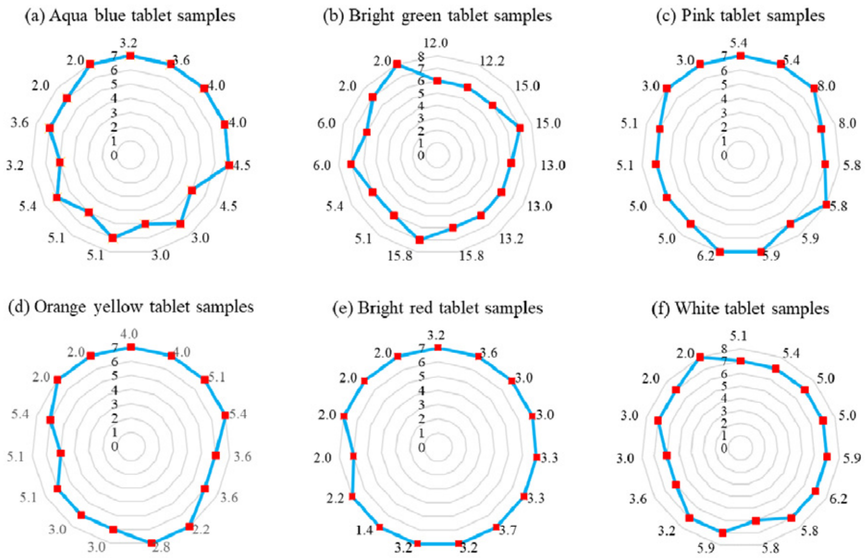


Figure 6. Radar map of circular-shaped tablet samples without notch feature using MOS* and $\Delta E^*$ values. Each sample is marked by a red symbol as well as a specific value. Each concentric circle indicates a certain MOS* value, which evenly increases from 1 (innermost circular) to 9 (outermost circular). There are 15 samples displayed successively in each color tablet group.

samples show a vague linear association arising from samples almost evenly distributed in two categories, while the bright red samples result from samples distributed in one category. This experiment shows that the similarity perception of circular-shaped tablets without notch features varies with surface basic color, but the color quality judgement should be based on the flexible $\Delta E^*$ threshold interval rather than the $\Delta E^*$ value.

### 3.2 *Color Similarity Perception of Differently Shaped Tablets with Two Notch Features*

In this section, tablets designed with straight V-shaped groove and straight U-shaped groove are contrasted by the rounded-cuboid-shaped samples described in Table I, triangular-columnar-shaped samples in Table II, and oval-shaped samples in Table III. Importantly, the marker size difference index refers to the visual difference determined by the displayed marker size of the distributed symbols; the marker size type index refers to the observed sizes of different visual markers of the distributed symbols; the symbols' linear association index refers to the visual linear association between the marker size of each symbol and its Euclidean distance from the coordinate origin.

From Table I, it can be found that rounded-cuboid-shaped tablet samples in aqua blue, orange yellow, and bright red show significant visual difference for the marker size of distributed symbols, while marker size types are not the same just for orange yellow samples based on straight V-shaped groove and straight U-shaped groove. Considering the symbols' linear association, the silvery white tablet samples are both vague for two notch features. Besides, tablet samples in bright green and pink exhibit obvious differences in groove characteristics.

In Table II, it is obvious that triangular-columnar-shaped tablet samples with V-shaped groove are all significantly visually different with marker size difference among the distributed symbols, but the tablet samples with U-shaped groove are mostly insignificant except aqua blue and orange yellow samples. Notch features influence observers' similarity perception of color tablets arising from the inconsistent marker size types. Moreover, the symbols' linear association can be observed obviously for aqua blue and orange yellow tablet samples compared with pink and silvery white tablet samples.

In Table III, it is seen that oval-shaped tablet samples with straight V-shaped groove and straight U-shaped groove give exactly the same results for the marker size difference of the distributed symbols. Orange yellow and silvery white tablet samples exhibit the same results for marker size types. With respect to the symbols' linear association, oval-shaped tablet samples show the same result for groove characteristics except bright red tablet samples.

