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Influence of the hue of absorption pigments on the perception of graininess

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Abstract

Valid and traceable instrumental measurements of all the visual attributes that characterize the appearance of a material (color, gloss, texture and translucency) are necessary to ensure good product quality control. The objective of this work is to evaluate the visual attribute of texture associated with special effect pigments in order to be able to establish a measurement scale. In particular, this study evaluates the influence of the hue of absorption pigments on the perception of graininess. For this purpose, nine samples with a systematic variation of hue angle were used. A visual experiment based on the comparison of triplets was designed, and a multidimensional scaling (MDS) analysis was applied to obtain relative values of perceived graininess. The results confirm that the hue angle of the absorption pigments does not influence the perception of graininess.

Introduction

Usually, by our bare eyes, we examine the surrounding objects, and we judge their qualities. We do this without caring about the whole stages of the optical process behind, which provide us with these clues for judging visually our surrounding, composed of objects made by a wide variety of materials. The visual appearance of objects is the most important aspect to assess their quality and materials, and directly affects the customer choice.

The term "appearance" refers to the visual sensation by which attributes of an object such as size, shape, color, texture, gloss, transparency, opacity, etc., are perceived [1]. It can lead to acceptance, rejection, or desire for objects and, consequently, is a very important factor in decision making [2-4]. For example, in many cases it induces judgments about the quality of products, conditioning their sale. Therefore, many companies in different industrial fields need to have procedures to control the appearance of their products. Historically, many of these procedures have been based on subjective visual evaluations by specialized operators. However, over-reliance on individuals has several practical problems. Expert opinion can vary and create conflicts for product acceptance. In addition, human capability varies with time, mood, age, and also from person to person. On the other hand, it is a costly method in time and resources. Nowadays, the available technology allows the development of automated methods of objective evaluation. Such methods, in addition to making the production chain more efficient, contribute to a considerable reduction in human assessment errors.

In order to objectively control the appearance, this should be first measured. Measurement scales are needed for the various perceptual attributes of objects. However, the human visual system is shaped by one's own experience, and appearance can be affected not only by physical conditions, but also by physiological, psychological, and sociocultural conditions. Therefore, having measurement scales that consider the personal cognitive aspects of the observer is not feasible, and the measurement of appearance should narrow its scope to objective conditions that admit generalization to any human observer. Thus, with the measurement of appearance, we will refer to the application of measurement techniques of magnitudes that can be linked to perceptual aspects, and their expression in the corresponding perceptual scale.

For the appearance characterization, we will focus on the measurement of four fundamental perceptual attributes: color, gloss, translucency, and texture [1]. All these attributes are related to how objects modify the light that reaches the observer's eyes. Thus, the study of the interaction of light with matter is fundamental to the development of appearance measurement scales and requires the measurement of physical quantities related to the reflection, transmission, refraction, absorption, and scattering of light by an object. It is also necessary to determine how light-matter interaction is linked to visual sensation. For this purpose, psychophysical methods are used, which consist of showing a series of objects to different observers and relating their visual assessments to the measurements of physical quantities in these objects. In this way, it is possible to identify which physical quantity and which conditions are the most relevant to define a correlation with the specific visual sensation to be measured. This relationship between the physical magnitude and visual sensation is what we call the measurement scale, which allows us to calculate numerical values for the subjective experience from the objective measurement. This relationship between the subjective experience and the objective measurement that defines the scale does not have to be linear and can include the measurement of several physical quantities.

In recent years, efforts have been made to achieve more attractive visual effects, and special effect pigments have appeared on the market [5, 6]. These pigments provide a strong color change with respect to illumination and observation angles. In addition to this angular dependence of color, materials with special effect pigments exhibit complex textures called sparkle and graininess. Specifically, sparkle is defined as the presence of small bright spots on a much darker background under directional illumination. On the other hand, graininess is characterized by an irregular light/dark pattern under diffuse illumination conditions [7, 8].

