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Correlation between the BYK's balance index and the appearance of visually assessed achromatic automotive finishes

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ABSTRACT

In the present investigation, the effectiveness of "Structure Balance Index" in correctly predicting the appearance of visually assessed achromatic automotive finishes was evaluated. For visual evaluation, the pair comparison method utilizing 16 observers assessing in a light cabinet, having a 45/0° viewing geometry, was used. The statistical results show that the observer repeatability and reproducibility were acceptable. However, evaluation of the Balance index (B) illustrates that the tolerance regions of green, yellow and red in the Balance chart of the presently prepared achromatic samples differed from the BYK's originally defined regions when compared to visual assessments. This means that this index cannot be extended to all lightness levels. Furthermore, such acceptability regions of green, yellow and red are not symmetrical enough for different lightness to promote the balance index for general use. Instead, this index can be regarded as a secondary fine-tuning corrector of Wd and LW parameters.

1. Introduction

Apart from performance and cost, the automobile's appearance is the most important factor for a customer to select a car. Appearance plays a vital role in the developing and marketing of automotive products. In many markets, the consumer unconsciously judges the quality of such products only by their surface appearances. This is why, evaluating the total appearance of automotive finishes is so important. Surface appearance is described by color and geometric attributes such as haze, gloss, distinctness of image (DOI), orange peel, etc. Many instruments and various indices have been used to quantify the quality of surface appearance as compared to visual assessments [1–9]. The most commonly used instrument to measure the appearance of automotive finishes was the Autospec QMS-BP. This instrument measured gloss, DOI and orange peel. An overall appearance value (NAP) was calculated by combining measured gloss, DOI, and orange peel values [1,10]. The quality of paint systems has increased tremendously over the years; however, there are still considerable problems in controlling appearance influenced by smoothness of a surface. In the automotive industry, surface smoothness is often referred to as orange peel. The ASTM E284-09a standard defines orange peel as the appearance of irregularity of a surface resembling the skin of an orange [11]. Orange peel describes surface structures, which we see as a wavy pattern of light and dark areas. In recent years, BYK-Gardner developed an instrument called the Wave scan that measures the waviness of the surface by scanning and recording the optical profile of the surface [12]. This optical profile is then broken into several bands named "structure size" with wavelengths of 0.1–30 mm. Each structure size or Wave scan parameter (Wa, Wb, Wc, Wd and We) has a contrast value from 0 to 100, which is related to the average amplitude of the wave and the surface waviness will decrease with lowered values of contrast. Therefore, the perceived surface appearance is a result of the interrelation between the short waves in the range 0.1–1 mm and the long waves in the range 10–30 mm [12–14].

The correlation between human evaluation and instrumental estimation of surface waviness has been investigated by some researchers. In 2004, Girox at the BYK-Gardner studied the correlation between visual perception and measurement parameters of three different instruments, namely Autospec QMS-BP, Wave scan plus and Wave scan DOI. Eleven measured parameters inclusive of dullness (Du), Wa, Wb, Wc, Wd, We, Gloss, DOI, orange peel, long wave (LW) and short wave (SW) were considered in that work. It was found that a combination of Wave scan parametric values is in a

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good agreement with visually perceived appearance, and amongst all studied instruments, the Wave scan DOI results in the best correlation of instrumental measurements with visual evaluation [1]. Gradisching also investigated the performance of the Wave scan DOI in measuring the orange peel of automotive finishes, and the correlation between visual perception and measurements made by this instrument. Based on the obtained results, he found that there are two peaks at Wb (>25) and Wd (>13) in the structure spectrum of paint panels with unacceptable appearances [15].

In 2008, a new Index named "Structure Balance Index (B)" was defined by a European automotive research group, the objective being quantitative expression of surface appearance, harmony and uniformity of automotive finishes. This index was to simultaneously evaluate both short waves and long waves of a surface making a balance between the two. This Balance Index (B) was derived as a function of Wb and Wd values as shown in Eq. (1) [16–18]

$$B = 10 \times \frac{\mathrm{Wb} - \mathrm{Wb}_0}{\mathrm{Wb}_0}, \quad \text{where } \mathrm{Wb}_0 = 6 \times \sqrt{\mathrm{Wd}} + 4 \tag{1}$$

Tolerancing the total appearance could then be actuated by the aid of the BYK's Balance chart. This chart consists of green, yellow and red regions on a Wd parameter versus B index plot. In the acceptable green region, the B Index varied between −5 and 5 and the Wd parameter was less than 20. In the uncertain (control) yellow region, the Wd parameter was less than 30 and the B Index varied between −10 and 10. In the unacceptable red region, all samples have an undesirable visual appearance.