For the aqua blue tablet group, tablet samples with straight V-shaped groove and those with straight U-shaped groove exhibit the same results for samples that are rounded-cuboid-, triangular-columnar-, and oval-shaped, which further indicates that the designed notch features have little effect for current aqua blue tablets with specific shapes as well as the orange yellow tablet group. Moreover, all the remaining color groups do show visual changes among the three shape features. It should be noted that shape features have a low effect for tablets with straight V-shaped groove but a strong influence for tablets with straight U-shaped groove only in the bright red tablet group. Besides, three shape features do influence the perceived similarity for tablets with straight V-shaped groove more obviously than those with

**Table II.** Contrast of similarity perception for triangular-columnar-shaped samples.

| Shape feature | Surface color | Notch feature | Marker size difference | Marker size types | Symbols' linear association |
|---|---|---|---|---|---|
| Triangular-columnar-shaped samples | Aqua blue | Straight V-shaped | Significant | 4 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Global obvious |
| | Bright green | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Inapparent | 3 | Local obvious |
| | Pink | Straight V-shaped | Significant | 4 | Vague |
| | | Straight U-shaped | Inapparent | 3 | Local obvious |
| | Orange yellow | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Significant | 4 | Global obvious |
| | Bright red | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Inapparent | 2 | Local obvious |
| | Silvery white | Straight V-shaped | Significant | 3 | Vague |
| | | Straight U-shaped | Inapparent | 2 | Local obvious |

**Table III.** Contrast of similarity perception for oval-shaped samples.

| Shape feature | Surface color | Notch feature | Marker size difference | Marker size types | Symbols' linear association |
|---|---|---|---|---|---|
| Oval-shaped samples | Aqua blue | Straight V-shaped | Significant | 4 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Global obvious |
| | Bright green | Straight V-shaped | Inapparent | 1 | Vague |
| | | Straight U-shaped | Inapparent | 2 | Vague |
| | Pink | Straight V-shaped | Inapparent | 3 | Local obvious |
| | | Straight U-shaped | Inapparent | 2 | Local obvious |
| | Orange yellow | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Global obvious |
| | Bright red | Straight V-shaped | Significant | 4 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Local obvious |
| | Silvery white | Straight V-shaped | Inapparent | 3 | Vague |
| | | Straight U-shaped | Inapparent | 3 | Vague |

straight U-shaped groove in the bright green tablet group, the pink tablet group, and the silvery white tablet group.

For a more vivid comparison, the scatter diagram of specifically designed tablet samples with a straight notch feature in the MOS*–$\Delta E^*$ plane for six surface colors is shown in Figure 7. Most symbols with straight V-shaped groove are irregularly distributed on both sides of the linear trend line, while it is impossible to express this by a simple linear function in the MOS*–$\Delta E^*$ plane. Basically, similarity perceived values of tablet samples with straight V-shaped groove are mainly located in area 5, 8. It can be easily observed that multiple MOS* values match one $\Delta E^*$ value with a different interval range. For example, for rounded-cuboid-shaped tablet samples with straight V-shaped groove, their MOS* values vary from 4 to 8 when the related $\Delta E^*$ value is set as 9. For triangular-columnar-shaped tablet samples with straight V-shaped groove, their MOS* values increase from 5 to 7 when the related $\Delta E^*$ value is set as 7. As regards the oval-shaped tablet samples with straight V-shaped groove, their MOS* values are all distributed into a range with three units when the related $E^*$ values are varied from 3 to 7.

In regard to the tablet samples with straight U-shaped groove, there are small changes in overall relevance between MOS* and $\Delta E^*$ distributed as shown in Fig. 7(b), varying with specific shape features. Obviously, the MOS* interval range of rounded-cuboid-shaped tablet samples with straight U-shaped groove becomes greater when the related $\Delta E^*$ value is set as 6. Moreover, for triangular-columnar-shaped tablet samples with straight U-shaped groove, the corresponding MOS* interval range also increases by one unit when the related $\Delta E^*$ value is close to 7. However, the MOS* interval range of oval-shaped tablet samples with straight U-shaped groove becomes smaller when the related $\Delta E^*$ value is set as 3.