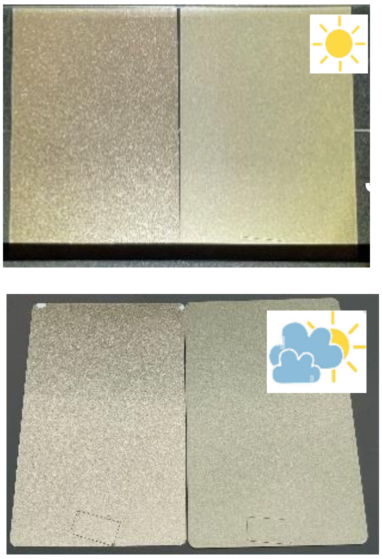

Figure 1. *Sparkle (top) and graininess (bottom) appearances.*

During the last ten years, there has been a breakthrough in the development of new commercial color measurement instruments, which are being used effectively by many industries. However, although the characterization of surfaces with effect pigments is important for the automotive, cosmetics or plastics sectors, there are only two companies with instruments for evaluating the typical visual texture associated with them: the BYK-Gardner BYK-mac i multi-angle spectrophotometer [9] and the MA-T12 and MA-T6 multi-angle spectrophotometers from the X-Rite company [10]. These devices digitally process the images captured by the camera integrated in each of them and provide different parameters associated with both visual textures, although they do not coincide. This lack of concordance is due to the fact that there is no international standard that defines a measurement scale for these textures. For this reason, the International Commission on Illumination (CIE) is working on the definition of measurement scales for these two texture attributes. In recent years, work has been done on the proposal of a measurement scale correlated with visual perception [11-13]. However, this preliminary scale was obtained from the study of achromatic samples, and the role played by the hue of absorption pigments is not taken into account. Therefore, the aim of this work is to analyze the influence of the hue of absorption pigments on graininess perception.

Materials and Methods

The set of samples was provided by PPG Ibérica. It consists of nine samples, each containing a different absorption pigment to achieve values of angular hue (h*) distributed around the complete chromatic diagram (Figure 2). The structural parameters of the metallic pigments were the same for all samples. A specific metallic pigment was used, called cornflake, with a median particle diameter of 21μm. In addition, the ratio between the absorption pigment and the metallic pigment was constant (1:9) in order to exclusively analyze the effect of hue on the perception of the graininess. A relative graininess difference of less than 2% (using the G index of the BYK-mac i multi-angle spectrophotometer), and a relative lightness difference (L* = 60.4 ± 4.1) of less than 7% were obtained with the same instrument (Table 1).

Figure 2. *Set of samples evaluated.*

Table 1. *Colorimetric and texture data in the 45º:0º geometry of the 9 samples used in the visual experiment (S_i sparkle density; S_a: sparkle area; S_G: general sparkle; G: graininess). In red are marked the two samples with values above the mean of the perceived graininess.*

	L*	a*	b*	C*	h°	S_i	S_a	S_G	G
1	54.5	17.3	7.8	19.0	24.2	7.5	28.5	4.3	6.9
2	66.6	-12.2	2.8	12.5	167.3	7.9	28.0	4.4	6.9
3	61.5	-4.6	-12.3	13.12	249.7	6.7	29.1	4.1	7.1
4	**59.8**	**15.4**	**-10.2**	**18.47**	**326.6**	**7.3**	**27.7**	**4.2**	**7.0**
5	64.5	2.3	14.6	14.73	80.9	7.1	27.9	4.1	6.9
6	63.1	8.2	-0.4	8.54	357.0	6.6	26.6	3.8	6.8
7	61.4	9.8	21.2	23.41	65.1	7.1	27.5	4.1	6.9
8	**56.4**	**-16.1**	**-16.6**	**23.13**	**225.8**	**6.3**	**28.4**	**3.9**	**6.7**
9	56.1	11.7	-5.9	13.1	333.19	6.5	28.2	3.9	7.1

A visual experiment was designed to obtain a relative value of perceived graininess (visual graininess). To carry out this visual experiment, the experimental assessments were made using a method of triplet comparison. This is a forced comparison method, i.e. the observer is forced to choose one of the samples presented. In this case, 84 triplets were made at random by combining the 9 selected samples and making non-repetitive combinations of the 9 samples in groups of 3. The presentations followed a pre-established disordered criterion, so that there was no sequence that could be detected by the observer and influence the observer's responses. Authors know it is a limited set of samples (just 9 samples). However, to increase the number of samples for this psychophysical experiment implies to increase the session duration for observers and the visual experiment was designed for the session to last 30 minutes to avoid observer fatigue and ensure better response. The observer's task is to indicate which sample (left or right) is the most similar to the central sample, focused just on the graininess and not on the color of the samples.

Firstly, observers were well-instructed about graininess appearances. To illustrate this texture to the observers, a solid sample without effect pigments was placed together with a test sample in the corresponding lighting booth. Graininess was introduced as a light/dark pattern leading to a granulated appearance.

The observer in each session evaluated the 84 triplets and performed three repetitions in different sessions (Figure 3). For the visual experiment, the VeriVide CAC 150 light booth was used [14] to control the observation conditions with diffuse illumination. This booth has good diffuse illumination; therefore, sparkle is canceled and only the graininess is perceived. The selected spectral distribution of the light source simulated that of the D65 illuminant with chromatic coordinates of x = 0.3127 and y = 0.3383, with a color temperature of 6439 K, and with a color rendering index, Ra, of 95 units. The illuminance on the sample plane is 1415 lx. The experiment was conducted in a dark room, and at the beginning of each session, the observer remained 3 minutes with only the cabinet light on, in order to adapt to the measurement conditions. All participating observers had good visual acuity with optical compensation. The visual acuity was measured with a Snellen test to guarantee a visual acuity test higher or equal to 20/20. In addition, the normal color vision was assessed with the Ishihara test. 21 observers (11 women and 10 men) with a mean age of (22.9 ± 3.6) years participated in the experiment.