In the present study, the effectiveness of this Balance Index (B) in correlating with visual assessments for a series of achromatic samples, namely, white, metallic gray and metallic black were evaluated; bearing in mind that the derivation of the Balance Index was based on dark colors only.

2. Experimental

2.1. Sample preparation

All paint panels having a size of 20×10 cm^2 were prepared at No. 1 Paint shop of Iran Khodro car manufacturing company. As a first step, the surface of all steel panels were washed and degreased. Steel panels were phosphated and were then coated by an epoxy-amine electrodeposited (ED) layer. Afterwards, a polyester/melamine primer surfacer was applied over the ED layer. The thicknesses of ED and primer layers were about 20 and 30–40 μm, respectively. Acrylic-melamine basecoat applied on the primer. After a short flash-off time, an identical acrylic-melamine clear coat was applied on the basecoat by the wet on wet method. The simultaneous curing process for the basecoat/clear coat system was carried out at 140 °C for 20 min. The thickness of cured base and clear coats were 12–15 and 40–45 μm, respectively. In this way, 35 achromatic paint panels for each of white, metallic gray and metallic black samples were prepared.

2.2. Instrumental measurements

The Wave scan DOI was used for evaluation of orange peel. This apparatus analyzes the surface structures according to their size, subdividing the measurement signals into 0.1–0.3 mm wavelength (Wa), 0.3–1 mm wavelength (Wb), 1–3 mm wavelength (Wc), 3–10 mm wavelength (Wd) and 10–30 mm wavelength (We) using mathematical filter functions. The values of Wa to We form a structure spectrum.

Table 1
The minimum, maximum and mean STRESS values for intra-observer repeatability of visual assessments of metallic black samples.

	Min	Max	Mean
STRESS (%)	3.90	18.06	8.06

2.3. Paint panel selection

13 white, 13 metallic gray, 13 metallic black paint panels were selected in such a way that they distributed and covered the BYK's Balance chart of a plot of Wd versus B as a far as possible.

2.4. Visual assessments

The visual assessment was carried out in a light cabinet set in a dark room, under a light source simulating D65 with a viewing geometry of 45/0°. The samples were evaluated at a distance of 40 cm. A panel of 14 observers with normal color vision, including 6 males and 8 females participated in the visual assessments. 8 observers had academic color technology backgrounds whilst the others were trained prior to participation. The visual method used was pair comparison. In this method, the observer decision is based on selecting the sample which has the better appearance between the pair under test. All the evaluations were carried out separately for the three achromatic paints (i.e. white, gray and black). For assessing repeatability, black samples were evaluated again by each observer. Subsequently, an acceptable tolerance was determined for each achromatic sample. Such quality ranking results were converted to quantitative equivalents, presented as visual scales, by the aid of the Thurstone's law of comparative judgments. It must be remembered that the Thurstone zero value is a conventional zero whilst the zero is actually assigned to the sample having the best visual appearance [19].

3. Results and discussion

The repeatability and reproducibility of observers were analyzed firstly to check the reliability of the visual data. The performance of the observers was reported in terms of STRESS (standardized residual sum of squares) values, which can be calculated using Eq. (2) [20]

$$\mathrm{STRESS} = \left(\frac{\sum (A_i - F_1 B_i)^2}{\sum F_1^2 B_i^2} \right)^{1/2}, \quad \text{with } F_1 = \frac{\sum A_i^2}{\sum A_i B_i} \tag{2}$$

where A_i is the target data and B_i is the reference data. The lesser the STRESS value, the better the conformance of sample data to target data. If two groups of data were identical, their STRESS value would be zero. Table 1 presents the STRESS values of intra-observer repeatability for metallic black samples.

The STRESS values for visual assessments of metallic black samples vary from 3.9 to 18.06. The results show that the average error involved in repeated assessments of black samples is about 8 percent; therefore, the observer repeatability is very good. The extent to which observers differed from one another was also investigated to obtain the inter-observer agreement (i.e. reproducibility

Table 2
STRESS values for inter-observer reproducibility of visual assessments.

Sample	STRESS (%)		
	Min	Max	Mean
White	7.56	17.57	10.31
Black	4.64	15.54	7.28
Gray	4.23	23.77	10.92