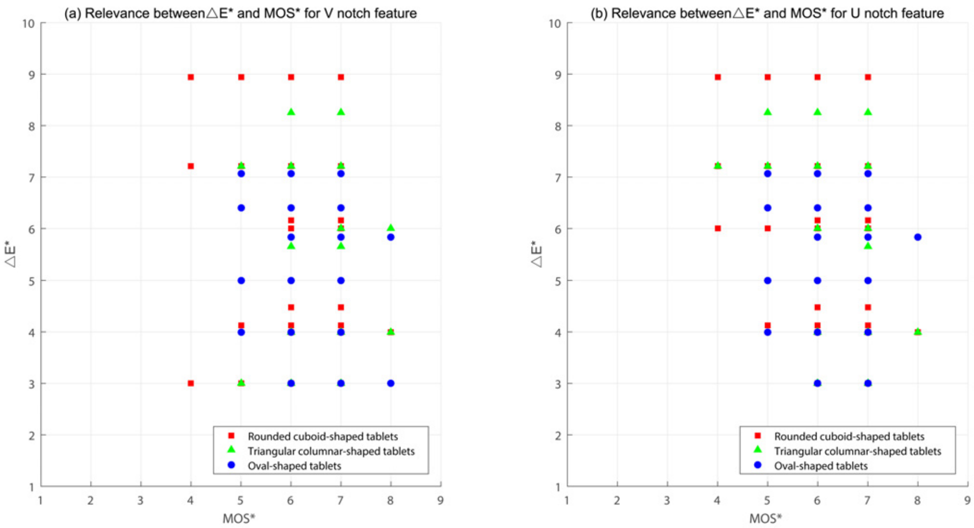


Figure 7. Scatter diagram of specifically designed tablet samples with straight notch feature in the MOS*–$\Delta E^*$ plane for six surface colors: the left plane is for V notch feature; the right plane is for U notch feature. The red symbols indicate rounded-cuboid-shaped tablet samples; the green symbols indicate triangular-columnar-shaped tablet samples; the blue symbols indicate oval-shaped tablet samples. There are 270 samples in each MOS*–$\Delta E^*$ plane. Some symbols may be obscured by nearby symbols.

## 4. COLOR SIMILARITY PERCEPTION OF CIRCULAR-SHAPED TABLETS WITH FOUR NOTCH FEATURES

Since circular-shaped tablets are more common in daily life, it is worth exploring the effects of more notch features on the similarity perception of color tablets. In Table IV, circular-shaped tablets with four specific notch features are contrasted vividly among straight V-shaped groove, straight U-shaped groove, crisscross V-shaped groove, and crisscross U-shaped groove.

For the aqua blue tablet group, tablet samples with straight U-shaped groove only present an obvious visual difference for the marker size of the distributed symbols even though their marker size types are all the same among tablets with four notch features. Besides, tablet samples in bright green and pink show similar effects on similarity perception based on the observed visual difference of marker size, but they display the same marker size type. Moreover, tablet samples in orange yellow and silvery white exhibit the related half symbols being affected by the notch feature erratically based on most of the same marker size types. Strangely, it is seen that tablet samples in bright red with four detailed notch features are all inapparent for marker size difference, but all show the same marker size type.

Considering the symbols' linear association, tablet samples in aqua blue and bright red are consistent among four notch features, while their related trends for observed linear association are not identical as shown in Table IV. Additionally, tablet samples in bright green did present obvious differences in groove characteristics except the crisscross V-shaped groove. It can be found that the crisscross groove is more likely to affect the color similarity perception of tablets than the straight groove as indicated by the current results for the observed symbols' linear association.