Figure 3. Setup of the visual experiment conducted to obtain a visual graininess scale.

Once the observers' responses were collected, they were processed using multidimensional scaling (MDS) analysis [15]. A novel non-metric multidimensional scaling method proposed by Wills et al. was used for analyzing paired comparisons [16]. The method is based on constructing a Euclidean space in which the Euclidean distance between a pair of samples corresponds to the perceptual distance between them by using modern convex optimization theory to solve for a Euclidean embedding.

From this analysis, the visual data (visual graininess) was obtained. It is important to mention that visual data are relative values and depend on the design of the visual experiment, but the tendency allows conclusions to be drawn on the appearance of the graininess attribute. In this work, the visual data were analyzed with the aim of analyzing the influence of the hue angle of the absorption pigment on the perception of graininess.

Results

First, the variability associated with the observers in the visual experiment was analyzed. The analysis focused on intra-variability (same observer, different repetitions) and inter-variability (responses of different observers). The variability associated with the individual observer response was 30%, and the inter-observer variability was 35%. These variability values are high compared to other visual experiments performed with the same procedure and the same objective [17, 18]. This result is indicative of the difficulty observers have in perceiving different samples in terms of graininess as reflected by the randomness of their responses. Moreover, it is worth noting that in this experiment intra-variability is similar to inter-variability, which is unusual, a fact that also highlights the observers' hesitancy in their response.

After applying multidimensional scaling to the observers' response to construct a space where the Euclidean distance between samples corresponds to the perceived graininess difference, a single statistically significant dimension is obtained, considered in this case as visual graininess. Figure 4 shows the visual graininess obtained for each of the samples as a function of the measured h* for the measurement geometry 45º:0º.

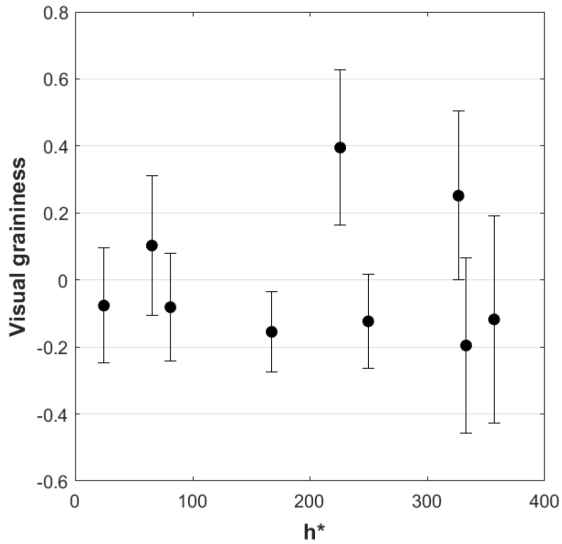

Figure 4. *Visual graininess associated with each sample as a function of the hue of the absorption pigment (h* (0-360º) corresponds to the hue-angle of the measurement geometry measured in the 45º: 0º).*

As can be seen in Figure 4, the graininess perceived by the observers is independent of the hue of the absorption pigment. The figure shows the large variability represented by the overlapping error bars, so it cannot be said that the hue of the absorption pigment influences the perception of graininess. However, there are two samples (h^* = 225.81 and h^* = 326.64) that stands out with a greater mean graininess value compared to the rest of the samples. The instrumental graininess values obtained with the BYK-mac i instrument does not explain this slightly larger variation. However, it should be noted that this behavior is not identical for all observers, and it is not possible to observe differences between the perceived graininess for each of the samples. The colorimetric data of these samples also do not help to explain these results. For this reason, it is necessary to further explore these results. On the one hand, the same visual experiment is being repeated with more observers to confirm these results. On the other hand, a new visual experiment is being designed with samples with a hue angle within this range to find out whether the perceived graininess could be related to certain hues. However, these results are in line with previous results obtained in the study of the influence of the hue of absorption pigments on the perception of sparkle. In this study, it was concluded that the perceived sparkle is independent of the hue of the absorption pigment [19].

Conclusions

In this work, the influence of the hue of the absorption pigments on the perception of graininess was evaluated. For this purpose, a visual experiment based on the comparison of triplets was designed and then processed with a multidimensional scaling method. The results show that the perceived graininess is independent of the hue of the absorption pigment (background). However, further visual experiments with new samples are necessary. On the one hand, the next step would be to evaluate the effect of the pigment hue itself on the perception of graininess, on the other hand, to confirm the results obtained so far with other effect pigments and/or combinations of them in order to be able to evaluate graininess globally and to be able to propose a measurement scale that fits the visual perception of graininess in all its aspects.

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