For a further vivid comparison, Figure 8 illustrates specific tablet samples with four detailed notch features in the MOS*–$\Delta E^*$ plane for six surface colors. Most symbols are obviously located on the lower side of the linear trend line, yet they are hardly expressed by a simple linear function in the MOS*–$\Delta E^*$ plane. In particular, the $\Delta E^*$ range of circular-shaped tablet samples is larger than that of rounded-cuboid-, triangular-columnar-, and oval-shaped tablet samples as well as covered samples with a large color difference. Similarly, it is obvious that multiple MOS* values match one fixed $\Delta E^*$ value with different interval ranges arising from different proportion combinations of the designed $\Delta L$, $\Delta C$, and $\Delta h$ values. In contrast with the straight U-shaped groove, the perceived MOS* values of tablet samples with straight V-shaped groove are relatively small for the symbols with $\Delta E^*$ values distributed in the intervals 1, 3 and 12, 13 (Fig. 8(a)). Moreover, the perceived MOS* values of the tablet samples with crisscross V-shaped groove are also smaller than those of the tablet samples with crisscross U-shaped groove when the related $\Delta E^*$ values are located in the interval 4, 8 (Fig. 8(b)). Fig. 8(c) shows a high perceived similarity value (MOS* value is 8) achieved by tablet samples with straight V-shaped, crisscross V-shaped, and crisscross U-shaped grooves. Alternatively, given a fixed $\Delta E^*$ value for tablets with four notch features, the intervals of the perceived MOS* values are the smallest for tablet samples with straight V-shaped groove when the related $\Delta E^*$ values are small and vice versa.

## 5. DISCUSSION

In this article, we describe the effects of geometric features on similarity perception of color tablets by psychological scaling experiments to explore the potential relevance between the similarity scaling value and the color difference. Currently,

**Table IV.** Contrast of similarity perception for circular-shaped samples.

| Shape feature | Surface color | Notch feature | Marker size difference | Marker size types | Symbols' linear association |
|---|---|---|---|---|---|
| Circular-shaped samples | Aqua blue | Straight V-shaped | Inapparent | 3 | Local obvious |
| | | Straight U-shaped | Significant | 3 | Local obvious |
| | | Crisscross V-shaped | Inapparent | 3 | Local obvious |
| | | Crisscross U-shaped | Inapparent | 3 | Local obvious |
| | Bright green | Straight V-shaped | Significant | 3 | Global obvious |
| | | Straight U-shaped | Significant | 3 | Global obvious |
| | | Crisscross V-shaped | Inapparent | 3 | Vague |
| | | Crisscross U-shaped | Significant | 3 | Global obvious |
| | Pink | Straight V-shaped | Significant | 3 | Vague |
| | | Straight U-shaped | Inapparent | 3 | Local obvious |
| | | Crisscross V-shaped | Significant | 3 | Global obvious |
| | | Crisscross U-shaped | Significant | 3 | Local obvious |
| | Orange yellow | Straight V-shaped | Inapparent | 2 | Local obvious |
| | | Straight U-shaped | Significant | 3 | Local obvious |
| | | Crisscross V-shaped | Significant | 4 | Global obvious |
| | | Crisscross U-shaped | Inapparent | 2 | Local obvious |
| | Bright red | Straight V-shaped | Inapparent | 2 | Vague |
| | | Straight U-shaped | Inapparent | 2 | Vague |
| | | Crisscross V-shaped | Inapparent | 2 | Vague |
| | | Crisscross U-shaped | Inapparent | 2 | Vague |
| | Silvery white | Straight V-shaped | Significant | 2 | Local obvious |
| | | Straight U-shaped | Significant | 2 | Local obvious |
| | | Crisscross V-shaped | Inapparent | 2 | Vague |
| | | Crisscross U-shaped | Inapparent | 3 | Local obvious |

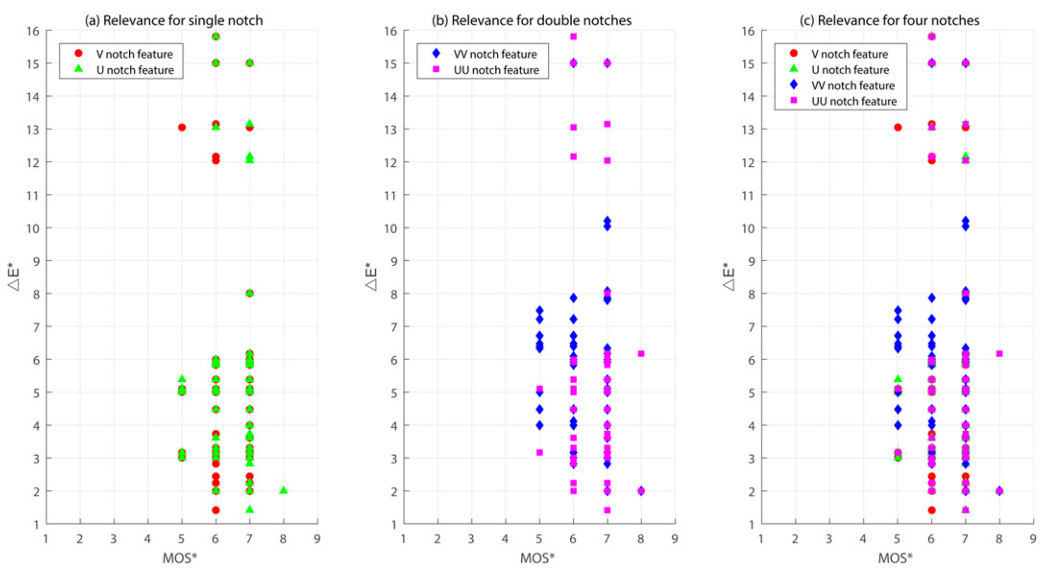


Figure 8. Scatter diagram of circular-shaped tablet samples with different notch features in the MOS*−$\Delta E^*$ plane for six surface colors: the left plane is for straight V-shaped groove and straight U-shaped groove; the middle plane is for crisscross V-shaped groove and crisscross U-shaped groove; the right plane is for four hybrid notch features. The red symbols indicate straight V-shaped groove; the green symbols indicate straight U-shaped groove; the blue symbols indicate crisscross V-shaped groove; the magenta symbols indicate crisscross U-shaped groove. There are 180 samples in the left plane and middle plane and 360 samples in the right plane. Some symbols may be obscured by nearby symbols.

although this approach is difficult for generating accurate linear functions based on the computational MOS* and $\Delta E^*$ values, we should emphasize that the visual quality of customized color tablets printed by 3D printing techniques could be inspected and judged by a more flexible interval rather than by a fixed color difference. Thus, this flexible interval can be optimized by the new precast configurations in future 3D printed tablets.

Importantly, this research provides a practical database including 990 tablet samples with different surface colors designed by our own chroma adjustment matrix. This matrix may contribute less to the obvious linear association in the first and second experiments, judging from the adjustment range of all chroma values such as $\Delta L$, $\Delta C$, and $\Delta h$, which needs further study based on the above-mentioned unexpected relevance results quantitatively by an artificial neural network. Alternatively, tablet samples are not adjusted with all identical chromatic changes when contrasting the related effects of shape features and notch features on similarity perception. This is because the slightly noticeable difference in each primary color on a tablet surface varies from color to color even if it is easily designed in the experimental setup.

Nevertheless, it is worth noting that this research provides two practical data visualization methods based on the scatter diagram and the radar map. In addition, the visual symbols' linear association presented in the tables is derived from the scatter diagrams that the authors have plotted in the supplemental material, which can provide greater spatial location relevance to most symbols. This visual analysis also corresponds to the accurate scaling magnitude in the MOS*–$\Delta E^*$ plane. Eventually, we should note that it is possible to create appropriate similarity scaling intervals for popular color tablets with uniform preconfigured chromatic parameters for more geometric features based on the proposed subjective scaling method. The cognitive neuropsychological interpretation of the current experimental results, which we did not perform, may provide a design reference for 3D printing of personalized pills.

## 6. CONCLUSION

Using two color similarity scaling tasks, we investigated similarity perception of displayed color tablets with four shape features and four notch features under CIE-recommended psychological scaling conditions. Our results indicate that there is no direct linear relationship between the computed color difference ($\Delta E^*$) and the perceived similarity value (MOS*) for all tablet samples with six surface colors. We found evidence revealing that shape features have little effect on similarity perception among most primary color tablet groups, especially for oval-shaped tablet samples. For circular-shaped color tablets, changes in notch features show insignificant impact on perceived similarity values from straight grooves to crisscross grooves, while local perception differences are obvious from straight V-shaped to straight U-shaped grooves. This finding provides design indicators for 3D printed color tablets.


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